10th VDE ITG International Vacuum Electronics Workshop (IVEW) 2026 and 16th International Vacuum Electron Sources Conference (IV*e*SC) 2026

August 26 - 29, 2026, Bad Honnef, Germany

organized by ITG-Fachausschuss MN 6 „Vacuum Electronics and Displays“

and the European Steering Committee of IVeSC

Book of Abstracts

Edited by G. Gaertner, A. Gallisian, W. Knapp and M. Thumm

Germany 2026

Organized and managed by:

VDE ITG Fachausschuss MN 6 „Vacuum Electronics and Displays“ and the European Steering Committee of IVeSC

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10th VDE ITG International Vacuum Electronics Workshop (IVEW) 2026
and
16th International Vacuum Electron Source Conference (IVeSC) 2026
August 26 – 29, 2026, Physikzentrum Bad Honnef (www.pbh.de), Germany

Conference, Previous Day

Wednesday, August 26, 2026

15:00 **16:15** **16:30**	**IVeSC Scientific Committee Meeting** **Coffee Break** **148th Meeting of the VDE ITG-Fachausschuss MN6** **"Vakuumelektronik und Displays"** Physikzentrum Bad Honnef (PBH), Meeting Room: **Winter Garden**
18:30 **(6.30 p.m.)**	Start of the Conference for all participants: **Come Together Dinner & Evening Discussion,** Physikzentrum Bad Honnef: Restaurant „**Lichtenberg**" (in the Cellar)

Conference Program, 1st Day

Thursday, August 27, 2026

Location: **Lecture Hall „Wilhelm und Else Heraeus"**

07:30	**Breakfast** in the dining hall on the ground floor of the Physikzentrum

08:30	**Welcome Address:** Chairs Wolfram Knapp and Alice Gallissian
	Session 1.1: Field Emission I Chair: Wolfram Knapp
08:40 *L1.1-1*	**C18I: UPDATE ON FIELD ELECTRON EMISSION SCIENCE AND TECHNOLOGY 2026 (Invited)** **Richard Forbes** University of Surrey, School of Mathematics and Physics, Guildford, Surrey GU2 7XH, UK Corresponding author: r.forbes@surrey.ac.uk or r.forbes@trinity.cantab.net
09:10 *L1.1-2*	**C4T: EVIDENCE FOR THE BREAKDOWN OF THE GENERAL PLANE-WAVE FIELD EMISSION THEORY IN NANOMETRIC EMITTERS** **F.F. Dalla'agno[1], T.A. de Assis[2], G. Meng[3], and J.P. Xanthakis[4]** [1]Federal University of Santa Caterina, Blumenau, Santa Caterina, Brazil 89036-004 [2]Institute of Physics, Fluminense Federal Univ., Niterói, Rio de Janeiro, Brazil 24210-340 [3]Xian Jiaotong University, Xian, P.R. China [4]National Technical University of Athens, Athens, Greece Corresponding author: jxanthak@central.ntua.gr

09:30 *L1.1-3*	**C13T: CRYOGENIC FIELD EMISSION ENHANCEMENT IN VERTICALLY ALIGNED CARBON NANOTUBES COLD CATHODES THROUGH TIP MORPHOLOGY ENGINEERING** **Luca Cecchini**[1,2] [1]Dipartimento di Fisica, Sapienza University of Rome, Piazzale Aldo Moro 2, 00185 Rome, Italy, [2]INFN Sezione di Roma, Piazzale Aldo Moro 2, 00185 Rome, Italy Corresponding author: luca.cecchini@roma1.infn.it
09:50 *L1.1-4*	**W35T: THE MANUFACTURE OF ELECTRONIC EMITTERS USING MODIFIED PHOTOSENSITIVE RESIN** **Daniel Burda[1,2], Stanislav Striteský[3], Mathias Bartl[4], Jan Sobków[5], Michal Krysztof[5], Rupert Schreiner[4], Milan Matekja[1,3], and Alexandr Knápek[1]** [1]Institute of Scientific Instruments of the Czech Academy of Sciences, Královopolská 147, 612 64 Brno, Czech Republic, [2]Faculty of Electrical Engineering and Communication, Brno University of Technology, Technická 3058/10, 616 00 Brno, Czech Republic [3]IQS nano s.r.o., A1 Park, Hall F2, Hlavní 110, 664 31 Lelekovice, Czech Republic [4]Faculty of Applied Natural Sciences and Cultural Studies, OTH Regensburg, 93053 Regensburg, Germany, [5]Faculty of Electronics, Photonics and Microsystems, Wroclaw University of Science and Technol., 11/70 Janiszewskiego St., 50-372 Wroclaw, Poland Corresponding author: daniel.burda@isibrno.cz
10:10 *L1.1-5*	**C15T: DESIGN AND EXPERIMENT OF A MULTI-BEAM ELECTRON SOURCE** **Lixin Zhang, Weixia Zhao, Junbiao Liu, Bohua Yin, and Li Han** Institute of Electrical Engineering Chinese Academy of Sciences, Beijing 100190, China Corresponding author: zhanglx@mail.iee.ac.cn
10:30	**Coffee Break**
	***Session 1.2*: Thermionic Emission** Chair: Alice Gallissian
11:00 *L1.2-1*	**C6I: RECENT ADVANCE IN DISPENSER CATHODE (Invited)** **Jinshu Wang** College of Materials Science & Engineering, Beijing University of Technology, China Corresponding author: wangjsh@bjut.edu.cn
11:30 *L1.2-2*	**C7I: THERMIONIC CATHODES MANUFACTURING (Invited)** **Daniel Busbaher** 3M Technical Ceramics, Inc., 695 Laco Dr., Lexington, KY 40514, USA Corresponding author: dbusbaher@mmm.com
12:00 *L1.2-3*	**C9T: CONTRIBUTIONS OF THE THEORY OF SCANDATE CATHODE EMISSION** **Georg Gaertner** Consultant, Aachen, Germany Corresponding author: georg.f.gaertner@t-online.de

12:20 *L1.2-4*	**C12T: EVOLUTION OF M-TYPE CATHODE EMISSION DURING LONG-TERM LIFE-TESTS** **S. Maine, D. Farjots, J.-M. Roquais, and A. Gallissian** Thales AVS France, 2 rue Marcel Dassault, 78140 Vélizy-Villacoublay, France Corresponding author: sylvain.maine@thalesgroup.com
12:40 *L1.2-5*	**C2T: ELECTRON EMISSION MODELING IN IONISATION GAUGES FOR MAGNETIC CONFINEMENT FUSION** **A. Glock[1,2], M. Griener[2], C. Drobny[2], G. Birkenmeier[1,2], H. Meister[2], and G. Schlisio[2]** [1]Technische Universität München, TUM School of Nat. Sc., Physics Dep., 85748 Garching [2]Max-Planck-Institut für Plasmaphysik, 85748 Garching / 17491 Greifswald, Germany Corresponding author: alexander.glock@ipp.mpg.de
13:00	**Lunch**
	***Session 1.3*: Gyrotrons I** Chair: Yubin Gong
14:30 *L1.3-1*	**W3I: PROGRESS IN EUROPEAN COLLABORATIVE GYROTRON DEVELOPMENTS FOR CEA AND GENERAL ATOMICS (Invited)** **Alberto Leggieri[1], Konstantinos A. Avramidis[2], Ioannis Chelis[2], Benjamin Ell[3], Lukas Feuerstein[3], Gerd Gantenbein[3], Stefan Illy[3], Jianbo Jin[3], John Jelonnek[3], François Legrand[1], Gérald Lietaer[1], Christophe Lievin[1], Rodolphe Marchesin[1], Cyrille Metayer[1], Moritz Misko[3], Ijaze M. Oumar[1], David Quetel[1], Tomasz Rzesnicki[3], Sebastian Stanculovic[3], Etienne Vallée[1], and Manfred Thumm[3]** [1]THALES Microwave and Imaging Subsystems, Vélizy-Villacoublay, France [2]National and Kapodistrian University of Athens, Athens, Greece [3]Karlsruhe Institute of Technology, Karlsruhe, Germany Corresponding author: alberto.leggieri@thalesgroup.com
15:00 *L1.3-2*	**W4I: MEGAWATT CLASS GYROTRON DEVELOPMENT AT MPP (Invit.)** **Monica Blank[1], Stephen Cauffman[1], and Philipp Borchard[2]** [1]Microwave Power Products, Inc (MPP), Palo Alto, CA 94304 USA [2]Dymenso LLC, San Francisco, CA, 94124 USA Corresponding author: monica.blank@mppinc.com
15:30 *L1.3-3*	**W36I: DEVELOPMENT OF HIGH-POWER MICROWAVE VACUUM ELECTRONICS AT KIT (Invited)** **J. Jelonnek[1,2], G. Aiello[3], B. Baumann[1], B. Bischofberger[1], R. Bertazzoni[1], B. Ell[1], L. Feuerstein[1], G. Gantenbein[1], S. Illy[1], J. Jin[1], T. Kobarg[1], D. Mondal[1], A. Marek[4], K. Mayer[4], A. Meier[3], M. Misko[1], T. Rzesnicki[1], A. Schmidt[1], S. Schreck[3], S. Stanculovic[1], D. Strauss[3], M. Thumm[1,2], M. Vöhringer[1,2], J. Weggen[1], N. Wirth[1], and C. Wu[1]** [1]IHM, [2]IHE, [3]IAM-AWP, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany [4]Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR), Wachtberg, Germany Corresponding author: john.jelonnek@kit.edu

16:00 *L1.3-4*	**W7T: EXPERIMENTAL PROGRESS IN HIGH-FREQUENCY TERAHERTZ GYROTRONS** **Feng Zhang, Jia-Ji Feng, Xin-Yin Cao, and Chao-Hai Du** School of Electronics, Peking University, Beijing, China Corresponding author: duchaohai@pku.edu.cn
16:20 **16:30**	**Group photo for all conference participants** **➔ in front of the main entrance to the Physikzentrum** **Coffee Break**
	***Session 1.4*: Gyrotrons II, Gyro-TWT, History of IVeSC** Chair: Monica Blank
16:50 *L1.4-1*	**W16T: EVALUATION OF A LOW VOLTAGE HIGH CURRENT OPERATION POINT FOR A HIGH-FREQUENCY AND VERY-HIGH ORDER MODE GYROTRON** **A. Schmidt, L. Feuerstein, S. Illy, M. Thumm, J. Jelonnek, and C. Wu** IHM, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany Corresponding author: andre.schmidt@kit.edu
17:10 *L1.4-2*	**W18T: QUASI-OPTICAL MODE GENERATOR FOR THE VERIFICATION OF A 238 GHz TE49,29 -MODE GYROTRON LAUNCHER ANTENNA** **M. Misko[1], L. Feuerstein[1], S. Illy[1], J. Jelonnek[1,2], J. Jin[1], A. Schmidt[1], M. Thumm[1,2], D. Wagner[3], and C. Wu[1]** [1]IHM, [2]IHE Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany [3]Max Planck Institute for Plasma Physics, Garching, Germany Corresponding author: moritz.misko@kit.edu
17:30 *L1.4-3*	**W20T: ONGOING DEVELOPMENT OF A GYRO-TWT TEST STAND UP TO 263 GHz AT IHM** **Max Vöhringer[1,3], Alexander Marek[2], Benjamin Bischofberger[1] Stefan Illy[1], Manfred Thumm[1,3], Chuanren Wu[1], and John Jelonnek[1,3]** [1]IHM, [3]IHE, Karlsruhe Institute of Technology (KIT), Kaiserstr. 12, 76131 Karlsruhe, Germany [2]Fraunhofer FHR, Fraunhoferstr. 20, 53343 Wachtberg, Germany Corresponding author: max.voehringer@kit.edu
17:50 *L1.4-4*	**W19T: NOVEL BROADBAND FREQUENCY AND AMPLITUDE MEASUREMENT SYSTEM FOR 263 GHz GYRO-TWT AMPLIFIERS** **B. Bischofberger[1], M. Vöhringer[1], M. Misko[1], A. Marek[3], S. Illy[1], M. Thumm[1,2], and J. Jelonnek[1,2]** [1]IHM Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany [2]IHE Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany [3]Fraunhofer-Institute for High-Frequency Physics and Radar Techniques (FHR), Germany Corresponding author: benjamin.bischofberger@kit.edu

18:10 *L1.4-5*	**C23T: 30 YEARS OF IVESC – SHORT HISTORICAL REVIEW (Invited)** **Georg Gaertner** Consultant, Aachen, Germany Corresponding author: georg.f.gaertner@t-online.de
18:30	**Start of the Poster Session** Chair: Georg Gärtner Posters may be presented until the end of 10th IVEW and 16th IVeSC. For the Poster Presentations, please see the end of this program.

19:00	**Conference Dinner & Evening Discussion** Physikzentrum Bad Honnef: Restaurant „**Lichtenberg**“ (in the Cellar)

Conference Program, 2nd Day

Friday, August 28, 2026

Location: **Lecture Hall "Wilhelm und Else Heraeus"**

07:30	**Breakfast** in the dining hall on the ground floor of the Physikzentrum

from 08:00 to 16:00	**PBH Office is open for financial matters, such as** - **payment for all cold drinks consumed during your stay at PBH** <ins>**and optional:**</ins> - **for an individual additional overnight stay from Saturday, August 29, to Sunday, August 30, 2026, with breakfast**

	***Session 2.1*: VED - Theory and Manufacturing** Chair: Manfred Thumm
08:30 *L2.1-1*	**W6I: MULTIFUNCTIONAL THz VACUUM ELECTRONIC SOURCES ENABLED BY MOMENTUM ENGINEERING AND SYMMETRY-BROKEN MICROSTRUCTURES (Invited)** **<ins>Chao-Hai Du</ins>, Ji-Tao Yang, and Feng Zhang** School of Electronics, Peking University, Beijing, China <ins>Corresponding author:</ins> duchaohai@pku.edu.cn
09:00 *L2.1-2*	**W34T: HIGH-ORDER TERAHERTZ VORTEX FIELDS DRIVEN BY FREE ELECTRON BEAM: PHASE MODULATION IN MULTI-HELICAL STRUCTURES** **Zonglin Mao, Ping Zhang, Xueer Wang, Yan Sun, Chengyu Zhang, Qingying Yi, <ins>Shaomeng Wang</ins>, and Yubin Gong** School of Electronic Science and Engineering, University of Electronic Science and Technology of China (UESTC), Chengdu, China <ins>Corresponding author</ins>: zhangping@uestc.edu.cn
09:20 *L2.1-3*	**W12T: ADVANCED MODELING OF VACUUM ELECTRON DEVICES** **<ins>Alexander Vlasov</ins>[1], Igor A. Chernyavskiy[1], Simon Cooke[1], David Chernin[2], and Thomas Antonsen, Jr.[2]** [1]U.S. Naval Research Laboratory, 4555 Overlook Avenue SW, Washington DC, 20375 [2]Leidos Inc., 4555 Overlook Avenue SW, Washington DC, 20375, USA <ins>Corresponding author:</ins> alexander.n.vlasov.civ@us.navy.mil
09:40 *L2.1-4*	**W13T: RECENT ADVANCES IN THE TESLA-FAMILY OF 2.5D LARGE-SIGNAL ALGORITHMS FOR THEIR APPLICATIONS TO THE MODELING OF KLYSTRONS AND TWTS** **<ins>Igor A. Chernyavskiy</ins>[1], Alexander N. Vlasov[1], and Thomas M. Antonsen, Jr.[2]** [1]US Naval Research Laboratory, Washington DC, USA [2]Leidos, Inc., Reston, VA, USA <ins>Corresponding author:</ins> igor.a.chernyavskiy.civ@us.navy.mil

10:00 *L2.1-5*	**W38T: QUANTITATIVE ASSESSMENT OF ADDITIVE MANUFACTURING FOR VACUUM ELECTRONICS IN THE Ka BAND FREQUENCY RANGE** **C.G. Whyte[1], C.R. Donaldson[1], K.M. Donaldson[2], D.C. Speirs[1], K.J. Wilson[1], K. Ronald[1], S. Tammas-Williams[2], K. Uzdowski[2], E. Schamiloglu[3], C.W. Robertson[1], P. MacInnes[1], A.R. Young[1], and A.J. MacLachlan[1]** [1]Department of Physics, SUPA, University of Strathclyde, Glasgow, G4 0NG, U.K. [2]University of Edinburgh, Edinburgh EH9 3FB, UK [3]University of New Mexico, Albuquerque, NM 87131-0001 USA Corresponding author: Colin.Whyte@strath.ac.uk
10:20	**Coffee Break**
	***Session 2.2*: Vacuum Interrupters** Chair: Gösta Mattausch
10:50 *L2.2-1*	**W24T: LOW- AND VERY LOW FREQUENCY SHORT-CIRCUIT CURRENT INTERRUPTION IN VACUUM** **Dietmar Gentsch[1], Andreas Lawall[2], and Sergey Gortschakow[3]** [1]ABB Ltd. Electrification - Distribution Solution (ELDS), Oberhausener Str. 33, 40472 Ratingen, Germany, [2]Siemens AG, 13629 Berlin, Germany [3]Leibniz Institute for Plasma Science and Technology (INP), 17489 Greifswald, Germany Corresponding author: dietmar.gentsch@de.abb.com
11:10 *L2.2-2*	**W14T: HIGH-CURRENT VACUUM ARCS AT LARGE GAPS: INFLUENCE OF ELECTRODE MOVEMENT** **Ralf Methling[1], Timo Meyer[2,3], David Cziumplik[2], Sergey Gortschakow[1], Michael Kurrat[2], and Dirk Uhrlandt[1,4]** [1]Leibniz Institute for Plasma Science and Technology (INP), 17489 Greifswald, Germany [2]Institute of High Voltage Technology and Power Systems, TU Braunschweig, Germany [3]Siemens Energy Global GmbH & Co. KG, Germany [4]Institute for Electrical Power Engineering, University of Rostock, Germany Corresponding author: methling@inp-greifswald.de
11:30 *L2.2-3*	**W8T: COMPARISON OF DIFFERENT CONTACT GEOMETRIES FOR CURRENT INTERRUPTION IN VACUUM USING LONG GAPS** **Marius Hinz[1], Dietmar Gentsch[2], Timo Meyer[1], and Michael Kurrat[1]** [1]TU Braunschweig, elenia Institute for High Voltage Technology and Power Systems [2]ABB AG, Calor Emag Mittelspannungsprodukte, Oberhausener Str. 33, 40472 Ratingen Corresponding author: marius.hinz1@tu-braunschweig.de
11:50 *L2.2-4*	**W9T: OBSERVATION OF PARTIAL INTERNAL FLASHOVERS ON VACUUM INTERRUPTER TEST SPECIMEN WIHOUT METAL VAPOR SHIELD** **Kai Schulze[1], Karen Flügel[1], Dietmar Gentsch[2], and Michael Kurrat[1]** [1]TU Braunschweig, elenia - Institute for High Voltage Technology and Power Systems [2]ABB AG, Calor Emag Mittelspannungsprodukte, Oberhausener Str. 33, 40472 Ratingen Corresponding author: ka.schulze@tu-Braunschweig.de

12:10 *L2.2-5*	**W11T: INFLUENCE OF MOVING AND FIXED CATHODES ON THE VACUUM ARC** **S. Gortschakow[1], N. Dorraki[2], A. Lawall[2], and F. Graskowski[2]** [1]Leibniz Institute for Plasma Science and Technology, Greifswald, Germany [2]Siemens AG, Berlin, Germany Corresponding author: Andreas.Lawall@siemens.com
12:30 *L2.2-6*	**W47T: IMPACT OF HUMIDITY ON THE EXTERNAL DIELECTRIC STRENGTH OF VACUUM INTERRUPTERS IN SYNTHETIC AIR INSULATION SYSTEMS** **Niclas Dölzer[1], Michael Beltle[1], Stefan Tenbohlen[1], and Dietmar Gentsch[2]** [1]Institute of Power Transmission and High Voltage Technology, University of Stuttgart, High Voltage Lab Ostfildern, Nielsenstr. 18, 73760 Ostfildern [2]ABB Ltd., Oberhausener Straße 33, 40472 Ratingen Corresponding author: niclas.doelzer@ieh.uni-stuttgart.de
12:50	**Lunch**
	***Session 2.3*: Tube History, Vacuum Gauges and Plasma** Chair: Jinshu Wang
14:20 *L2.3-1*	**C10T: ON THE HISTORY OF VACUUM ELECTRONICS: THE TUBE MUSEUM OF RWTH AACHEN UNIVERSITY** **Georg Gaertner** Consultant, Aachen, Germany Corresponding author: georg.f.gaertner@t-online.de
14:40 *L2.3-2*	**W39T: HIGH VACUUM MEMS DEVICES MINIATURIZED ANALYTICAL INSTRUMENTS** **Michal Krysztof, Tomasz Grzebyk, Piotr Szyszka, Pawel Urbanski, Marcin Bialas, Jakub Jendryka, Jan Sobków, and Jan Dziuban** Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland Corresponding author: michal.krysztof@pwr.edu.pl
15:00 *L2.3-3*	**W37T: PIRANI VACUUM GAUGES WITH ACTIVE HEAT-LOSS COMPENSATION** **Julian Eiler[1], Felicitas Teichert[1], Samarth Garewal[1], Stefan Weber[2], Peter Gerlesberger[2], Heinz Plöchinger[2], and Rupert Schreiner[1]** [1]Faculty of Applied Natural Sciences and Cultural Studies, OTH Regensburg, 93053 Regensburg, Germany [2]Thyracont Vacuum Instruments GmbH, 94036 Passau, Germany Corresponding author: julian.eiler@oth-regensburg.de

15:20 *L2.3-4*	**C11T: QUALIFICATION OF HEMPT HOLLOW CATHODE NEUTRALIZER WITH INTEGRATED GETTER** **Heiko Stalzer, Alexey Lazurenko, Ralf Heidemann, Gabriela Kucerová, Gabriel Suske, Joachim Daeubler, and Peter Holtmann** Thales Deutschland GmbH, Electron Devices, Soeflinger Str. 100, 89007 Ulm, Germany Corresponding author: heiko.stalzer@thalesgroup.com
15:40 *L2.3-5*	**C1T: 3D CFD SIMULATION OF VACUUM ARCS IN A TEST TUBE** **Frank Reichert** Siemens Energy, Paulsternstr. 26, 13629, Berlin, Germany Corresponding author: frank.reichert@siemens-energy.com
16:00 *L2.3-6*	**W2T: VISUALIZING AND QUANTIFYING IONIC WIND SPEEDS IN RING-TYPE PLASMA ACTUATORS USING SCHLIEREN IMAGE VELOCIMETRY** **Abdurrahman Musazay, Percy Atuiri, Matthias Lindner, Philipp Buchner, Clemens Jaroschek, Peter Bickel, and Rupert Schreiner,** Faculty of Applied Natural Sciences and Cultural Studies, OTH Regensburg, Germany Corresponding author: abdurrahman.musazay@oth-regensburg.de

16:20	**Meeting point in front of Physikzentrum at Hauptstraße 5 (street)**
16:30	**Bus shuttle service to Königswinter, Rheinallee, landing bridge 16 for a boat trip on the Rhine River**

	Evening event of the Joint Conference
17:30	**Start of all-inclusive cruise on the Rhine aboard the "Filia Rheni" operated by Bonner Personen Schiffahrt e.G. Bonn, heading South**
18:30	**3-course menu as a gourmet buffet with wine, beer, various non-alcoholic and hot drinks**
21:30	**End of the Rhine River cruise and bus shuttle service back to the Physikzentrum Bad Honnef**

Conference Program, 3rd Day

Saturday, August 29, 2026

Location: **Lecture Hall "Wilhelm und Else Heraeus"**

07:30	**Breakfast** in the dining hall on the ground floor of the Physikzentrum

from 08:00 to 12:00	**"Check-out" at PBH Office** - **With the payment for all cold drinks (for all 3 days!)** **and optional:** - **for an individual additional overnight stay from Saturday, August 29, to Sunday, August 30, 2026, with breakfast (free choice for all conference participants); prices: 75 € for a single room and 50 € per person in a double room**

	***Session 3.1*: X-Ray Sources, Microwaves and E-Beam Applications** Chair: Rupert Schreiner
08:30 *L3.1-1*	**C21I: COLD CATHODE BASED ELECTRON BEAM (C-BEAM) FOR EXTREME ULTRAVIOLET AND X-RAY SOURCE APPLICATIONS (Invited)** **Kyu Chang Park[1,2], Iksu Kim[1], Umesh Balasado Apugade[1], and Ravindra Patil[1]** [1]Affiliated Dept. of Information Display, Kyung Hee University, Seoul, Korea [2]AffiliatedWorld Beam Solution (WBS), Inc. Kyungheedaro, Seoul, Korea Corresponding author: kyupark@khu.ac.kr
09:00 *L3.1-2*	**W5T: XRF CHARACTERIZATION USING TRIPLE-CRYSTAL PYROELECTRIC X-RAY SOURCE** **Irshad Ebrahim, Karsten Harnisch, and Markus Wilke** Otto von Guericke University Magdeburg, Core Facility for Microscopy and Materials Analysis CMMA, Universitätsplatz 2, 39106 Magdeburg, Germany Corresponding author: irshad.ebrahim@ovgu.de
09:20 *L3.1-3*	**W30T: ELECTROSTATIC DEFLECTION SYSTEM FOR FOCUSING MULTI-BEAM ELECTRON SOURCES** **Mathias Bartl[1], Matthias Hausladen[1], Josef Sellmair[1], Philipp Buchner[1], Ali Asgharzade[1], Kamil Baranowski[2], Michal Krysztof[2], Daniel Burda[3], Alexandr Knápek[3], Dennis Kepic[4], Simon Edler[4], Andreas Schels[4], Michael Bachmann[4], and Rupert Schreiner[1]** [1]Faculty of Applied Natural Sciences and Cultural Studies, OTH Regensburg, Germany [2]Wroclaw University of Science and Technology, 11/17 Janiszewskiego Str, 50-372 Wroclaw, Poland [3]Institute of Scientific Instruments of CAS, Královopolská 147, 612 00 Brno, Czech Rep. [4]Ketek GmbH, 82737 Munich, Germany Corresponding author: mathias.bartl@oth-regensburg.de

09:40 *L3.1-4*	**W22T: VECTOR BASED MAGNETIC AXIS DETERMINATION OF SOLENOIDS FOR GYRO-DEVICES** **<u>B. Baumann</u>[1], M. Vöhringer[1,2], S. Illy[1], T. Kobarg[1], A. Papenfuß[1], T. Rzesnicki[1], J. Jelonnek[1,2], and M. Thumm[1,2]** [1]IHM, [2]IHE, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany <u>Corresponding author:</u> bodo.baumann@kit.edu
10:00 *L3.1-5*	**W49T: DEVELOPMENT OF A CYLINDRICAL EB SOURCE WITH RADIALLY OUTWARDS DIRECTED ELECTRON FLOW FOR COST-EFFICIENT PHYTOSANITARY TREATMENT OF SEEDS** **<u>G. Mattausch</u>, T. Teichmann, F. Winckler, R. Blüthner, B. Meyer, H. Flaske, and M. Dietze** Fraunhofer Institute for Electron Beam and Plasma Technology FEP, Dresden, Germany <u>Corresponding author:</u> goesta.mattausch@fep.fraunhofer.de
10:20	**Coffee Break**
	***Session 3.2*: IOTs and TWTs** Chair: Chao-Hai Du
10:50 *L3.2-1*	**W15I: DESIGN AND SIMULATION OF A 434 MHz INDUCTIVE OUTPUT TUBE (Invited)** **Dingyu Gu[1,2], Jiaqiu Tian[1,2], Hirwa Sakindi Alain[1,2], Shaomeng Wang[1,2], Zhanliang Wang[1,2], Qingying Yi[1,2], and <u>Yubin Gong</u>[1,2]** [1]National Key Laboratory of Science and Technology on Vacuum Electronics [2]Terahertz Radiation and Application Key Laboratory of Sichuan Province, University of Electronic Science and Technology of China (UESTC), China <u>Corresponding author:</u> ybgong@uestc.edu.cn
11:20 *L3.2-2*	**C5T: A STATIC MAGNETIC FIELD FOCUSING ELECTRON GUN FOR 915 MHz INDUCTIVE OUTPUT TUBES** **Jiaqiu Tian[1,2], Runqin Wang[1,2] , Shaomeng Wang[1,2], Zhanliang Wang[1,2], Zhigang Lu[1,2], and Yubin Gong[1,2]** [1]National Key Laboratory of Science and Technology on Vacuum Electronics [2]Terahertz Radiation and Application Key Laboratory of Sichuan Province, University of Electronic Science and Technology of China (UESTC), Chengdu, China <u>Corresponding author:</u> ybgong@uestc.edu.cn
11:40 *L3.2-3*	**W21T: DELAY LINE STRUCTURES FOR HIGH-POWER AND HIGH-FREQUENCY TWTS** **<u>Philip Birtel</u>[1], Mathias Pech[1], and Lucie Sabaut[2]** [1]Thales Deutschland GmbH, Söflinger Str. 100, 89075 Ulm, Germany [2]Thales AVS France, 2 Rue Marc Dassault, 78140 Vélizy-Villacoublay, France <u>Corresponding author:</u> philip.birtel@thalesgroup.com

12:00 *L3.2-4*	**W23T: Ka-BAND UPGRADE OF TIRA: THE FUTURE OF RADAR SPACE OBSERVATION IN EUROPA** **Alexander Marek and Jens Klare** Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR, Fraunhoferstr. 20, 53343 Wachtberg, Germany Corresponding author: alexander.marek@fhr.fraunhofer.de
12:20	**Lunch**
	***Session 3.3*: Field Emission II** Chair: Kyu Chang Park
13:50 *L3.3-1*	**W44T: CMOS-SENSOR CALIBRATION FOR THE MEASUREMENT OF FIELD ELECTRON CURRENTS** **Matthias Hausladen[1], Ali Asgharzade[1], Mathias Bartl[1], Andreas Schels[2], Philipp Buchner[1], and Rupert Schreiner[1]** [1]OTH Regensburg, 93053 Regensburg, Germany [2]Ketek GmbH, München, Germany Corresponding author: matthias.hausladen@oth-regensburg.de
14:10 *L2.3-2*	**W46T: AN OVERVIEW OF THE DEVELOPMENT OF SILICON NANOWIRE ELECTRON SOURCES** **Philipp Buchner[1], Matthias Hausladen[1], Mathias Bartl[1], Ali Asgharzade[1], Markus Langmantel[1], Josef Sellmair[1], Kamil Baranowski[2], Michal Krysztof[2], Daniel Burda[3], Alexandr Knápek[3], Dennis Kepic[4], Simon Edler[4], Andreas Schels[4], and Rupert Schreiner[1]** [1]Faculty of Applied Natural Sciences and Cultural Studies, OTH Regensburg, 93053 Regensburg, Germany [2]Wroclaw University of Science and Technology, 11/17 Janiszewskiego Str, 50-372 Wroclaw, Poland [3]Institute of Scientific Instruments of CAS, Královopolská 147, 612 00 Brno, Czech Rep. [4]Ketek GmbH, 82737 Munich, Germany Corresponding author: philipp.buchner@oth-regensburg.de
14:30 *L3.3-3*	**W29T: SPATIALLY RESOLVED STUDY OF GRID EFFECTS IN FIELD EMISSION ARRAYS USING THE CMOS ELECTRON DETECTORS** **Ali Asgharzade, Matthias Hausladen, Mathias Bartl, Philipp Buchner, Markus Langmantel, and Rupert Schreiner** OTH Regensburg, 93053 Regensburg, Germany Corresponding author: ali.asgharzade@oth-regensburg.de
14:50 *L3.3-4*	**C14T: VERTICALLY ALIGNED MULTI-WALLED CARBON NANOTUBE (MWCNT) ARRAYS FOR X-RAY SOURCES APPLICATIONS** **Mariana Trujillo Arredondo and Pierre-Louis Gautherin** THALES AVS France SAS, 460 rue de Pommarin 38430 Moirans, France Corresponding author: mariana.trujilloarredondo@thalesgroup.com

10th VDE ITG International Vacuum Electronics Workshop (IVEW) 2026
and
16th International Vacuum Electron Source Conference (IVeSC) 2026
August 26 – 29, 2026, Physikzentrum Bad Honnef (www.pbh.de), Germany

Conference, Previous Day

Wednesday, August 26, 2026

15:00 **16:15** **16:30**	**IVeSC Scientific Committee Meeting** **Coffee Break** **148th Meeting of the VDE ITG-Fachausschuss MN6 "Vakuumelektronik und Displays"** Physikzentrum Bad Honnef (PBH), Meeting Room: **Winter Garden**
18:30 (6.30 p.m.)	Start of the Conference for all participants: **Come Together Dinner & Evening Discussion,** Physikzentrum Bad Honnef: Restaurant „**Lichtenberg**" (in the Cellar)

Conference Program, 1st Day

Thursday, August 27, 2026

Location: **Lecture Hall „Wilhelm und Else Heraeus"**

07:30	**Breakfast** in the dining hall on the ground floor of the Physikzentrum

08:30	**Welcome Address:** Chairs Wolfram Knapp and Alice Gallissian
	Session 1.1: Field Emission I Chair: Wolfram Knapp
08:40 *L1.1-1*	**C18I: UPDATE ON FIELD ELECTRON EMISSION SCIENCE AND TECHNOLOGY 2026 (Invited)** **Richard Forbes** University of Surrey, School of Mathematics and Physics, Guildford, Surrey GU2 7XH, UK Corresponding author: r.forbes@surrey.ac.uk or r.forbes@trinity.cantab.net
09:10 *L1.1-2*	**C4T: EVIDENCE FOR THE BREAKDOWN OF THE GENERAL PLANE-WAVE FIELD EMISSION THEORY IN NANOMETRIC EMITTERS** **F.F. Dalla'agno[1], T.A. de Assis[2], G. Meng[3], and J.P. Xanthakis[4]** [1]Federal University of Santa Caterina, Blumenau, Santa Caterina, Brazil 89036-004 [2]Institute of Physics, Fluminense Federal Univ., Niterói, Rio de Janeiro, Brazil 24210-340 [3]Xian Jiaotong University, Xian, P.R. China [4]National Technical University of Athens, Athens, Greece Corresponding author: jxanthak@central.ntua.gr

15:10 *L3.3-5*	**W32T: CONCEPT OF MAXIMIZING THE eGUN LIFETIME OF AN FIELD EMISSION IONIZATION VACUUM GAUGE** **Markus Langmantel[1], Matthias Hausladen[1], Stefan Weber[2], Peter Gerlesberger[2], Heinz Plöchinger[2], Joachim Wolf[3], and Rupert Schreiner[1]** [1]OTH Regensburg, 93053 Regensburg, Germany [2]Thyracont GmbH Passau, Germany [3]Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany Corresponding author: markus.langmantel@oth-regensburg.de
15:30 *L3.3-6*	**W1T: FIELD EMISSION SOURCES FOR ASTRO-PARTICLE PHYSICS PROJECTS** **J. Wolf[1], M. Angelucci[4], A. Asgharzade[3], R. Cimino[4], E. Ellinger[7], R. Gaior[8], M. Hausladen[3], Caio Ishikawa[6], K. Martens[6], R. Schreiner[3], M. Schultz-Ritz[1], A. Schwenck[2], L. Spallino[4], Xiaoxin Wang[6], and Ch. Weinheimer[5]** [1]Institute of Experimental Particle Physics, KIT, 76131 Karlsruhe, Germany [2] Institute of Astro-Particle Physics, KIT, 76344 Eggenstein-Leopoldshafen, Germany [3] Faculty of Applied Natural Sciences and Cultural Studies, OTH Regensburg, 93053 Regensburg, Germany [4] INFN - Laboratori Nazionali di Frascati, Via E. Fermi 54, 00044 Frascati (Rome), Italy [5] Institute for Nuclear Physics, University of Münster, Wilhelm-Klemm-Str. 9, 48149 Münster, Germany [6] Kavli IPMU (WPI), UTIAS, The University of Tokyo, Kashiwa, Chiba 277-8583, Japan [7] FK4-Astroteilchenphysik, Bergische Universität Wuppertal, Gaußstr. 20, 42119 Wuppertal, Germany [8] LPNHE, Sorbonne Université, CNRS/IN2P3, 75005 Paris, France Corresponding author: joachim.wolf@kit.edu
15:50	**Closing Words:** Chairs Wolfram Knapp and Alice Gallissian

16:00	**Coffee Break** → **End of Conference: 16:30**

Poster Presentation

Thursday, August 27, 2026 - Saturday, August 29, 2026

Location: **In the Entrance Area of the Lecture Hall "Wilhelm und Else Heraeus"**
Chair: Georg Gärtner

	Field Emission:
P1	**C19P: ON THE ADVANTAGES OF USING THE SCALED FIELD *f* AS THE AUXILIARY PARAMETER IN MURPHY-GOOD FIELD EMISSION THEORY** **Richard Forbes** University of Surrey, School of Mathematics and Physics, Guildford, Surrey GU2 7XH, UK Corresponding author: r.forbes@surrey.ac.uk or r.forbes@trinity.cantab.net
P2	**W27P: THUNGSTEN-GRAPHITE CATHODES AS ELECTRON SOURCES FOR 3D-PRINTED FIELD EMISSION MICROSCOPES** **Mohammad M. Allaham[1], Daniel Burda[1], Alexandr Knápek[1], Michal Krysztof[2], Kamil Baranowski[2], Mathias Hausladen[3], and Rupert Schreiner[3]** [1] Institute of Scientific Instruments of CAS, Kr´alovopolsk´a 147, 612 00 Brno, Czech Republic [2] Wroclaw University of Science and Technology, 11/17 Janiszewskiego Str, 50-372 Wroclaw, Poland [3] Ostbayerische Technische Hochschule Regensburg, 93053 Regensburg, Germany Corresponding author: allaham@isibrno.cz
P3	**W41P: MEMS INFINITY - MULTIPLE USE MEMS ADAPTER TO MEASURE FIELD EMISSION IN VACUUM ENVIRONMENT** **Igor Czerwiec, Gracjan Malinowski, and Michal Krysztof** Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland Corresponding author: 277680@student.pwr.edu.pl
P4	**W42P: THE STUDY OF HIGH AND LOW DOPED P-TYPE SILICON FIELD EMITTERS** **Gracjan Malinowski, Igor Czerwiec, and Michal Krysztof** Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland Corresponding author: 277657@student.pwr.edu.pl

P5

W45P: DEPOSITION OF CARBONOUS NANOTIPS ON FIELD EMITTERS

Fabian Hecht, Josef Sellmair, Philipp Buchner, Mathias Bartl, Matthias Hausladen, and Rupert Schreiner
Faculty of Applied Natural Sciences and Cultural Studies, OTH Regensburg,
93053 Regensburg, Germany
Corresponding author: fabian.hecht@oth-regensburg.de

Thermal and Photo Emission:

P6

C22P: EVIDENCE FOR SEMICONDUCTING BEHAVIOR OF SCANDATE CATHODES

B. Vancil[1], V. Schmidt[1], C. Osborne[1], D. Jones[1], M. Caplan[2], W. Ohlinger[3], M. Green[4], and T.J. Balk[5]
[1]e beam Inc., Beaverton, OR 97007, USA
[2]Caplan Physics Applications, Freemont, USA
[3]Ohlinger Consulting, Babson Park, USA
[4]Consulting Services, Palo Alto, CA, USA
[5]University of Kentucky, Lexington, USA
Corresponding author: bernie@ebeaminc.com

P7

C3P: ELECTRON EMISSION FROM REFRACTORY AND NON REFRACTORY CATHODES

Margarita Baeva
Leibniz Institute for Plasma Science and Technology, Felix-Hausdorff-Str. 2,
17489 Greifswald, Germany
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P8

C17P: A RAPID PHOTOEMISSION MODEL FOR BEAM OPTICS CODES

Kevin L. Jensen
IREAP, University of Maryland, College Park, MD, 20742-3511 USA
Corresponding author: kjensen@umd.edu

Microscope Electron Sources:

P9

C16P: DESIGN OF A THERMAL FIELD ELECTRON GUN IMMERSED IN THE MAGNETIC LENS FIELD

Weixia Zhao, Lixin Zhang, Junbiao Liu, Bohua Yin, and Li Han
Institute of Electrical Engineering Chinese Academy of Sciences, Beijing, 100190 China
Corresponding author: zhaowx@mail.iee.ac.cn

P10

C20P: PROOF THAT IN FIELD ELECTRON AND ION MICROSCOPES THE ELECTRON/ION PATH IS INDEPENDENT OF THE CHARGE/MASS QUOTIENT

Fernando F. Dall-Agnol[1], Thiago A. de Assis[2], and Richard Forbes[3]
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[2]Institute of Physics, Fluminense Federal Univ., Niterói, Rio de Janeiro, Brazil 24210-340
[3]University of Surrey, School of Mathematics & Physics, Guildford, Surrey GU2 7XH, UK
Corresponding author: fernando.dallagnol@ufsc.br or r.forbes@surrey.ac.uk

P11	**W40P: ELECTRON BEAM FOCUSING USING AN OCTUPOLE** **Damian Opiela, Janusz Rozum, and Michal Krysztof** Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland Corresponding author: 275611@student.pwr.edu.pl
P12	**W43P: MODULAR 3D-PRINTED MEMS PLATFORM FOR A FIELD EMISSION SCANNING ELECTRON MICROSCOPE** **Janusz Rozum, Damian Opiela, and Michal Krysztof** Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland Corresponding author: 278017@student.pwr.edu.pl
	Microwave Tubes:
P13	**W10P: DESIGN AND ELECTROMAGNETIC ANALYSIS OF AN INPUT CAVITY FOR 648 MHz INDUCTIVE OUTPUT TUBES** **Hirwa Sakindi Alain[1,2], Jiaqiu Tian[1,2] , Dingyu Gu[1] , Shaomeng Wang[1,2] , Zhigang Lu[1,2] , and Yubin Gong[1,2]** [1]National Key Laboratory of Science and Technology on Vacuum Electronics, [2]Terahertz Radiation and Application Key Laboratory of Sichuan Province, University of Electronic Science and Technology of China (UESTC), Chengdu, China Corresponding author: ybgong@uestc.edu.cn
P14	**W17P: A SHORT PULSE RESONANT CAVITY FOR 915 MHz MAGNETRON** **Hao Yin[1,2], Jiaqiu Tian[1,2], Shaomeng Wang[1,2], Zhanlian Wang[1,2], Zhigang Lu[1,2], and Yubin Gong[1,2]** [1]National Key Laboratory of Science and Technology on Vacuum Electronics, [2]Terahertz Radiation and Application Key Laboratory of Sichuan Province, University of Electronic Science and Technology of China (UESTC), Chengdu, China Corresponding author: ybgong@uestc.edu.cn
P15	**C8P: DESIGN OF A LOW CATHODE LOADING, HIGH COMPRESSION RATIO ELECTRON-OPTICAL SYSTEM FOR D-BAND TWTs** **Kunqing Duan[1,2], Jun He[1], Qinglun Liu[1], Yongliang Liu[1], Dehui Zhai[1], Cha Gao[1], and Muguang Li[1]** [1]Discipline and Technology Center of Vacuum Electronic Devices and Systems, Aerospace Information Research Institute, Chinese Academy of Sciences No.5 Yanqi East 2nd Road, Huairou, Beijing 101407, China [2]University of Chinese Academy of Sciences No.1 Yanqihu East Rd, Huairou District, Beijing, 101408, China Corresponding author: skyboyhj@163.com

P16 **W33P: NUMERICAL INVESTIGATION OF 1 kW MICROWAVE HEATING APPLICATOR FOR ENHANCED POWER ABSORPTION IN ASPHALT PAVEMENTS**

Noojilla Satya Lakshmi Aparna[1], A.K. Jha[1], Ravinder Beemagani[1], M.V. Kartikeyan[2]
[1]Department of Electrical Engineering, IIT Tirupati, India
[2]Indian Institute of Information Technology, Design and Manufacturing, Kancheepuram, India
Corresponding author: kartik@ieee.org

Dielectrophoresis and Electroporation:

P17 **W31P: SILICON-BASED MICROFLUID CHANNEL STRUCTURES FOR FUTURE HUMAN CELL MANIPULATION BY DIELECTROPHORESIS AND ELECTROPORATION**

Johannes Wiedmaier, Johannes Sendtner, Simon Hummel, Lars Krenkel, and Rupert Schreiner
Ostbayerische Technische Hochschule Regensburg, 93053 Regensburg, Germany
Corresponding author: johannes.wiedmaier@oth-regensburg.de

Electron-Beam Technologies:

P18 **W48P: TOWARDS HIGH-POWER PULSED ELECTRON-BEAM-SUSTAINED PLASMAS: A DEVELOPMENT PLATFORM FOR INNOVATIVE HIGH-VOLTAGE AND PULSED-POWER ELECTRONICS**

A. Zschalig, L. Dingklage, L. Lorenz, R. Labitzke, C. Cornelius, and G. Mattausch
Fraunhofer Institute for Electron Beam and Plasma Technology FEP, Dresden, Germany
Corresponding author: anthony.zschalig@fep.fraunhofer.de

Gyrotrons:

P19 **W28P: FEASIBILITY STUDIES OF A 140 GHz, 2.4 MW, CW GYROTRON CAVITY**

M.V. Kartikeyan[1], Manfred Thumm[2], S. Yuvaraj[1], R. Beemagani[3], and A.K. Jha[3]
[1]Indian Institute of Technology Tirupati, Yerpedu 517619 (AP), India
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[3]Indian Institute of Information, Design and Manufacturing, Kancheepuram, Chennai 600127, India
Corresponding author: kartik@ieee.org

P20 **W25P: INITIAL DESIGN STUDIES OF A > 200 kW, 30/60 GHz, DUAL-FREQUENCY GYROTRON**

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Corresponding author: kartik@ieee.org

P21	**W26P: DESIGN STUDIES OF A TRIODE MIG AND OUTPUT WINDOW FOR A 30/60 GHz DUAL-FREQUENCY GYROTRON** **K. Srinath[1], R. Beemagani[1], A.K. Jha[1], S. Yuvaraj[2], and M.V. Kartikeyan[2]** [1]Indian Institute of Technology Tirupati, Yerpedu 517619 (AP), India [2]Indian Institute of Information, Design and Manufacturing, Kancheepuram, Chennai 600127, India Corresponding author: kartik@ieee.org

UPDATE ON FIELD ELECTRON EMISSION SCIENCE AND TECHNOLOGY, 2026

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ABSTRACT

This Presentation aims to give a high-level overview of the present state of both technological and scientific work on field electron emission (FE).

Hoped for technological developments include: improved needle-type electron sources, in particular for electron beam instruments such as electron microscopes, improved large area electron sources, particularly those involving carbon based emitters, and new forms of "small flat transistors", based on "ballistic" electron travel in vacuum or air.

Work on the basic theory of FE continues slowly, with a large current emphasis on tidying up various basic aspects of the theory and reducing various types of entrenched error and weak practice, but also an emphasis on developing theory for "sharply curved" and "nanoscopic" emitters. There seems an urgent need for further significant theoretical development, in particular further improved theory relating to sharply curved emitters (and to related data-analysis procedures) and to "getting atoms into the theory".

FE theory continues to play a role in discussion of the origin of electrical breakdown in vacuum, with an interesting related development being observation of the growth of carbon nanowhiskers.

In the last 100 years there has only been one experiment that has been able to make a more-or-less reliable comparison between FE experiment and theory. A second method of doing this has recently been suggested and will be briefly described. Both experimental methods confirm that 1950s Murphy-Good FE theory is better than 1920s type FE theory (which is still often used).

More sophisticated theoretical developments involve the application of density-functional-theory to FE, other advanced computational techniques, and the development of a "digital twin" approach to real-time data analysis.

At a more fundamental level, there seem to be deep quantum-mechanical issues associated with some aspects of field electron emission, for example the origin of the "arrow of time", and the question of how the field electron (emission) microscope actually works, given that nowadays we can "see" electron bonds in the apex of a carbon nanotube.

Adjacent to FE there are other significant tasks under way, including improvement of aspects of the theory of electrostatics of pointed objects (including the so-called "classical lighting-rod effect)", and the question of whether the definition of voltage in the relevant International Standard actually does correspond to the quantity that engineers measure with a digital voltmeter.

Relevant references will be included in the written-up version of this presentation.

C18I: Richard Forbes, Invited oral presentation (IVESC)

Evidence for the Breakdown of the general Plane-Wave Field Emission Theory in Nanometric Emitters

F.F. Dall'agnol[1], T.A. de Assis[2], G. Meng[3] and J.P. Xanthakis[4]

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It is well-known that neither the elementary triangular barrier Field Electron Emission (FE) equation nor the Murphy-Good FE equation holds at the nanometric scale of emitters. This has been recently supported by the experimental work of Meng and coworkers [1]. Here, we give evidence that even the general FE theory based on plane waves and Cartesian symmetry is not valid. To this end, we have calculated the local electrostatic potential distribution for emitters with apex radii of 2 nm and 4 nm, with a planar anode located at a gap distance of d = 25 nm and 50 nm, respectively. The local electrostatic potential distributions were calculated using finite elements method in a 2D axisymmetric simulation domain in COMSOL by solving the Laplace equation [2]. Subsequently, the local electrostatic potential was used to reproduce the experimental data of Meng *et al.* [1] by employing the general theoretical expression for the local transmitted current density through an arbitrary potential barrier using plane waves as eigenstates. That is, the expression for the local current density J

$$J = \frac{emk_BT}{2\pi^2\hbar^3}\int ln\left[1 + exp\left(\frac{E_F - E_n}{k_BT}\right)\right] D(E_n)\, dE_n \quad (1)$$

where D is the transmission coefficient, E_n are the normal energies of the electrons and the remaining symbols have their conventional meaning. The $D(E_n)$ depend on the tunneling potential distribution $U(x)$ which is constructed by adding a spherical image potential and the work function to the calculated complete electrostatic potentials i.e. no linearity in the potential was assumed (like in the elementary or in the Murphy-Good FE equations) or even corrections up to second order like in the Kyritsakis-Xanthakis equation [3] Then, in normal practice, the current is I=J*A where A is the area which is treated as a parameter. The calculated slopes of the ln(I) vs 1/V curves – (where V is voltage) - deviated significantly from the experimental ones signifying that the true nature of the eigenstates in these nanometric emitters due to confinement and localization must be taken into account. We note that A cannot affect the slopes of these curves. By describing the emitters as paraboloids [4] i.e. by using wavefunctions with wavefronts that fit the emitter surface we have managed to reproduce the experimental data of the R=2 nm emitter. Calculations to reproduce the 4 nm emitter I-V characteristics are under way.

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C4T, J.P. Xhantakis, oral presentation (IVESC)

Cryogenic Field Emission Enhancement in Vertically Aligned Carbon Nanotubes Cold Cathodes through Tip Morphology Engineering

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Vertically aligned carbon nanotubes (VACNTs) represent a promising solution as cold electron cathode, due to their high aspect ratio and nanoscale tip radius. Their field emission (FE) properties enable low turn-on fields and stable current densities, from fA to mA regime [1]. Moreover, they present a superior mechanical, electrical and chemical stability in ultra-high vacuum, both at room and cryogenic temperature [1]. These qualities make VACNT-based cathodes highly attractive as scalable, microstructured electron sources, enabling robust integration into compact, chip-level devices for fundamental physics applications, including compact accelerators [2], precision electron injectors [3], and low-background detection systems in rare-event dark matter experiments [4].

We present a quantitative investigation of the correlation between tip morphology and FE properties of VACNTs at cryogenic temperature. Three VACNT samples were systematically characterized to assess the impact of tip morphological modifications on electron emission performance. Field emission measurements were conducted at T = 2.8 K, enabling operation close to the ideal conditions of the Fowler–Nordheim model and representing one of the first observations of FE in vacuum below 10 K [5] .

The field enhancement factor β was extracted through Fowler–Nordheim analysis, supported by independent and precise determination of the work function via ultraviolet photoemission spectroscopy (UPS) and accurate evaluation of the cathode–anode distance. Plasma etching was found to significantly enhance emission performance, yielding β values up to $(15.2 \pm 2.5) \times 10^3$, more than doubling that of the as-grown sample .
A detailed morphological analysis was carried out using atomic force microscopy, enabling statistical evaluation of the tip radius of curvature r_c. By correlating morphological and electrical data, we establish a clear inverse relationship between the field enhancement factor and the tip curvature radius, described by $\beta(r_c) = k/r_c$, with $k = (175 \pm 13)$ μm.

This result provides a predictive framework for estimating FE performance directly from surface morphology measurements, bypassing the need for complex cryogenic setups.

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C13T: L. Cecchini, oral presentation (IVESC)

THE MANUFACTURE OF ELECTRONIC EMITTERS USING MODIFIED PHOTOSENSITIVE RESIN

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ABSTRACT

This study presents the experimental fabrication of electron emitters. The process involves two main steps. First, a two-photon lithography (2PL) system (IQnano3D, IQS nano) is employed to print the base structure along with the electrodes using a photosensitive resin (ResIQ, IQS nano). The resulting printed structures typically reach a height of approximately 50 µm. In the second step, these cured resin base structures undergo thermal treatment. This treatment transforms the surface of the resin into a conductive layer through heat-induced modification. The conductive layer may also be created via electroless plating or metal evaporation.

Each chip is fabricated on a square silicon substrate with dimensions of 10 × 10 mm, upon which the modified structures are formed. The emitter geometry is kept simple and the shapes have increased base area to provide good adhesion to the silicon substrate. Chips containing the conductive features were individually evaluated for outgassing in an ultra-high-vacuum chamber (~10^{-7} Pa) [1].

These chips are intended for testing and integration into low-energy electron optical systems, such as [2], with the aim of developing compact electron-emitting devices.

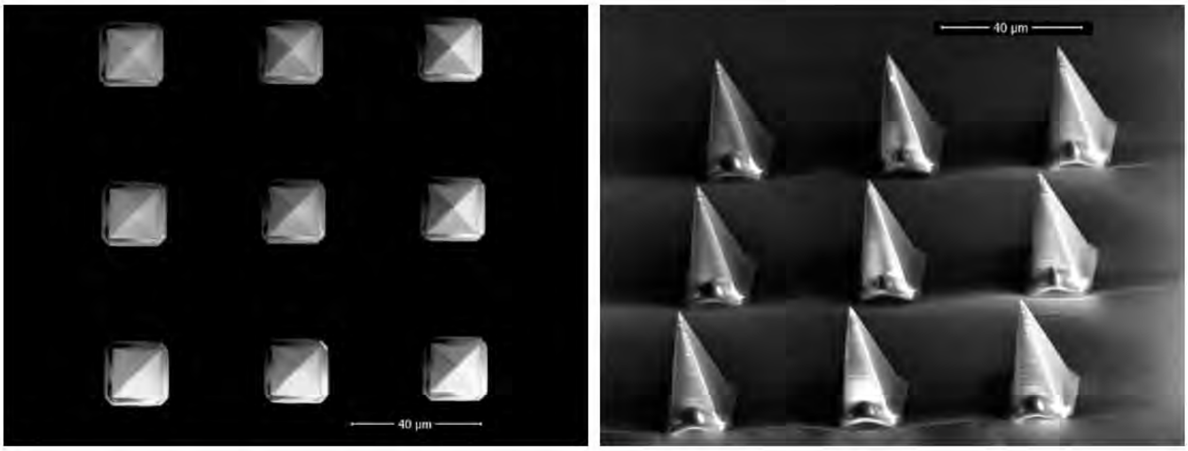

Fig. 1. a) SEM image of a pyramid-like array of fabricated resin-based emitter structures, left: top view, right: side view tilted by 30 degrees.

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W35T, D. Burda, oral prsentation (IVEW)

Design and experiment of a multi-beam electron source

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Electron Emission Phenomena and Modelling, Thermionic and Field Emission, Oral

In recent years, high-throughput, large-area microscopic imaging based on multiple electron beams has been developed [1,2], promoting progress in related fields such as life sciences, neuroscience, and semiconductor inspection[3,4]. The multi-beam electron source plays a key role in such high-throughput setups.

In this work, a multi-beam electron source based on a thermal field electron gun has been developed. The Schottky emitter provides a reasonably constant angular current density. Within this angular current density, a collimator is used to manipulate the divergent beam. The collimated beam then impinges on an aperture array, which splits the single beam into multiple beams, and these are subsequently focused by a micro-arrayed Einzel lens (MAEL). Both the aperture array and the MAEL are fabricated using MEMS technology. To achieve high-precision assembly of the MEMS devices, we developed a dedicated assembly tool for the multi-aperture, multi-layer structure, achieving a positioning error of less than 500 nm. In the experiment, a 10×10 grid of electron beams was obtained, and the spot sizes could be adjusted by varying the focusing voltage applied to the MAEL (see Fig. 1).

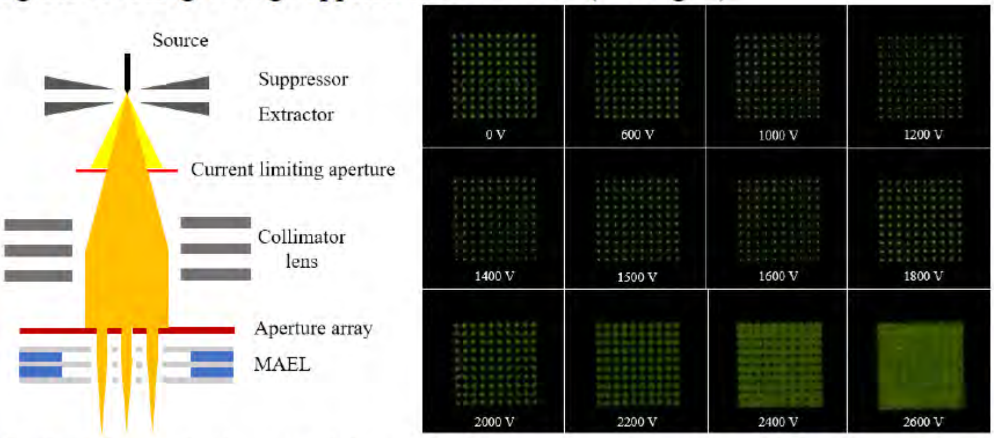

Fig 1 Left: Schematic design of the multi-beam electron source. Right: The experimental results of the multi-beam electron source.

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C15T, L. Zhang, oral presentation (IVESC)

Session 1.2 Thermionic Emission

Recent advance in dispenser cathode

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As the electron source of vacuum electron devices, the performance of cathodes plays an important role in the device stability and operational durability. In recent years, we made a serial studies on the mixed matrix of Ir-W scandate cathodes, introduction of inert barrier layer Ni in the dispenser cathode, optimizing the composition of barium-calcium aluminates[[1-3]. In order to improve the emission property, a new $BaO\text{-}CaO\text{-}Al_2O_3\text{-}BaF_2$ quaternary aluminate impregnant was obtained and the addition of BaF_2 decreases the viscosity and melting point of the aluminate impregnants. The emission current density of Ba-W cathode impregnated with quaternary aluminate impregnant can reach 15.89 $A{\cdot}cm^{-2}$ at 1100°C$_b$, which is 1.11 times higher than that of the without BaF_2. Theoretical calculations confirm that introducing fluorine triggers the number of point defects and barium compound in impregnant to gain electron convert to the metastable $Ba^{\delta+}$ ($0 < \delta < 2$), enhancing the ability to produce active substance Ba. The introduction of Ni can inhibit the reaction between W and Ba-Ca-aluminates during the impregnation process of the matrix. After cathode activation, the surface Ba:O ratio is 0.88:1.00, much higher than the Ba dispenser cathode without Ni doping. The pulse electron emission current density at 1100℃$_b$ was 18.65 A/cm^2. It has a low evaporation rate and the accelerated lifetime test predict a lifetime of over 160000 hours. W-Ir matrix scandate cathode presented the highest emission current density of 83.43 A/cm^2 at 900 °C$_b$. Ir can decrease the evaporation of active substance, effectively stabilizes the W-O-Ba-Sc surface configuration, and therefore significantly enhances the emission property of the cathode.

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C6I, J. Wang, invited oral presentation (IVESC)

THERMIONIC CATHODES MANUFACTURING

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ABSTRACT

A thermionic (dispenser) cathode is an electron source commonly used in Vacuum Electronic Devices (VED). Its operation is based on principals of thermionic emission, and while the physics of the thermionic emission is well understood and described, the cathode's performance depends on many factors, including but not limited to materials' purity and properties, manufacturing process control, facility cleanliness and environmental controls, and most importantly operators' skills. Since the cathodes cannot be tested for performance before being installed into electron guns (or a specially designed test equipment), it is critical that all these requirements are met at the highest possible level. However, some other, post-manufacturing processes are also critical for the cathode performance, including proper packaging, storage and activation processes.

This paper will not address the physics of the thermionic emission and will be focused on the manufacturing processes and best practices implemented at 3M Technical Ceramics to ensure high quality and reliability of the thermionic cathodes.

C7I: D. Busbaher, invited oral presentation (IVESC)

Contributions to the theory of Scandate cathode emission

G. Gaertner, Aachen (C9T, oral, IVESC 2026, Bad Honnef)

In a paper of B. Vancil et al. „New Theory of Emission for Scandate Cathodes“ [1] presented at IVEC 2026, with a parallel paper by M. Caplan et al. [2], the authors give evidence, that Scandate cathodes exhibit features of semiconductor cathodes similar to oxide cathodes. Of course these features are well known, among these are the anomalous Schottky behaviour in saturation, the field dependence of activation and peak shifts of Miram plot work function distributions dependent on peak electric field (see also G. Gaertner, Y. Wang [3]). In the paper of Caplan he fitted the anomalous Schottky characteristic with oxide cathode theory as outlined by Wright, Woods and Morgulis [4,5], but with the result of a Debye length of 2.1 µm*. Yet B. Vancil et al. [1] show by high resolution characterization, that the Sc rich layer on tungsten is very thin, in the order of 6 nm, with oxide particles in the order of 20 nm. Hence there is a clear contradiction between these very thin films and a Debye length of 2.1 µm*(*the definition of λ_D of Caplan differs by a factor $\sqrt{2}$). The Debye screening length is a characteristic parameter for charge separation and band bending at the surface of a semiconductor between donors and acceptors and is given by $\lambda_D = (\varepsilon \varepsilon_0 kT / (e^2 n_i))^{1/2}$ where n_i is the density of ionized donors [3,4,7]. Of course one prerequisite is, that the semiconducting layer is thicker than the respective Debye length. A first specific theory was derived by Raju and Maloney [6] for semiconductor layers thinner than λ_D on metals, giving a transition from thick oxide to metallic behaviour. According to B. Vancil the experimental Schottky characteristic [2] could not be fitted with their theory.

There are three possibilities to explain the discrepancy between the very thin Sc and BaO layers on the cathode surface and the large Debye length. First: Due to the electrical image expansion of the beamlets originating at distributed Ba-scandate particles (emissive spots) of about 15 – 20 nm diameter by a factor of 100 – 200 the apparent large Debye length can be explained, in line with the model of G. Gaertner [8]. The second possibility is, that the large Debye length occurs only at larger oxide particles or at the oxides in the larger pores, which strongly contribute to high electron emission; but this is also in line with the beamlet effect for a bit larger spots. The third possibility relies on the scaling of λ_D, which is decreasing with increased density of ionized donors $\mathbf{n_i}$. With the following parameters $\mathbf{n_i} = 3*10^{17}$ cm^{-3} similar to Chin et al. [9], ε(Ba-scandate) ≈10 and T = 1260 K λ_D = 14.1 nm is obtained, consistent with the 15 nm oxide particle thickness of the characterization [1]. Yet for uniform emitting layers e.g. of 6 nm thickness this would be in clear contradiction with the observed Debye length and also with the low Richardson constant of Scandate cathodes. The major advantage of scandate cathodes over oxide cathodes with their limited dc loadability is consistent with the model, namely due to very thin Ba.Sc-oxide layers of scandate cathodes the conductivity limitation disappears.

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EVOLUTION OF M-TYPE CATHODE EMISSION DURING LONG-TERM LIFE-TESTS

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ABSTRACT

Numerous models have been proposed to predict the lifetime of thermionic cathodes [1-5], yet long-term experimental validation remains scarce, particularly over multi-decade timescales. In this work, the long-term evolution of the zero-field saturation current density of multiple M-type impregnated cathodes was investigated over four decades. The cathodes, impregnated with Ba–Ca aluminate (4:1:1) and coated with an osmium–ruthenium layer, were mounted in dedicated bulbs and operated in diode configuration at a current density of 1.5 A/cm² across a range of temperatures (970-1030°CB). Periodic measurements of J_0 reveal a clear and systematic degradation of the emission over time.

Complementary analyses of end-of-life cathodes by SEM, Auger spectroscopy, and XPS provide insight into the underlying ageing mechanisms. The experimental results show good agreement with the semi-empirical life prediction model proposed by Schroff [2]. Altogether, these results provide a consistent framework for understanding cathode ageing and contribute to improved lifetime prediction in thermionic devices.

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C12T: S. Maine, oral presentation (IVESC)

ELECTRON EMISSION MODELLING IN IONISATION GAUGES FOR MAGNETIC CONFINEMENT FUSION

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ABSTRACT

Preferences:

IVeSC – Oral presentation
Electron Emission Phenomena and Modelling – Thermionic and Field Emission

In magnetic confinement fusion, neutral gas density measurements are a critical diagnostic parameter for plasma control. The ASDEX ionisation gauge is a diagnostic instrument capable of providing spatially and temporally resolved measurements of neutral gas pressure around the vessel in the presence of strong magnetic fields. Its design features a linear electrode configuration comparable to a vacuum tube triode [1]. The internal physics of the device have been studied through qualitative computational modelling [2] and experimental optimization campaigns [3]. While prior simulation efforts using electrostatic particle-in-cell (PIC) methods successfully reproduced diagnostic characteristics under specific equilibrium conditions, they failed to predict a broader range of operational parameters and dynamic state transitions. This talk presents ongoing work at the Max-Planck-Institute for Plasma Physics (IPP) to develop a capable, synthetic ASDEX ionisation gauge model based on a self-consistent, fully dynamic PIC-MCC (Particle-in-Cell with Monte Carlo Collisions) using an open-source framework. If successful, this work would not only enable further design optimization for next-generation fusion experiments but also provide a better understanding of signal instabilities observed during diagnostic operation [4].
The focus of the talk will be placed on the numerical methods used, as well as the benchmarking of thermionic electron emission from a heated cathode. First simulation results for different emitter configurations, materials, and biasing potentials are validated against measurement data. Emphasis will also be placed on tractable model simplifications and their empirical impact on prediction accuracy.

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C2T: A. Glock, oral presentation (IVESC)

Session 1.3: Gyrotrons I

PROGRESS IN EUROPEAN COLLABORATIVE GYROTRON DEVELOPMENTS FOR CEA AND GENERAL ATOMICS

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ABSTRACT

This paper summarizes recent progress at THALES on two continuous-wave (CW) industrial gyrotrons developed for fusion Electron Cyclotron Heating and Current Drive, namely the TH1511 for WEST [1] and the TH1512 for DIII-D [2]. Both programs combine THALES industrial design and fabrication with electromagnetic and electron-optics design activities at KIT and NKUA and target reliable Megawatt-class operation with high Gaussian mode output beam content, depressed-collector efficiency enhancement and compatibility with long-pulse operation. The developments address distinct plasma scenarios and magnetic-field constraints while preserving a common industrial architecture based on a diode magnetron injection gun, independently adjustable superconducting magnet circuits, advanced cavity cooling, quasi-optical mode conversion and a swept depressed collector. The TH1511 is specified for 105 GHz, 1 MW CW operation in the WEST tokamak, where three units will support steady-state plasma scenarios up to 1000 s. It operates in the TE-20,8 cavity mode with electron beam parameters around 78 kV and 45 A. The TH1512 is specified for 117.5 GHz, 900 kW CW operation in the DIII-D tokamak, where two units will support 10 s pulses with accurate power modulation and deposition control. It operates in the TE24,8 mode with beam voltage up to 92 kV and beam current above 35 A. Prototype fabrication was completed at THALES using qualified processes for vacuum integrity, high-voltage insulation, hydraulic cooling, and dimensional reproducibility. Short-pulse validation was performed at the KIT FULGOR facility with calorimetric power measurements, heterodyne frequency diagnostics, and infrared beam imaging [3]. For the TH1511, 1 ms non-depressed operation at 104.984 GHz yielded about 1.2 MW at 50 A, while depressed-collector operation provided 1 MW at about 46% efficiency and 1.1 MW in 3 ms pulses. For the TH1512, 1 ms non-depressed operation at 117.703 GHz exceeded 1.3 MW at 43 A and depressed-collector operation produced 1.03 MW with efficiency above 48% in 3 ms pulses. Long-pulse operation of the TH1511 tube delivered 1 MW at 45% efficiency for 5 s at CEA, where testing is continuing toward longer pulses. Long-pulse tests of the TH1512 gyrotron delivered 950 kW at 42.5% efficiency for 10 s at KIT, where the unit successfully passed the factory acceptance test. These results validate the common design approach across two frequency bands and two fusion devices and indicate that both gyrotrons have reached a maturity level consistent with technical requirements.

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W3I: A. Leggieri, invited oral presentation (IVEW)

MEGAWATT CLASS GYROTRON DEVELOPMENT AT MPP

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ABSTRACT

MPP is currently engaged in the design, development, and demonstration of several 500 kW – 1 MW power level gyrotrons at millimeter wave frequencies for both fusion and non-fusion applications. MPP has designed, built, tested and delivered the first of two 600 kW continuous wave (cw) dual frequency 70/105 GHz gyrotrons for the Oak Ridge National Laboratory's Material Plasma Exposure eXperiment (MPEX) program [1]. Detailed design features as well as the results of experimental demonstrations will be given. In addition, MPP has designed and built a 1 MW cw 105 GHz gyrotron for a deep hole drilling application. To date, the gyrotron fabrication is complete and tests are planned for Spring 2026. Test results, if available, will be discussed.

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W4I: M. Blank, invited oral presentation (IVEW)

Development of High-Power Microwave Vacuum Electronics at KIT

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ABSTRACT

The demand for megawatt-class gyrotrons for Electron Cyclotron Resonance Heating (ECRH) and plasma control in fusion devices is steadily increasing. At the same time, requirements on output power, efficiency, operational flexibility, reliability, and industrial manufacturability are becoming more stringent. KIT addresses these challenges as part of Europe's coordinated fusion research efforts.

Until 2024, research focused on gyrotrons for a prospective EU DEMO power plant operating at moderate magnetic fields (< 6 T), targeting frequencies of 170 GHz and output powers of up to 2 MW in continuous-wave (CW) operation. In parallel, KIT advanced gyrotron technologies for major fusion experiments such as Wendelstein 7-X (W7-X) [1] and ITER [2], and developed adapted variants of the W7-X gyrotrons for TCV (Switzerland) [3], CEA/WEST (France) [4], and GA/DIII-D (USA) [5].

Since 2024, emerging fusion start-ups have introduced concepts for compact fusion devices operating at substantially higher magnetic fields, which require gyrotrons at frequencies above 200 GHz. In Germany, this development is driven by Proxima Fusion with its Proxima Alpha and Stellaris projects [6]. Proxima Alpha requires gyrotrons operating at 238 GHz with output powers exceeding 1 MW. Within the BMFTR project HeatQIS (launched at the end of 2025), KIT, Proxima Fusion, and Diamond Materials GmbH & Co. KG are jointly developing suitable gyrotrons, diamond windows, and launcher components. A first industrial gyrotron, manufactured by Thales (France), is scheduled for testing at KIT by 2029.

In parallel, building on earlier developments of 1.5 MW gyrotrons for W7-X, KIT and IPP are working within the BMFTR project HiPMiB on a 2 MW version of the 140 GHz gyrotron for Wendelstein 7-X. This system is also targeted for industrial realization by Thales, with testing planned for early 2029.

Looking ahead, future fusion devices may operate at even higher magnetic fields (e.g., SPARC) [7]. Besides the development of stronger magnets, operation at the second harmonic of the electron cyclotron frequency represents a promising alternative. Within a EUROfusion Enabling Research activity, KIT and NKUA are investigating corresponding high-efficiency gyrotron concepts [8]. Achieving overall efficiencies of $\geq 60\,\%$ will require the implementation of multistage depressed collectors (MDCs). KIT has longstanding expertise in E×B-type MDCs, has already presented the design, manufacture and first test of a first short-pulse prototype, and is currently advancing both theoretical and experimental work toward CW-capable systems [9].

Beyond fusion-related high-power gyrotrons, KIT is also pursuing the development of gyrotron traveling-wave tubes (gyro-TWTs) for applications such as space radar. In collaboration with Fraunhofer FHR, a joint research group has been established. Furthermore, within the DFG Collaborative Research Center "HyPERiON", KIT is developing a 263 GHz, 1 kW gyro-TWT amplifier for DNP-NMR spectroscopy, with a first prototype planned in the current funding phase.

This presentation provides a comprehensive overview of KIT's activities in high-power microwave vacuum electronics, covering both fusion and non-fusion applications.

Acknowledgements

W36I: J. Jelonnek, invited oral presentation (IVEW)

Experimental Progress in High-Frequency Terahertz Gyrotrons

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ABSTRACT

Terahertz radiation sources have attracted significant attention due to their wide applications in high-resolution imaging, spectroscopy, and advanced communications. Gyrotrons, as high-power vacuum electronic devices, are ideal candidates for generating high-frequency, high-power terahertz radiation. This paper presents two recent advancements in THz gyrotron technology and experiments at Peking University: the development of terahertz harmonic gyrotrons based on superconducting magnets and experimental research on terahertz pulsed gyrotrons with high field pulsed magnets.

First, axis-encircling electron beams (also known as large orbit beams), characterized by their inherent mode-selection properties, can significantly reduce the mode spectral density in overmoded cavities [1]. This facilitates high-harmonic operation and enables the generation of high frequency terahertz radiation at relatively low magnetic fields. A magnetic cusp gun (MCG) with strong robustness in operating parameters produces a large orbit beam with extremely low velocity spread (as low as 0.4%) within a magnetic field range of 4–9 T, providing the foundation for continuous switching among multiple harmonics over a wide magnetic field range. Experimental results demonstrate that the developed large orbit gyrotron (LOG) can sequentially excite five different harmonic modes. The third harmonic achieved an output power of 0.68 kW at approximately 650 GHz, corresponding to an electronic efficiency of 2.16%. The good agreement between experiments and simulations validates the correctness of the design and the accuracy of the measurements.

Second, the gyrotron with high-field pulsed magnet provides another solution to meet the magnetic field requirements for high-frequency operation. The current mini-pulse-magnet platform can achieve a maximum field strength of up to 40 Tesla. Based on the fundamental harmonic interaction of the high-order whispering-gallery mode (WGM) $TE_{13,3}$ [2], terahertz radiation with millisecond-level pulse width and joule-level energy around 560 GHz is obtained. Moreover, the inherent time-varying properties of the pulsed magnetic field provides a natural path for achieving the high-efficiency operation in the hard-excitation region in every pulse, without the need for manual tuning [3]. The asymmetry of the operating range in the up-tuning and down-tuning semi-waveforms is also observed in the experiments, which is a direct manifestation hard-excitation-induced hysteresis.

In conclusion, the successful demonstration of multi-harmonic switching in LOGs and the exploitation of hard-excitation dynamics in pulsed systems provide critical insights for the future realization of high-power, stable, and frequency tunable THz radiation sources based on vacuum electronics.

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W7T, F. Zhang, oral presentation (IVEW)

Evaluation of a Low Voltage High Current Operation Point for a High-Frequency and Very-High Order Mode Gyrotron

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ABSTRACT

The HEATQIS project, funded by the Federal Ministry of Research, Technology and Space (BMFTR), develops key technologies for future high magnetic field fusion power plants, focusing on plasma electron cyclotron resonance heating (ECRH). The project includes the investigation of ECRH components such as superconducting magnet systems, diamond windows, and launcher systems for future stellarator-based fusion reactors such as Proxima Alpha. Central to the project is the development and manufacture of a 238 GHz, 1.7 MW $TE_{49,29}$ mode coaxial-cavity gyrotron for 100 s long-pulse operation. Here, the gyrotron will be investigated under two alternative operating regimes: Low Voltage High Current (LVHC, 75 kV, 75 A) and High Voltage Low Current (HVLC, 90 kV, 63 A). The comparison focuses on the influence of both concepts on electron gun performance, beam–wave interaction in the cavity, After-Cavity Interaction (ACI), and collector efficiency, with particular attention to the challenges associated with high-frequency gyrotrons operating at high mode indices and the resulting differences compared to already established gyrotrons.

The electron gun design is evaluated with respect to peak electric field strength and the associated risk of arcing for both operating points. In addition, the interaction efficiency is compared for cavity designs individually optimized for the LVHC and HVLC regimes. The analysis includes the impact of the operating point on ACI effects [1], also considering the implications for the dimensions of the quasi-optical launcher. The collector performance is investigated with emphasis on the slowest electrons reaching the collector and their influence on collector efficiency and with the points before the overall gyrotron efficiency. The study aims to evaluate the suitability and limitations of both operating regimes for efficient and reliable operation of the HEATQIS gyrotron.

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Topic

Vacuum Electronic and Discharge Devices and their Applications
Microwave Tubes (TWTs, Klystrons, Fast-Wave Devices …)

W16T: A. Schmidt, oral presentation (IVEW)

Quasi-Optical Mode Generator for the Verification of a 238 GHz TE49,29 -Mode Gyrotron Launcher Antenna

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ABSTRACT

Gyrotrons are high-power electron vacuum tubes capable of generating millimeter waves in the megawatt range [1] and are a key technology for Electron Cyclotron Resonance Heating (ECRH), Current Drive (CD), and Collective Thomson Scattering (CTS) diagnostics in magnetically confined fusion plasmas. For the next generation of high-field plasma fusion devices, a megawatt-class gyrotron operating at 238 GHz is currently under development [2].

For this gyrotron, the very high-order cavity mode $TE_{49,29}$ has been identified as the designated operating mode. Efficient transmission of the generated millimeter-wave power requires conversion of this high-order TE mode into a linearly polarized fundamental Gaussian $TEM_{0,0}$ beam. This task is realized by an internal mode-converting launcher antenna in combination with beam-shaping reflectors. Due to the extremely tight manufacturing tolerances and the limited tolerance for deviations from the design, experimental low-power verification of the launcher antenna and the quasi-optical system is essential prior to high-power operation inside the gyrotron.

This contribution presents the design of a dedicated quasi-optical mode generator setup developed for cold measurements of a 238 GHz $TE_{49,29}$-mode launcher antenna. A Gaussian millimeter-wave beam is generated by a horn antenna and shaped using a set of cylindrical Teflon lenses and a quasi-parabolic mirror, enabling coupling into an optimized resonant coaxial cavity with a perforated wall. The excited rotating $TE_{49,29}$-mode is then used for the verification of the gyrotron launcher antenna.

Acknowledgment

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W18T, M. Misko, oral prsentation (IVEW)

Ongoing Development of a Gyro-TWT Test Stand up to 263 GHz at IHM

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ABSTRACT

The generation of high-power microwaves up to 263 GHz is of considerable interest for numerous applications, including communications, spectroscopy, and space situational awareness. To address this demand, a variety of different gyrotron travelling-wave tube (gyro-TWT) configurations have been developed over the past decades, including designs employing cylindrical [1], dielectrically loaded [2], quasi-optical [3], and helically corrugated [4] interaction circuits.

Despite their structural differences, all gyro-TWT variants share common features: All utilize the weakly relativistic electron cyclotron maser interaction principle [5], which enables the amplification of broadband input signals to power levels in the kilowatt range. Efficient operation necessitates a homogeneous axial magnetic field within the interaction region, a high-voltage power supply for electron beam acceleration, and an electron emitter capable of delivering the required beam current.

At IHM, the amplifier research activities are focused on gyro-TWTs employing a helically corrugated interaction region (HCIR), hereafter referred to as helical gyro-TWT [4]. The HCIR configuration facilitates second-harmonic electron cyclotron frequency operation, thereby reducing the required magnetic flux density by a factor of two.

This contribution presents the ongoing development of a dedicated test stand for gyro-TWTs and provides an overview of the critical components required for their experimental validation. Particular emphasis is placed on the requirements and design of the 5.5 T superconducting magnet to enable efficient operation of helical gyro-TWTs up to 263 GHz. The magnet features a variable magnetic field profile and a 50 mm diameter warm borehole, allowing for flexible operation of gyro-TWTs for different frequencies. In addition, an electron gun [6] capable of delivering axis-encircling beam currents of up to 1 A, as well as the new power supply providing up to 65 kV and 4 A, are described.

The presented components establish the basis for initial experimental investigation of helical gyro-TWTs and provide a versatile platform for future studies of a broad range of gyro-type devices.

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W20T, M. Vöhringer, oral presentation (IVEW)

A Broadband Measurement Platform for Frequency and Amplitude Analysis of a 263 GHz Gyro-TWT

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ABSTRACT

Gyro-traveling wave tube (gyro-TWT) amplifiers are promising sources for generating sequenced microwave pulses in dynamic nuclear polarization nuclear magnetic resonance (DNP-NMR) spectroscopy. During their development, accurate and broadband spectrum diagnostic tools are essential to verify performance and ensure reliable operation. This work presents a novel, modular, and real-time-capable diagnostics system based on a heterodyne receiver architecture, enabling simultaneous frequency and amplitude characterization of a 263 GHz gyro-TWT amplifier.

The system incorporates an external front-end module with a sub-harmonic mixer, which can be flexibly positioned and exchanged to accommodate different frequency ranges through the use of mixers with varying waveguide dimensions. This modular design allows the characterization of gyro-TWT amplifiers across multiple frequency bands through different front-end modules. After down-conversion, the system utilizes two complementary measurement approaches. The first employs a filter bank with parallel detector diodes for real-time frequency and RF power measurement. Due to its low latency, this path can also serve as a trigger for rapid shutdowns in the event of amplifier malfunctions. The second approach uses a high-speed oscilloscope to capture the down-converted signal and perform short-time Fourier transform (STFT) analysis, enabling flexible adjustment of temporal and spectral resolution during post-processing.

By combining these methods, the system enables redundant power level measurement and achieves a real-time bandwidth of 38 GHz through ambiguous mixing over a frequency range of 160-288 GHz. The system delivers a frequency resolution of up to 10 kHz, a dynamic range of 40 dB, and a power measurement uncertainty within ±21 % for the given gyro-TWT amplifier. In addition, pulse durations as short as 250 ns can be reliably resolved.

Future extensions include amplifier gain and phase characterization, for which concepts have already been developed and validated in preliminary experiments, increasing its future flexibility and use-cases.

W19T: B. Bischofberger, oral presentation (IVEW)

30 years of IVESC – a short historical review

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With the 16th International Vacuum Electron Sources Conference (IVESC) 2026 here in Bad Honnef, Germany, we also celebrate 30 years of IVESC. At the 1994 TRI Services/NASA Cathode Workshop in Cleveland / USA it was decided to start an international vacuum electron sources conference in continuation of this biennial cathode workshop, which had been organized by the cathode research groups in US Army, Navy and Airforce, and by NASA since 1978 in USA, but only with limited participation by European and Japanese researchers. The 16th IVESC is also the 25th cathode conference in the sequence Cathode Workshops → IVESC. The first IVESC was organized by Philips Research and took place in Eindhoven / The Netherlands in 1996 and was chaired by Dr. Sjaak Deckers from Philips Research. About 200 participants gathered there (105 from Western Europe, 27 from Eastern Europe, 23 from Japan, 2 from Korea, 33 from USA). The Proceedings (a selection of 54 papers) were published in a special issue of Applied Surface Science, a tradition which lasted till the 5th IVESC. It was also decided to change the location biennially from Europe to Asia and then to USA. In 1998 the second IVESC was hold in Tsukuba/Japan and was chaired by Prof. Shigehiko Yamamoto from the University of Tsukuba, with some 182 participants, among these 142 from Asia. The third IVESC in Orlando, Florida followed in 2000, hosting 106 participants, among these 56 from USA. It was chaired by Edwin Wintucky from NASA and was locally organized by IEEE. The fourth IVESC in Saratov in 2002 was the first IVESC in Russia and had in total 176 participants (142 from Russia). The 5th IVESC 2004 in Beijing hosted about 166 participants from 14 countries, among these 144 from Asia Pacific, presenting about 165 papers in form of orals or posters (116 from China). 45 selected papers were published in Appl. Surf. Sci. 251 (2005). The 6th IVESC in Monterey, California was a joint conference with the 7th IVEC. General Chair was Robert Fickett (CPI, USA) with Co-Chairmen B. Levush (NRL, USA) and E. Wintucky (NASA, USA; IVESC part); 155 orals and 110 posters were presented, with the majority of contributions from USA. 41 orals and 18 posters were contributed by IVESC. The 7th IVESC took place at Queen Mary University of London in 2008. Conference Chair was Prof. David S. Barratt from Blackburn MicroTech Solutions (formerly LG.Philips Displays Blackburn). From the 79 participants 37 came from Europe. The generally high participation from the conference site region shows, how important the site change is in order to involve the whole electron emission community over the years. The following conferences will be addressed in the presentation and also a complete list of proceedings and books of abstracts will be given there.

The 13th IVESC in 2020 was planned as the first joint conference with 7th ITG IVEW in Bad Honnef, but due to Corona could only take place online in Thales virtual room (France). IVESC chair was Dr. J.-M. Roquais and IVEW chair was Dr. W. Knapp. 31 IVEW and 38 IVESC contributions were presented. Now the 16th IVESC 2026 is a joint conference with 10th VDE ITG International Vacuum Electronics Workshop (IVEW) again, with the chairs Dr. Wolfram Knapp (IVEW) and Dr. Alice Gallissian (IVESC). 49 abstracts were contributed by IVEW and 23 abstracts by IVESC, with about 80 participants. We wish this joint conference further success and express our thanks to the organizers. By the way, also ITG IVEW can celebrate a jubilee, since it is the 20th conference/workshop in a row, which started with 1st NTG-Conference on "Electron Tubes and Related Devices" 1977 in Garmisch-Partenkirchen. After the 10th ITG-Conference on Displays and Vacuum Electronics 2004 in Garmisch-Partenkirchen it was continued by the 1st ITG International Vacuum Electronics Workshop 2008 in Bad Honnef.

C23I, G. Gaertner, invited oral presentation (IVESC)

Multifunctional THz Vacuum Electronic Sources Enabled by Momentum Engineering and Symmetry-Broken Microstructures

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ABSTRACT

The Terahertz frequency range, situated between the microwave and infrared regions, has long been identified as a frontier for next-generation technological breakthroughs [1]. However, the development of compact, high-power, and spectrally agile THz sources remains a significant challenge, often referred to as the "THz Gap." While solid-state devices face inherent thermal and power density limitations at higher frequencies, vacuum electronic devices (VEDs) have re-emerged as a premier solution. This is due to their exceptional power-handling capabilities, vacuum-based low-loss transport, and high scalability of interaction circuits from millimeter to micron scales [2]. This work presents significant progress in the development of multifunctional THz vacuum electronic sources by leveraging subwavelength periodic microstructures and advanced beam-wave interaction physics.

Central to this research is the utilization of free electrons to excite Cherenkov radiation within customized electromagnetic environments. By employing the principles of momentum engineering, we integrate spoof surface plasmons (SSPs) and sophisticated grating architectures to bridge the momentum mismatch between slow moving electrons and fast electromagnetic waves. This approach allows for the precise alignment of the electron beam's slow-wave space charge line with specific Floquet–Bloch harmonics. Such deterministic control enables the design of devices with unprecedented functional flexibility. We demonstrate tunable far-field directivity, allowing for dynamic beam steering without mechanical movement, and wideband polarization synthesis, which is critical for complex communication and imaging environments. Furthermore, we report the generation of broadband tunable vortex beams carrying defined orbital angular momentum (OAM), offering a new dimension for high-capacity THz multiplexing. A key highlight of this work is the proposal of a novel, all-electric THz frequency comb concept. Unlike traditional combs that rely on complex optical pumping or mode-locked lasers, our design exploits symmetry-broken quasi-bound states in the continuum (quasi-BICs). By strategically introducing structural asymmetries into the periodic micro-resonators, we transform non-radiating dark modes into leaky resonances with extremely high-quality factors. The resulting extreme near-field enhancement facilitates intense electron-wave interaction, producing a stable, comb-like spectrum directly from an electron beam. This mechanism provides a pathway toward high-precision THz metrology and molecular spectroscopy in a compact vacuum-sealed package.

In conclusion, by emphasizing the microscale control of electron-wave interactions through dispersion tailoring and topological physics, this work establishes a new design paradigm for THz VEDs. The integration of momentum engineering and BIC-inspired architectures paves the way for a new generation of multifunctional, compact THz sources. These advancements hold transformative potential for high-resolution radar, cognitive electronic warfare, and advanced spectroscopic sensing, ensuring that vacuum electronics remain at the heart of the THz revolution.

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W6I, Chao-Hai Du, invited oral presentation (IVEW)

High-Order Terahertz Vortex Fields Driven by Free Electron Beam: Phase Modulation in Multi-Helical Structures

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ABSTRACT

Utilizing azimuthally varying slow-wave structures to apply precise spatial phase modulation to electromagnetic waves provides a novel degree of freedom for free-electron vortex radiation. Previous studies have shown that when free electrons pass through a helical superstructure, spatial vortex fields can be effectively excited and manipulated via the Smith-Purcell radiation (SPR) mechanism[1]. By loading a helical superstructure onto a metallic cylindrical shell, the cooperation between an annular electron beam and a multi-helical structure can control the topological charge of the vortex radiation based on its number of grooves and handedness[2]. Furthermore, the Cherenkov wakefield mechanism excited by dielectric-loaded structures has been proven to be an effective approach to enhancing the coherence and frequency selectivity of vortex radiation[3].

This paper presents the latest research progress on the beam-wave interaction between an electron beam and a multi-helical superstructure, with the expectation of reproducing and expanding the generation of vortex radiation fields within a more streamlined architecture by driving multi-filar helices with a circular electron beam. Focusing on the azimuthal phase modulation effect of the multi-helical structure, a dielectric-loaded structure is taken as an example: at the 500 GHz band, when a circular electron beam propagates through a hollow dielectric cylinder (with a wall thickness of 100 μm) loaded with multi-filar metallic helices, the internally excited field is modulated by the helical structure and directly radiates into a free-space vortex field carrying orbital angular momentum.

The angular momentum of this vortex field maps directly to the handedness and the number of strands in the multi-helical structure. Under the condition that the radiation power and operating frequency remain essentially stable, the topological charge of the vortex radiation field can be independently controlled solely by altering the handedness and the number of helices. In this work, both the number of helices and the topological charge are increased to 4, which has been verified by simulations, successfully and stably converting the internally excited fields into a spatially uniform, high-order multi-mode vortex radiation.

To fully reveal the performance and potential of the helical structure, based on the streamlined architecture where a circular electron beam directly drives the metallic helices, this paper also conducts performance comparison and optimization regarding core parameters such as the number of helices, duty cycle, and pitch, further clarifying the modulation characteristics of the multi-helical structure. This work expands the spatial radiation dimension of free-electron-induced terahertz waves, providing a highly promising multi-mode radiation source scheme for future terahertz communications and high-resolution imaging.

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W34T, S. Wang, oral presentation (IVEW)

ADVANCED MODELING OF VACUUM ELECTRON DEVICES*

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ABSTRACT

The computer modelling and optimization now are critical components in the development of vacuum electron devices (VEDs) suitable for accurate prediction of device operation what can accelerate the design of new devices with improved performance. Advanced computer modeling can substantially reduce amount of experimentations and to be at the highest level called "First pass design success" [1], as the ultimate goal of numerical modelling. Through years the joint team from Naval Research Laboratory (NRL) and Leidos (former SAIC) developed variety of codes for modeling and design of VEDs. The codes are based on models that are commonly used to calculate beam particle motion in self-consistently evolving fields. We distinct between "First principles" (PIC) codes and "Parametric/Hybrid beam wave interaction" codes. The recent twin review papers [2-3] contain detailed description of approaches and algorithms implemented in the codes. First principles codes solve for the charged particle dynamics with minimal approximations. Parametric/Hybrid beam wave interaction codes essentially describe the same dynamics but solving a reduced set of equations, which is based on a number of physically proven simplifying approximations. This approach results in computational savings which make design and optimization more efficient. We are going to discuss advantages and limitations of both approaches for modleing of variety of VEDs such as gyrotrons, Helix based TWTs, klystrons, Multiple-Beam Klystrons (MBKs), and Coupled Cavity (CC) and Folded/Serpentine Waveguide (FW) Travelling-wave tube (TWT) Amplifiers. We also will discuss applicability of different NRL codes for optimization including advanced optimization based on adjoint approach what is developed recently.

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W12T, A. Vlasov, oral presentation (IVEW)

RECENT ADVANCES IN THE TESLA-FAMILY OF 2.5D LARGE-SIGNAL ALGORITHMS FOR THEIR APPLICATIONS TO THE MODELING OF KLYSTRONS AND TWTS*

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ABSTRACT

The developed in the US Naval Research Laboratory (NRL) TESLA-family of 2.5D large-signal codes [1-6] is based on a set 4 highly accurate and efficient algorithms. The codes currently are widely used by the Vacuum Electronics (VE) industry and US companies as computational tools capable to model linear-beam amplifiers, including klystrons, MBKs, IOTs, EIKs and TWTs. These codes, being capable to produce the same level accuracy of solutions as the Particle-in-cell (PIC) codes, are far less demanding on computer resources and memory, while allowing fully 2D modelling of the VE amplifiers on a single core of the modern CPUs. To meet the challenges of the fast progressing area of VE amplifiers, we continue to extend and improve all TESLA algorithms to enable modelling of increasingly advanced and complex structures and designs. For example, recent trend in development of TWTs based on increasingly "open" Serpentine Slow-Wave Structures (SWSs) required extension of the code TESLA-FW algorithm to take into account potential effects of inter-gaps "coupling" [7]. Another part of our activity involves extension of the applicability of TESLA algorithms with their applications to high-power microwave (HPM) amplifiers: recent improvements in the klystron code TESLA algorithm enabled accurate modelling of the experimental relativistic klystron [8]. More general algorithm of the code TESLA-ZM [6] enabled geometry-driven large-signal modelling of a wide variety of VE amplifiers, including klystrons and TWTs. Recent extension of this algorithm enabled linear ("zero-drive") stability analysis of the TWTs [9]. Following the previously completed study [10], ongoing development of the code TESLA-ZM algorithm targets modelling of such challenging phenomena as large-signal instabilities, including Drive-Induced Oscillation (DIO) [11]. We will present an overview of these developments and demonstrate results of application of newly improved and extended TESLA algorithms to the modelling of variety of experimental amplifiers.

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W13T, I. Chernyavskiy, oral presentation (IVEW)

QUANTITATIVE ASSESSMENT OF ADDITIVE MANUFACTURING FOR VACUUM ELECTRONICS IN THE Ka BAND FREQUENCY RANGE

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ABSTRACT

Vacuum electronics depends on achieving phase synchronism between streams of electrons and electromagnetic waves, usually confined by a waveguide. Many techniques require subtle metallic structures with complex mechanical connectivity to mediate the phase speed of the electromagnetic signals over a range of frequencies to enable this synchronism. The emergence of additive manufacturing techniques offers significant potential to impact on this requirement, which is increasingly difficult to meet as feature sizes decrease, to address the needs of applications demanding higher frequencies. Challenges remain however for these novel fabrication methods, as the materials used in vacuum electronics need to be non-porous, must be able to withstand extreme temperatures during fabrication and bakeout procedures, so any inclusions and defects can be problematic. Furthermore, as frequencies increase the effective conductivity of the metallic surfaces decreases, and becomes very sensitive to the surface roughness. This leads to increased microwave power loading of the surfaces and losses in the transmitted signals, whilst larger scale imperfections in the profile can lead to loss in the required wave dispersive behaviour. The Universities of Strathclyde, New Mexico and Edinburgh are therefore undertaking quantitative comparative investigation of the performance of components manufactured by additive methods compared to more conventional electrodeposition.

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W38T, C. Whyte, oral presentation (IVEW)

LOW- AND VERY LOW FREQUENCY SHORT-CIRCUIT CURRENT INTERRUPTION IN VACUUM

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ABSTRACT

Vacuum interrupters are a safe and reliable part of electrical power systems. Those devices are designed for a broad operation frequency range from 50/60 Hz [1] in conventional networks down to 16.7/25 Hz in rail electrical power systems [2]. Expanding green energy applications such as wind turbines, pumped storage, DC to AC converters in solar parks and shipboard applications bring new requirements to interrupter systems as they can generate temporary fault conditions with very low frequencies [3]. Depending on phasing, the long arcing times and high transferred charge may occur, making current interruption at the current zero (CZ) difficult [4]. In the present work the interruption performance limit to frequencies between 0.5 – 2 Hz based on the test performed at 16.7 and 50 Hz was calculated [5]. The contact erosion rates were also grouped into three different clusters as a function of the current, and the erosion during multiple short-circuit operations from 10-40 kA rms at 50 Hz and at several hundred of amperes at 0.5 – 5 Hz. Test sequences from the generator circuit breaker standard are also examined, such as delayed CZ and very high direct current (DC) offset tests. These tests are effectively equivalent to lower frequency tests. In addition, low frequency tests at 2.4 Hz and 1250 A have been performed to observe the impact of multiple switching operations on the contacts, metal vapor deposit on the ceramics, and heat build-up. The vacuum interrupters equipped with three different contact systems and sizes were used.
Finally, in order to study the properties of arc at low frequencies more in detail, experiments in a model vacuum chamber at 2.4 and 3.5 Hz and rms current in the range 1000 – 1750 A have been performed. Arc dynamics have been analysed by means of high-speed camera technique.

Preferred format of presentation: O: Oral

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W24T, D. Gentsch, oral presentation (IVEW)

High-Current Vacuum Arcs at Large Gaps: Influence of Electrode Movement

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ABSTRACT

Vacuum interrupters (VIs) have been established as the standard technology in the medium voltage range, e.g,, in distribution networks. For the last decade, the development towards higher voltage levels has been opening a growing number of applications in the HV range like in transmission lines, also forced by demands for reliable SF6-free solutions. Typical designs are based on larger contact gaps and the serial connection of multiple VIs. Larger gaps can lead to a specific behaviour of the arc and the attachment modes at the electrodes which depend in addition on the polarity of the moving contact [1].
We report on analysis of arc modes for larger gaps through a combination of electrical and optical data. Experiments were conducted using CuCr25 butt contacts at peak currents of up to 15 kA and a frequency of 35 Hz, with a contact gap of 30 mm at current zero, and with operating the moving contact either as the anode or as the cathode. The arc behaviour was observed using a high-speed camera (HSC) and optical emission spectroscopy (OES) [2]. The HSC captures the arc dynamics, while a computer-aided evaluation facilitates the analysis of different arc modes. The OES results allow for an estimation of the spatial distribution of copper and chromium atoms and ions in particular in the region of the anode spots. Different arc behaviour and anode attachment modes were observed, particularly influenced by the polarity of the movable contact. The time after contact separation at which the arc changes into a jet mode is longer in case of the moved cathode in comparison with the moved anode.

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W14T, R. Methling, oral presentation (IVEW)

Comparison of different contact geometries for current interruption in vacuum using long gaps up to 45 mm

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ABSTRACT

The evolving expansion of decentralised renewable energy generation facilities requires an efficient and reliable electric transmission grid. A key component is the circuit breaker, which must operate with low losses in closed position and also be capable of interrupting a fault current across a wide range of switching conditions. The climate-friendly and low-maintenance vacuum circuit breaker has been established in the medium-voltage sector for several years and are the dominating technology in this voltage levels [1]. When the contacts get opened under load, a vacuum arc is formed, which can be observed and analysed. To meet the requirements of higher voltage levels, studies at higher contact gaps are necessary. For high-voltage applications, many studies involving axial magnetic field (AMF) contacts, which promise a high switching capability at long gaps [2]. The alternative contact geometry of the transversal magnetic field (TMF) contacts offers the advantages of lower losses when closed with a lower manufacturing cost [3]. Both contact geometries use the formation of magnetic field, to distribute the vacuum arc over the whole surface. However, the application of the TMF contacts at higher voltage levels remains underexplored.

This study presents the results of current interruptions in a vacuum environment at large contact gaps up to 45 mm for various opening trajectories. Both TMF and AMF contacts were used for current interruptions up to 31.5 kA for frequencies of 50 Hz and 35 Hz. The lower frequency enables the larger contact gap of 45 mm at current zero. The different opening trajectories are implemented with a programmable servo drive

For each measurement, electrical data (current, voltage and gap) and optical data were captured and used for the evaluation. The vacuum interrupter is fitted with two angle arms and mirrors, enabling a high-speed camera to capture images with 30.000 fps from two angles. A python program allows a three-dimensional analysis of the vacuum arc between the contacts. Particular emphasis is placed on the analysis of different arc modes (diffused and constricted arcs), as well as an assessment of local contact erosion caused by the charge distribution on the contact surfaces.

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W8T, M. Hinz, oral presentation (IVEW)

Observation of partial internal flashovers on vacuum interrupter test specimen without metal vapor shield

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ABSTRACT

In medium voltage, the vacuum interrupter (VI) has emerged as the predominant switching technology [1]. As SF_6 is subsequently banned in Europe for higher voltages, the emerging gap in technology can be filled by vacuum technology [2]. To efficiently enhance its electric strength and enable an application at higher voltages, among other things a more profound comprehension of the VI as an insulation system is imperative.

The present contribution is an examination of a modified VI devoid of a metal vapor shield with the objective of observing the influence of the shielding on the breakdown process under lightning impulse stress. The results of the performed measurements are documented in the form of voltage data and recordings with a high-speed camera.

A reference measurement of a VI with metal vapor shields reveals the presence of an external flashover path on both halves of the split ceramic insulation structure. In certain experiments involving the modified VI, an external flashover is observable on only one half of the ceramic structure. In addition to the camera footage, it is observed that these breakdowns exhibit a voltage curve that is significantly different from the typical flashovers, where the entire path is externally visible. Therefore, it is hypothesized that the other part of the breakdown propagates inside the VI in vacuum.

While the occurrence of partial internal breakdown is discernible in positive polarity as well as in negative polarity with an inverted VI, the non-observable part is invariably located on the anode side of the VI. Furthermore, it has been observed that subsequent to multiple instances of breakdown, a slight deconditioning effect may be discerned in the series of measurements where partial internal breakdowns are assumed to occur.

The observation of the transition from external to internal breakdown or vice versa leads to the conclusion that it is necessary to observe breakdowns in VIs more closely especially when raising the external flashover voltage to a point where internal breakdowns may occur even on non-modified VIs. The results indicate that a combination of breakdown processes occurs concurrently and is not always limited to the external insulation. A more thorough examination of the mechanisms behind the observed phenomena is necessary to provide a precise description of the breakdown process of VI as an insulation system.

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W9T, K. Schulze, oral presentation (IVEW)

INFLUENCE OF MOVING AND FIXED CATHODES ON THE VACUUM ARC

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ABSTRACT

In Vacuum Interrupters (VIs) there are typically a moving and a fixed contact which are separated during the switching process. While switching AC-currents the polarity of the contacts can be different from one to the other operation. Although the VIs are successfully operating in both polarities, recently there have been some differences noted in the behaviour of the vacuum arc depending on whether the cathode was the moving or the fixed contact. In this publication we try to get some insight on the underlying processes which lead to this polarity dependant behaviour. For this we observed the behaviour of the vacuum arc in a vacuum chamber by a high-speed camera. Additionally, the burn-off rate of the electrodes in different setups have been measured. The results give some insight into the effect of the polarity during the switching operation in a vacuum interrupter.

W11T, A. Lawall, oral presentation (IVEW)

IMPACT OF HUMIDITY ON THE EXTERNAL DIELECTRIC STRENGTH OF VACUUM INTERRUPTERS IN SYNTHETIC AIR INSULATION SYSTEMS

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ABSTRACT

Due to the high global warming potential (GWP) of sulfur hexafluoride (SF_6), its application in electrical equipment is increasingly restricted by international legislation, such as the current EU's Regulation on fluorinated greenhouse gases. Consequently, natural origin gases (NOGs) are gaining significant importance as climate-friendly alternatives for gas-insulated systems (GIS) as they offer a very low GWP and ease of handling.

In modern medium-voltage (MV) applications, these gases (and synthetic air in particular) are typically utilized in combination with vacuum interrupters. While SF_6 has been researched for decades, there is limited knowledge regarding the dielectric properties of NOGs under pressurized conditions, particularly concerning the external dielectric strength of vacuum switches. A critical challenge is the influence of humidity, which can enter the system via surface adsorption during assembly or post-assembly through leakages driven by partial pressure gradients [1].

In contrast to SF_6 insulation, where humidity is primarily a concern if condensation occurs on surfaces, oxygen-containing NOGs exhibit a higher sensitivity to moisture within the gas phase. Humidity leads to the formation of $O_2(H_2O)_n^-$ clusters [2], which increase negative ion density and have been shown to influence the partial discharge inception voltage (PDIV) [3].

This work investigates the dielectric behavior of synthetic air using a strongly inhomogeneous electrode configuration (needle-plane arrangement) within a pressure range of 0.15 to 0.5 MPa, and a systematic variation of humidity content from 5 to 5300 ppmv. To characterize the PD inception behavior and determine the breakdown voltage (BDV), various diagnostic methods are utilized, including IEC 60270, UHF, and HFCT sensors. The results provide vital insights for the insulation design of vacuum-based switching equipment and evaluate the reliability of existing PD diagnostic systems under varying environmental conditions.

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W47T, N. Dölzer, oral presentation (IVEW)

Session 2.3 Tube History, Vacuum Gauges and Plasma

On the History of Vacuum Electronics: The Tube Museum of RWTH Aachen University

G. Gaertner, Aachen (oral C10T for IVESC 2026)

The "Museum of Tubes and Communication Techniques" of the Institutes of High Frequency Technology (IHF) and of Communications Engineering (IENT) of RWTH Aachen University in Melatener Str. 23+25 was founded by Professor Aschoff (communication) [1] and Professor Döring (tubes) in 1952. Prof. Döring is well known to some of the audience from the ITG/NTG Fachtagungen in Garmisch-Partenkirchen and his presentations on Gyrotrons and other tubes [2]. With over 1000 exposition items the museum reflects the dramatic development of these technologies from their historical beginning to their modern status [3,4]. Early communication in the 18th century was essentially based on optical techniques, which were followed by various developments of wired telegraphy systems [1,3]. Vacuum tube technology then offered a „new" solution, starting 1904 with the diode rectifier by John A. Fleming (UK) and Arthur Wehnelt (Germany) and continuing in 1906 with the triode by Lee de Forest (USA) and von Lieben (Austria). In 1916 followed the tetrode by Walter Schottky and in 1926 the pentode by Bernard Tellegen (Philips, NL). Numerous radio tube types are shown in the exhibition. Also low power reflex klystrons, a Philips 600 kW multicavity klystron of 500 Mhz and about 3 m length, other microwave tubes and X-ray tubes are shown, and last but not least several types of CRT tubes. The rise and fall of radio tubes and cathode ray tubes and the historical trends and technological waves in vacuum electronics and neighboring fields will also be discussed [5]. In contrast to the generic technology cycles of radio-receiving tubes and cathode-ray display tubes, microwave tubes did experience only a partial replacement by solid-state devices and defend the high-power, high-frequency domain.

Unfortunately the exhibition is currently disassembled due to renovation of the building. We all hope, that the exhibitions will be set up again after renovation, because this tube museum is a unique collection and witness of the historical development of vacuum electronics. After Prof. Döring the tube collection of the IHF was continued by Prof. H. J. Schmitt and later by Prof. B. Rembold. Currently the director of the IHF is Prof. D. Heberling, whereas Dipl. Ing. J. Pamp is in charge of the tube collections [6]. The director of the IENT is Prof. A. Raake and responsible for the part of communication techniques is Dr.-Ing. C. Rohlfing [6]. We should thank them for maintaining this unique museum in Aachen.

The tube museum should not experience the detrimental fate of the Computer Museum of RWTH Aachen, which was closed and abandoned in 2009, with some acquisitions by other museums. The city of Aachen certainly honors the heritage of Charles the Great, but it seems it does not really honour its technical history with the same intensity.

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HIGH VACUUM MEMS DEVICES – MINIATURIZED ANALYTICAL INSTRUMENTS

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ABSTRACT

Modern scientific tools such as electron microscopes, X-ray machines, and mass spectrometers all rely on very strong vacuum conditions to work properly. Traditionally, creating such a vacuum requires large equipment and complex pumping systems. These setups are expensive, bulky, and difficult to miniaturize, which limits their use outside specialized laboratories.

Recent progress in microtechnology offers a completely new approach. Instead of using large external systems, scientists can now create and maintain a vacuum inside tiny devices, similar in size to a few millimetres. At Wroclaw University of Science and Technology, researchers have developed a miniature vacuum pump that can be integrated directly into microdevices [1]. This tiny pump can generate extremely low pressure without the need for external equipment.

Thanks to this breakthrough, it is now possible to build very small and fully integrated vacuum-based devices. Examples include miniature X-ray sources [2], compact gas analysers [3], and small mass spectrometers [4] and miniaturized scanning electron microscopes [5]. These devices combine vacuum technology, electronics, and advanced materials into a single sealed structure, making them more robust, portable, and energy-efficient than traditional systems.

This new approach represents a major shift in how vacuum technology can be used. Instead of large, stationary installations, we can now design small, independent devices tailored to specific applications. Such systems could find use in space missions, environmental monitoring, medical diagnostics, and many other fields where size, mobility, and efficiency are important.

Overall, these developments open the door to a new generation of compact scientific instruments that can operate outside traditional laboratory environments, bringing advanced measurement capabilities closer to real-world applications.

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W39T, M. Krysztof, oral presentation (IVEW)

PIRANI VACUUM GAUGES WITH ACTIVE HEAT-LOSS COMPENSATION

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ABSTRACT

Pirani sensors measure the thermal conductivity of a residual gas in a vacuum in order to determine the pressure by generating a temperature gradient between the sensing element and a heatsink. Usually, the measuring range of Pirani sensors is limited from approx. 10^{-4} mbar up to several hundred Millibars or even atmospheric pressure. Therefore, Pirani sensors are often combined with other technologies like ionization vacuum gauges to cover lower pressures [1]. Thus, there is an interest in extending the measuring range of Pirani sensors to avoid additional technologies and to cover the high vacuum regime down to 10^{-6} mbar.

Langer has derived in [2] a theoretical model that states increasing the ratio between the active area of the sensing element and its parasitic losses also increases the sensitivity in high vacuum and extends the measuring range at the same time towards lower pressures. Since there are limits in increasing the active area of a sensing element, investigations have been made to minimize the parasitic losses through active counter heating [3].

This effect has already been confirmed using a MEMS chip. The chip consists of an under-etched sensing element with the shape of a miniaturised hotplate. Additional heating elements are placed on the suspensions to limit their parasitic heat loss [4]. Since MEMS technology only pays off in high quantities, additionally a conventional micro-wire Pirani with standard Pt100 elements was built. The sensing element of the sensor is a helix-shaped micro wire, which is suspended between two pins. On these pins, the Pt100 elements are attached with a conductive epoxy glue and act as additional heating elements (Fig. 1). During operation, they are used to generate heat on the pins to limit the parasitic heat flow over them. It can be shown that active counter-heating using additional heating elements on the suspensions of the sensing element increases the sensitivity in low pressure regimes. Furthermore, this extends the measuring range by up to one order of magnitude.

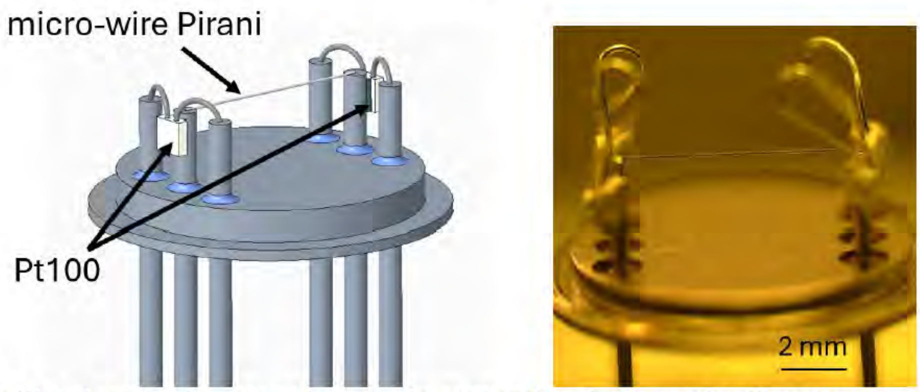

Fig. 1: Sketch and microscope image of a conventional micro-wire Pirani sensor with additional Pt100 heating elements to limit the parasitic heat losses over the pins.

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W37T, J. Eiler, oral presentation (IVEW)

Qualification of HEMPT Hollow Cathode Neutralizer with integrated getter

Heiko Stalzer[1], Alexey Lazurenko[1], Ralf Heidemann[1], Gabriela Kučerová[1], Gabriel Suske[1], Joachim Daeubler[1], Peter Holtmann[1]
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ABSTRACT

Thales Microwave Imaging and Subsystems (MIS) at Ulm site in Germany qualified a thermionic gas discharge dispenser hollow cathode neutralizer [1] HCN6500, impregnated with Ba/Ca-Aluminate. This neutralizer is operated with an internal hot getter to dispense with an external purifier of the flow control unit (FCU), which removes cathode poisoning contaminants as oxygen and water from the propellant. The HCN6500 is derived from the fully space qualified HCN5000, which is currently demonstrating in-orbit operation with the HEMPT-3050 (High Efficiency Multistage Plasma Thruster) Electric Propulsion (EP) System on the Heinrich Hertz Satellite supported by the DLR (Deutsches Zentrum für Luft und Raumfahrt) and is integrated into the new HEMPT-EV0 EP technology which is expected to finish its lifetime test in Q1/2027 [2]. The HCN6500 is based on the HCN5000 cathode technology. As the EV0 [3] it was redesigned in terms of production costs and industrialisation to account for the needs of the growing space satellite constellation market with numbers of up to thousands of satellites per constellation [4,5]. The use of an internal hot getter instead of an external purifier is beneficial in handling during performance testing and satellite integration and in terms of costs for the thruster system. High getter capacity allows the choice of rather low propellant grades to save costs and to maintain the flexibility for the loading process from the source to the spacecraft. Thales MIS presents results of the HCN6500 qualification in the context of getter operation. Two qualification vehicles have been vacuum tested at the Thales MIS test facility in Ulm. To accelerate the test campaign, the neutralizers have been fed with a specifically contaminated Krypton gas to demonstrate the getter capacity. One device under testing was operated continuously in Keeper or plasma mode while the second was submitted to 10600 complete on/off cycles consisting of a heating and a subsequent Keeper phase. The hollow cathode performance was monitored by continuous data acquisition, notably Keeper voltage, heater resistance as indicator for the cathode temperature and inlet pressure. The operating point was chosen to comply with the specification of the HEMPT-EV0 lifetime test.

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C11T, H. Stalzer, oral presentation (IVESC)

3D CFD SIMULATION OF VACUUM ARCS IN A TEST TUBE

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ABSTRACT

The contribution deals with the simulation of vacuum arcs in a test tube [1] using a three-dimensional (3D) Magneto Hydrodynamic Model (MHD) at two temperatures (electronic and ionic) based on Ansys Fluent. The model describes a subsonic arc in vacuum between the electrodes of the test tube, submitted to an Axial Magnetic Field (AMF) [2]. Figure 1 shows the 3D solution domain used in this study.

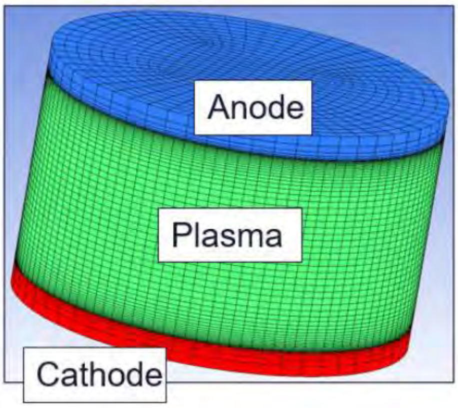

Figure 1: Geometry studied

The contribution presents results from a parametric study on arc characteristics including varying AMF strength, ablation rate and current intensity. The simulation model is validated by the comparison of measured and simulated arc voltages.

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C1T, F. Reichert, oral presentation (IVESC)

Visualizing and quantifying ionic wind speeds in ring-type plasma actuators using Schlieren Image Velocimetry

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ABSTRACT

Plasma actuators are active flow control devices that operate by ionizing air to generate a body force that results in an induced airflow known as ionic wind [1]. Accurately measuring this ionic wind is critical for evaluating actuator performance. Traditional visualization and quantification methods such as hot-wire anemometry, Pitot tubes, and standard Particle Image Velocimetry (PIV), are often intrusive, require physical probes or flow-seeding particles, and such as in the case of PIV, are often expensive. The Schlieren imaging technique offers a non-intrusive alternative that visualizes fluid density gradients [2]. This work presents a methodology to extract velocity information from these visualizations using Schlieren Image Velocimetry (SIV). Instead of tracking seeded particles as one does with PIV, we track the naturally occurring density fluctuations within the wind flow patterns across the Schlieren frames. By applying the cross-correlation algorithms inherent in standard PIV software to these images, we compute spatially resolved ionic wind velocity vectors [3]. This diagnostic approach is implemented on ring-type plasma actuators, which, due to their radial symmetry, result in a body force that is directed perpendicular to the surface (Figure 1). Analysis reveals wind velocities exceeding 4 m/s for an actuator with diameter 32 mm, 150 µm thick dielectric, and operated at 1 kHz with 10.4 kV peak-to-peak applied voltage. Our work demonstrates that quantitative flow maps of the induced wall jets can be acquired, and that SIV is an effective and inexpensive alternative for both visualizing and quantifying the ionic wind generated in plasma actuators.

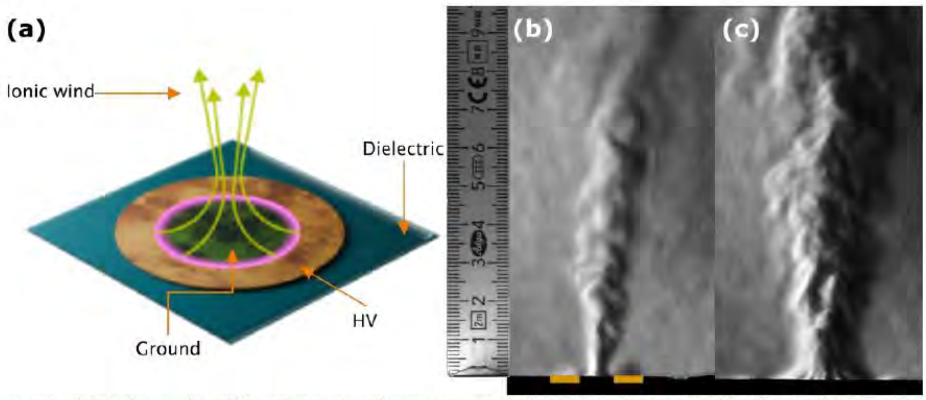

Figure 1: (a) Schematic of the ring-type plasma actuator depicting the vertically directed ionic wind. Schlieren visualization of the ionic wind generated in ring-type plasma actuators of (b) 8 mm, and (c) 32 mm inner diameter. The placement of the electrodes in this side-view is superimposed in orange.

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W2T, A. Musazay, oral presentation (IVEW)

Cold Cathode Based Electron Beam(C-beam) for Extreme Ultraviolet and x-ray source applications

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ABSTRACT

Here we present cold cathodes-based electron sources for the EUV (extreme ultraviolet) and x-ray sources. We developed cold cathode electron beam(C-beam) with carbon nanotubes (CNTs) electron emitters and applied as electron sources for semiconductor and display inspection and metrologies application. We developed the EUV light sources with C-beam irradiation techniques and applied for EUV mask pellicle inspection [1]. The EUV light sources shows very stable operation, short-term stability less than 1% and reliable long-time operation. The quality of EUV light sources collimated with MLMs(multi-layer-mirror) and apertures. Also, high performance x-ray sources with C-beam observed and confirm resolution less than 30 μm and possible low voltage and lower dose inspection of secondary ion batteries and microscopy [2]. The resolution and anode current would be controlled by C-beam size and CNT emitters density distribution. Detail of C-beam fabrications, performances of the beam and design of the beam would be presented, The EUV light sources and x-ray sources fabrication and performaces would be presented.

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C11I, K.C. Park, invited oral presentation (IVESC)

W5T: XRF CHARACTERIZATION USING TRIPLE-CRYSTAL PYROELECTRIC X-RAY SOURCE

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ELECTROSTATIC DEFLECTION SYSTEM FOR FOCUSING MULTI-BEAM ELECTRON SOURCES

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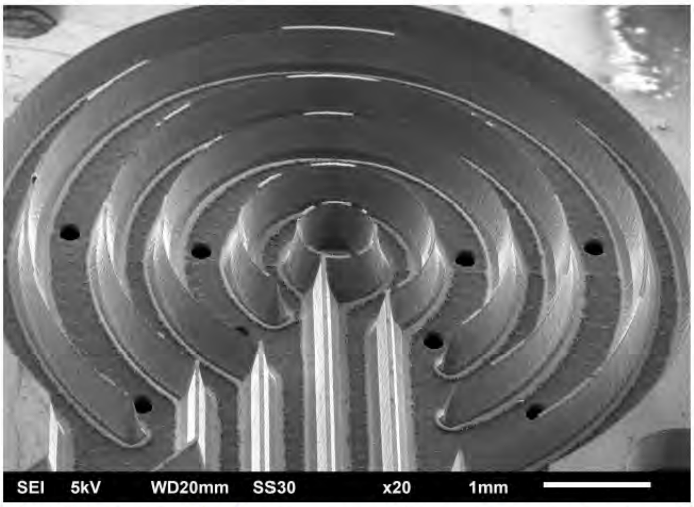
ABSTRACT

This work demonstrates the focusing capabilities of electrostatic optics designed for focusing of multiple electron beams originating from different emission sites. Focusing is achieved using a two-stage system. First, the various electron beams are deflected so that they meet at a central point. Since the emission tips were placed on concentric circles, all electron beams belonging to a circle can be deflected using common structures. The usage of a SOI wafer allows the integration of these so-called deflectors directly on the extraction grid. The SEM image in Figure 1a shows the resulting radially symmetrical structure of the deflectors. A macroscopic einzel lens is used to produce a miniaturized image of this superimposed electron beam, resulting in a focusing effect. The feasibility of this two-stage approach is demonstrated by a FEM-simulation (Figure 1b). The electrostatic optics were characterized both individually and in combination with each other using a highly defined electron beam from an SEM (Jeol JSM-6400F) and with self-fabricated emitters (e.g. [1]). Using the electron beam of a SEM allows the properties of the electrostatic optics to be pre-examined without being influenced by non-ideal effects caused by real emitters. A CMOS image sensor was used for the visualization of the general emission pattern of the multi beam electron source and the changes of the pattern caused by the electrostatic optics [2].

a)



b)

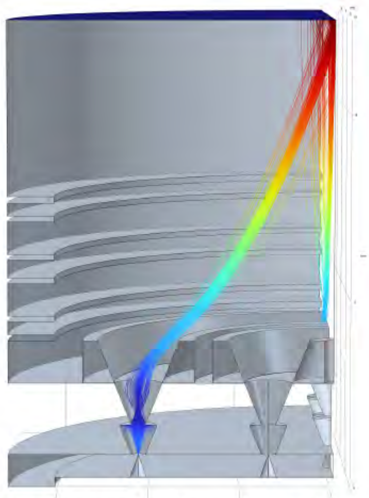


Fig. 1. a) SEM image of deflector structures integrated on an extraction grid used for deflecting multiple electron beams on a central point. The extraction holes of the grids are placed on concentric circles. Each circle is surrounded by an inner and outer deflector. b) Simulated electron trajectories for a combination of deflectors and single lens optics.

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W30T, M. Bartl, oral presentation (IVEW)

Vector Based Magnetic Axis Determination of Solenoids for Gyro-Devices

B. Baumann[1], M. Vöhringer[1,2], S. Illy[1], T. Kobarg[1], A. Papenfuß[1], T. Rzesnicki[1], J. Jelonnek[1,2], M. Thumm[1,2]

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ABSTRACT

High-power vacuum electronic devices (VEDs), especially gyro-devices, rely on precise alignment with the magnetic field of the superconducting solenoids in which they operate. Accurate knowledge of the magnetic axis relative to the device axis is therefore essential, with required tolerances on the order of a few tens of micrometers.

This presentation introduces a novel vector-based method for determining the magnetic axis of superconducting solenoids with fields up to 11 T. The approach uses measurements from a 3D Hall probe and reconstructs the magnetic axis by evaluating the intersections of projected magnetic field vectors. In contrast to conventional methods, the proposed algorithm enables simultaneous determination of axis tilt and lateral shift from a single circular measurement layer, reducing measurement effort while maintaining high precision.

The method was developed and validated through detailed simulations incorporating realistic measurement noise and positioning uncertainties. The results demonstrate that the algorithm can reconstruct axis tilt with an accuracy better than 0.01 deg. and lateral displacement within 60 µm. Based on these investigations, quantitative requirements for the measurement and positioning accuracy were derived, providing practical guidelines for implementation in high-field measurement environments.

The presented work establishes an efficient and precise approach for magnetic axis characterization of superconducting solenoids used in gyro-device applications and provides the basis for improved alignment procedures in high-power RF systems.

W22T, B. Baumann, oral presentation (IVEW)

DEVELOPMENT OF A CYLINDRICAL EB SOURCE WITH RADIALLY OUTWARDS DIRECTED ELECTRON FLOW FOR COST-EFFICIENT PHYTOSANITARY TREATMENT OF SEEDS

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ABSTRACT

The phytosanitary treatment of seeds before planting with accelerated electrons offers a purely physical, environmentally friendly alternative to chemical dressing. While pathogens on and within the seed coat are reliably inactivated by this method, the embryo remains unaffected. This is possible because the penetration range of the electrons can be precisely tuned by the acceleration voltage of the beam generator. Depending on the seed variety, tailored recipes make sure that the recommended amount of energy is applied with appropriate surface uniformity and depth distribution. To integrate the electron treatment into seed production workflows, several container-integrated units (comprising the electron sources, power supplies, control system, supply and media distribution) were transferred into production over the past years. These units are highly productive and can treat (depending on the crop type) up to 25 tons / hour but they also require significant investment and, hence, large annual product throughput for amortization. Therefore, the main objective of the presented source development was to make the electron treatment economically appealing even for customers with smaller annual volumes (below 5,000 tons). In close collaboration with RAUSSENDORF GmbH, a mobile, modular and small container system was designed, which, following electron treatment, also allows for the application of biological plant strengtheners – organic fertilizers or symbiotic bacteria and fungi that promote plant growth, enhance nutrient uptake or protect against soil-borne pests and diseases.

As a key component for this machine concept, Fraunhofer FEP has developed a novel cylindrical electron source which emits electrons into atmosphere radially outwards to treat the surrounding curtain of falling seed, facilitating a throughput of about 10 tons / hour, which fits the typical productivity of upstream and downstream processes in commercial seed processing plants well. Like the linear sources previously available, this source is designed for acceleration voltages up to 150 kV and a rated power of 30 kW. However, by housing all the components for electron emission and acceleration inside the cylinder, significant savings are achieved in terms of space requirements and manufacturing costs.

Primary topic:	*Laser-, Electron-Beam-, Ion-Beam- and Plasma Processing Systems*
Secondary topic:	*Grid Controlled Tubes*
Presentation format:	*Oral*

W49T, G. Mattausch, oral presentation (IVEW)

Session 3.2: IOTs and TWTs

DESIGN AND SIMULATION OF A 434 MHz INDUCTIVE OUTPUT TUBES

Dingyu Gu[1,2], Jiaqiu Tian[1,2], Hirwa Sakindi Alain [1,2], Shaomeng Wang[1,2], Zhanliang Wang[1,2], Qingying Yi[1,2], Yubin Gong[1,2]
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Presentation: Poster
Primary Topic: Vacuum Electronic and Discharge Devices and their Applications
Secondary Topic: Grid Controlled Tubes

ABSTRACT

The inductive output tube (IOT) is a linear-beam amplifier in which an RF grid-controlled electron gun directly bunches the beam, thereby enabling high-efficiency and high-linearity amplification [1]. This paper presents the design and simulation of the input cavity, electron gun, and output cavity of a 434 MHz IOT.

In this tube, electrons are emitted from a spherical cathode heated by an internal heater. A spoke-grid structure is employed, and the grid is placed in close proximity to the cathode, with a cathode–grid spacing of 0.7 mm. The RF signal is applied directly between the cathode and the grid, so that beam density modulation is established in the electron-gun region [2]. The grid is connected to the grounded cavity housing, and insulating ceramic spacers electrically isolate the housing from both the cathode and the grid.

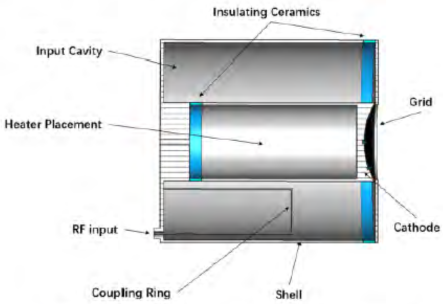

Fig. 1 Cross-section of the input cavity

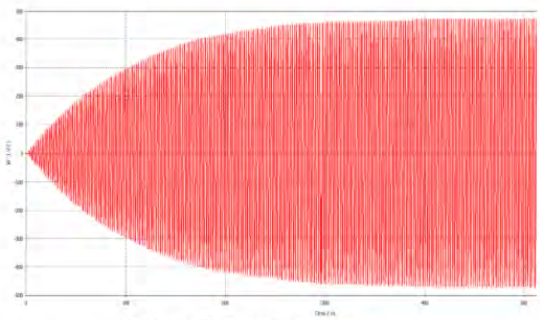

Fig. 2 RF output power

The device is simulated in CST Studio Suite 2024. Under operating conditions, with an input RF power of 1500 W, the peak cathode-to-grid RF voltage reaches 770 V, and the maximum beam current is 16 A. The cathode is biased at −60 kV, while the grid bias relative to the cathode is −300 V. In the absence of RF drive, the dc beam current is approximately 0.23 A. The density-modulated electron beam then passes through the grounded anode aperture and enters the output section. The output cavity adopts a re-entrant resonant-cavity structure, and the overall efficiency reaches 47%, with a peak output power of up to 227 kW.

This work is supported by National natural science foundation of china (Grant No.62527804).

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W15I, Y. Gong, invited oral presentation (IVEW)

A STATIC MAGNETIC FIELD FOCUSING ELECTRON GUN FOR 915 MHZ INDUCTIVE OUTPUT TUBES

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ABSTRACT

Inductive output tubes (IOTs) combine the characteristics of the Klystron and the Tetrode, resulting in excellent linearity and high efficiency [1]. Compared with other high-gain devices in the P-band, such as the Klystron, the IOTs in the P-band can achieve miniaturization of size while maintaining good gain [2,3]. In order to apply IOTs to biological imaging, it is critical to increase the maximum power of IOTs to 500 kW at the imaging frequency. In the attempt to increase the emission power by designing IOTs electron guns, it was hoped to achieve this by enhancing the emission current. The promotion of the emission current needs to suppress the divergence of the electron beam. Without adding additional focusing electrodes, it is feasible to achieve full focusing of the electron beam using a constant magnetic field throughout the process.

The static magnetic field focusing electron gun proposed in this paper can emit a maximum current of 28 A under the working conditions of 50 kV anode voltage, 200 V grid DC bias voltage and 2.5 kW input power, as shown in Fig.1. The interception of the grid in the simulation is 30%. The simulation of the beam-wave interaction was carried out using the electron beam emitted from the static focusing electron cavity, and the efficiency of the interaction was 40%. The anode current contains the DC component, the fundamental frequency component, and the high-order harmonic components. In general, the fundamental frequency component in the anode current is responsible for more than half, as shown in Fig.2.

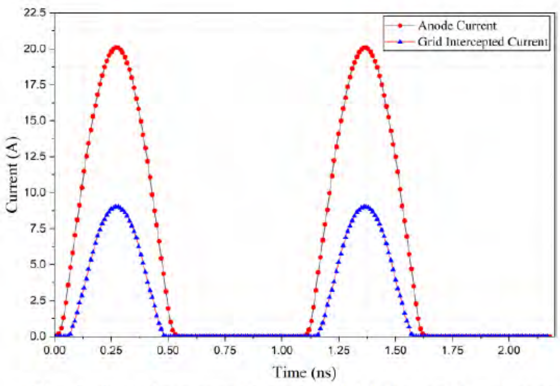

Fig.1 Anode current and grid intercept current

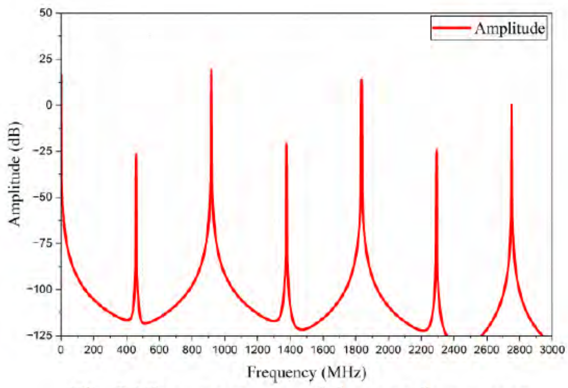

Fig.2 The spectrum of the anode current

Primary topic: Vacuum Electronic and Discharge Devices and their Applications
Secondary topic: Grid Controlled Tubes   Presentation: O : Oral

References

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C5T, Y. Gong, oral presentation (IVESC)

Delay Line Structures for High-Power and High-Frequency TWTs

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Abstract

Traveling-Wave Tubes (TWTs) continue to a be competitive source of RF power, from satellite navigation in L-Band [1] to satellite-borne Radar in X-Band, to satellite communications in Ku-, Ka- and V-Band [2], [3]. TWTs provide high output power, high efficiency, resilience to environmental changes, and good bandwidth and linearity.
TWTs operate by transferring the kinetic energy of an electron beam to an RF wave, thus creating RF amplification. Unlike many other vacuum-electron devices, the exchange of energy takes place continuously while beam and RF wave travel together along a delay line. The delay line reduces the phase velocity of the RF wave to that of the electrons, typically 0.1c to 0.3c. This way, synchronism is kept between the bunches in the electron beam and the decelerating phase of the RF, which is a requirement for any continuous beam-wave interaction.
The key performance parameters for delay lines are the level of dispersion (determining the bandwidth of the TWT), the strength of the electric field in the beam tunnel ("coupling impedance", related to the beam tunnel diameter), power handling capabilities, size, and manufacturing effort. Each delay line type also has different oscillation modes, requiring careful analysis to avoid stability problems.
Historically, there have been a large number of delay line topologies. From the 1990s, the large majority of TWTs were designed and manufactured with helical delay lines, which combine very good bandwidth with high interaction impedance and acceptable manufacturing from L-Band (1 GHz) to the lower Ka-Band (20 GHz). However, it is difficult to scale this type of delay line beyond Q-Band (40 GHz). TWT designs addressing higher frequencies, or trying to increase the output power, typically feature "Folded-Waveguide" (FWG) delay lines, which combine higher power-handling capabilities with easier manufacturing, but are generally more narrow-band and less efficient.
This contribution will compare these to types of delay lines, focusing on use-cases at Thales, particularly for high-power and/or high-frequency TWTs, and highlighting current developments and trends, such as alternative manufacturing methods.

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W21T, P. Birtel, oral presentation (IVEW)

Ka-Band Upgrade of TIRA: The Future of Radar Space Observation in Europe

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ABSTRACT

The Tracking and Imaging Radar (TIRA) of Fraunhofer FHR is one of the most capable ground-based sensors for space domain awareness in Europe. To meet the challenges posed by the trend toward ever-smaller satellites, by dense mega-constellations and increasing space debris, TIRA is undergoing major upgrades. One of it is a new Ka band imaging radar with integrated tracking capabilities [1]. Moving from the current Ku band imaging radar to the new system operating at Ka band, enables a substantially larger resolution in the range and cross-range direction by increasing the bandwidth and center frequency, respectively.

The new Ka-band system will be powered by two coupled-cavity TWTs from Microwave Power Products (MPP) integrated in a quasi-optical power-combining front end. The front end uses free-space Gaussian beam propagation, polarization-selective wire-grids, and Faraday-rotator-based duplexers to provide low-loss transmission, high isolation between transmit and receive paths, and full polarization ability.

Given the critical role of the Ka-band TWTs and the RF front end in overall system performance, FHR is building a dedicated Ka-band test stand. This facility allows safe and flexible experimentation with the RF, high-voltage, cooling, control, and protection system of the future TIRA installation in a laboratory setting. It will support detailed characterization of single TWTs and the combined chain in terms of output power, efficiency, gain and phase flatness over bandwidth, pulse shape, stability, and long-term drift. The test stand will also be used to validate the quasi-optical components under high-power operation, verify polarization switching and modulation schemes, and qualify interlock and monitoring concepts for reliable unattended operation.

The presentation will describe the Ka-band transmitter architecture, the quasi-optical power-combining and duplexing concept, and the design and role of the new test stand, highlighting how advanced vacuum-tube technology underpins the next generation of radar space observation in Europe.

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W23T, A. Marek, oral presentation (IVEW)

CMOS-Sensor Calibration for the Measurement of Field Emission Electron Currents

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ABSTRACT

The use of field emission electron sources (FES) in X-ray sources or ionization vacuum gauges is still uncommon due to the restricted lifetime of field emission arrays (FEAs), often caused by high current loads. In [1], we showed that the lifetime-limiting effects (degradation) can be significantly reduced by distributing a total emission current across multiple FES-Chips. Similarly, the lifetime of a single FEA-chip depends on the emission distribution across its individual emitters.
However, it was found that the emission current of a FEA is usually distributed very inhomogeneously [2]. To investigate current distribution and its temporal behavior, we developed a CMOS-based imaging method capable of resolving current distributions on FEAs quantitatively over several orders of magnitude by mapping shares of spot signal intensities onto the measured integral current [3].
The mathematical description of the image sensor signal presented in [3], derived from a modified version of Kramers' law [4], has now been extended by a calibration constant C_C, enabling the determination of individual field emitter currents from the raw optical spot signal S_{Raw0}:

$$S_{Raw0} = C_C \cdot t_E \cdot I \cdot U^b \quad \rightarrow \quad I = \frac{S_{Raw0}}{C_C \cdot t_E \cdot U^b}$$

Here, t_E denotes the exposure time of the image sensor, I the cathode current, and U the cathode's extraction voltage or the electron's acceleration voltage respectively. The voltage exponent b is a simplified linear approximation, describing the electron-photon conversion of bremsstrahlung [4], as well as additional absorptive effects [3]. If C_C is known, an emission current I_S can be calculated from S_{Raw0} and compared with the electric emission current I_e. For a n-doped FEA-chip (5-10 Ωcm, Fig. 1a) this comparison is presented in Fig. 1b. The results show that the image-signal-derived current I_S matches the actual emission current I_e with an average accuracy of approximately 2 % over 5 min and a standard deviation of 3 %

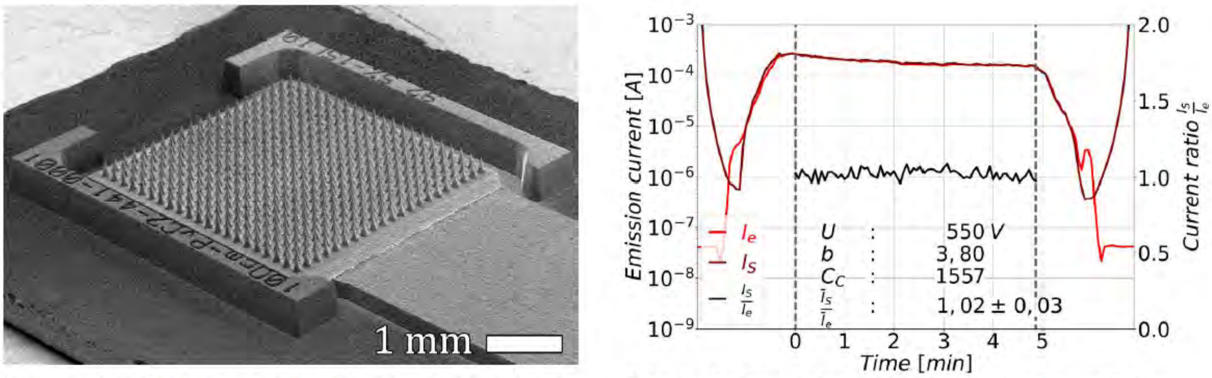

Fig. 1: a) SEM image of the Si-FEA. b) Comparison of the calculated signal current I_S vs the emission current I_e.

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W44T, M. Hausladen, oral presentation (IVEW)

AN OVERVIEW OF THE DEVELOPMENT OF SILICON NANOWIRE ELEKTRON SOURCES

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ABSTRACT

This contribution presents recent progress in the development of field-emission-based electron sources. Key requirements for such sources include high emission currents at low extraction voltages, a compact and monolithic design, long-term operational stability, and high electron transmission through the extraction electrode in order to utilize the emitted electrons as efficiently as possible. To meet these requirements, the cathodes were first optimized with respect to material selection and emitter geometry. This optimization led to the development of silicon nanowire-on-microtube cathodes (Fig. 1, left), combining an adapted emitter geometry to minimize mutual field shielding with the use of low-doped silicon. The increased resistance of the material limits the current of dominant emitters, thereby promoting a more homogeneous emission distribution. At the same time, it suppresses thermal runaway of individual emitters, preventing their destruction and substantially increasing the achievable current density [1]. Based on these cathodes, two types of electron sources were developed for different application requirements. First, electron sources with a glass insulation spacer and an aligned silicon extraction grid were fabricated (Fig. 1, center) [1]. These devices exhibit very good long-term stability and high robustness against electrical discharges between the cathode and the extraction grid. Second, electron sources with an integrated metal extraction gate were realized using benzocyclobutene as the insulating material (Fig. 1, right) [2]. These sources can be fabricated at wafer level and provide a promising platform for the direct integration of additional electrodes at the emitter level, for example for incorporating electron lenses directly into the cathode architecture.

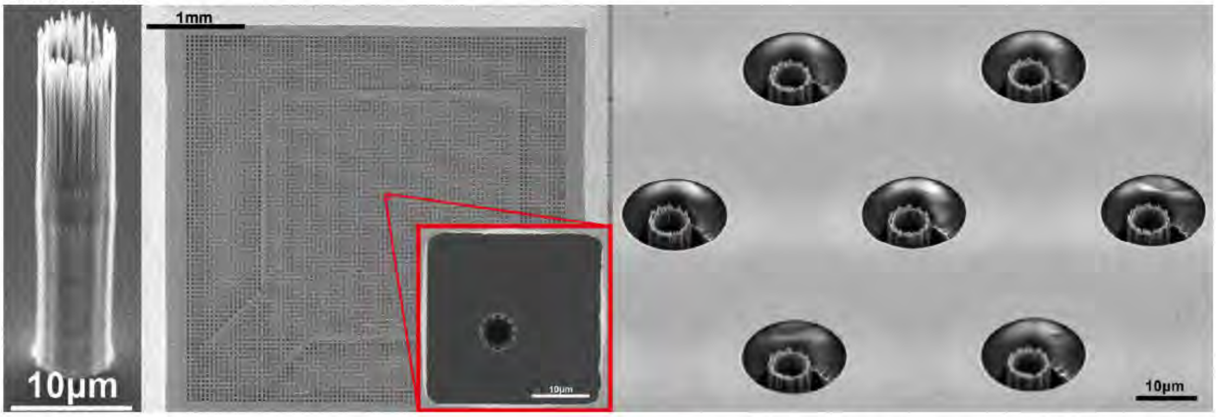

Fig. 1. Left: Single Microtube with Si-Nanowires. **Middle:** Microtube array with glass insulation path and aligned extraction grid. The insert depicts a detail top-down view of a single microtube centered in its grid opening. **Right:** Section of an electron source with integrated extraction gate using benzocyclobutene as an insulator.

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W46T, P. Buchner, oral presentation (IVEW)

Spatially Resolved Study of Grid Effects in Field Emission Arrays Using the CMOS Electron Detector

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Field emission arrays often show non-uniform current distribution, only a few tips carry most of the current, while many others remain inactive or degrade quickly.

In our earlier work, we developed field emission arrays (FEAs) using laser-micromachining and MEMS technology. The first generation used a 4 × 4 arrangement of emitters. Based on this, we designed a larger 21 × 21 array with 441 tips (Fig. 1a). Compared with the 4 × 4 FEAs, this design showed improved overall emission and could operate at lower extraction voltages. When a grid was integrated, a higher total current was achieved, while degradation was reduced and the lifetime increased [1].

In parallel, we developed a method that uses a metal-coated CMOS image sensor (Fig. 1b) to measure the spatial distribution of emission current in real time. It does not require phosphor screens or scintillators. Using this technique on 21 × 21 arrays without a grid (Fig. 1c), we found that less than 20% of the tips carry most of the emission current, while more than 40% remain inactive or fail early. These results show that emission is strongly non-uniform in non-grid designs [2].

In this work, we will study the same 21 × 21 field emission arrays with an integrated grid, using the CMOS Electron Detector. This will allow comparison of grid and non-grid configurations under comparable conditions. We will analyze how the grid influences tip activation, their contribution to the total emission current, and the overall uniformity of the array. The goal is to understand whether the grid can reduce the dominance of a few high-emission tips and improve current sharing across all 441 emitters. A better understanding of these effects will help to optimize the design and operation of field emission arrays, reduce local degradation, and extend the lifetime of electron sources for applications such as ionization vacuum gauges and electron tube amplifiers.

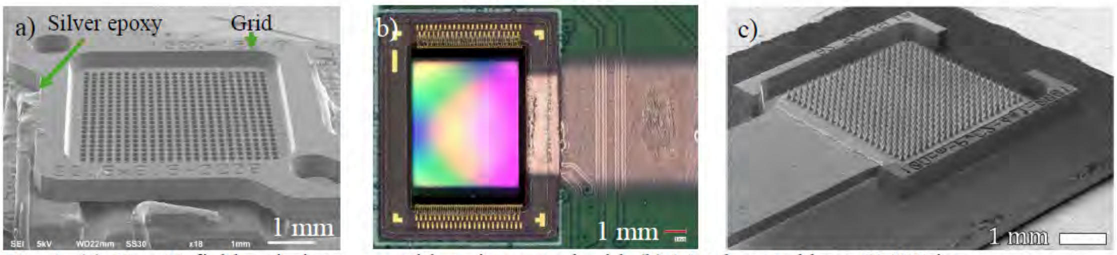

Fig. 1: (a) 21 × 21 field emission array with an integrated grid. (b) Metal-coated bare CMOS image sensor (IMX477). (c) 21 × 21 field emission array without a grid.

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W29T, A. Asgharazade, oral presentation (IVEW)

Vertically aligned multi-walled carbon nanotube (MWCNT) arrays for X-ray sources applications

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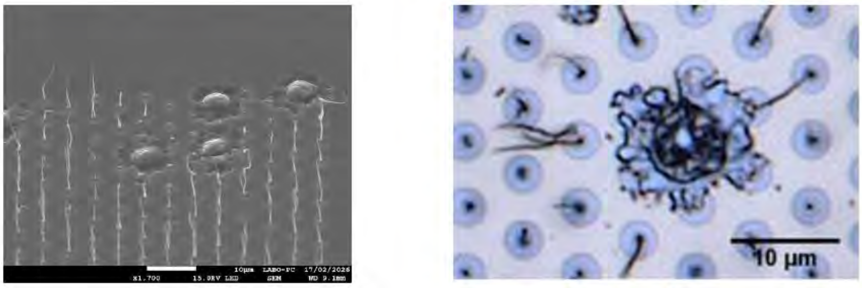
ABSTRACT

Carbon nanotubes (CNT) have generated significant interest as field emitters in electron emission applications [1], primarily due to their high aspect ratio and nanometer-scale apex radius. These characteristics enable local field amplification, allowing CNT to achieve electron emission at relatively low applied voltages and to respond almost instantaneously to variations in the electric field. As such, CNT are promising candidates for next-generation X-ray sources [2]. We develop vertically aligned CNT arrays as cold cathodes for X-ray tubes, targeting applications that require operation with pulse widths on the order of hundreds of microseconds.

Plasma-enhanced chemical vapor deposition (PECVD) enables precise control over the growth, morphology, and electrical emission properties of CNT arrays. Using this technique, we have developed CNT arrays with surface areas of a few square millimeters, achieving emission current densities of up to 1 A/cm². We investigate electron emission under dynamic vacuum conditions, CNT cathodes. Both morphological and electrical evolutions are systematically monitored. Aging experiments were conducted over 1.5×10^9 pulses at a current density of 0,3 A/cm². Ageing phenomena are characterized by analyzing CNT degradation, crater formation, and the evolution of the geometrical field enhancement factor (β). The study is further extended by evaluating the electron emission characteristics using a grid as the extraction electrode in both diode and triode configurations.

By correlating the morphological and electrical evolution of CNT arrays with electrode configuration and operational parameters, this study deepens the understanding of their durability and demonstrates the robustness of CNT emitters and confirm their suitability for long-term operation in X-ray sources



(a) *(b)*

Figure 1. Crater formation after ageing

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C14T, M. Trujillo Arredondo, oral presentation (IVESC)

Concept of Maximizing the eGun Lifetime of an Field Emission Ionization Vacuum Gauge

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ABSTRACT

Ionization vacuum gauges are commonly used in different fields of application, including scientific applications for measuring low pressures under specific conditions, such as low temperatures. Their operating principle is based on impact ionization caused by accelerated electrons and the proportionality of ion current to particle density. The most common electron source for these gauges is a hot cathode. This type of electron source has many disadvantages like a significantly high loss due to thermal radiation. Furthermore, the heat can lead to problems in some applications, like in cryostatic environments. The investigation to overcome such limitations and to achieve higher efficiency led to the usage of the field emission effect in alternative electron emission sources like carbon nanotubes (CNTs) and silicon-based emitters. [1] Due to degradation and other influences, the lifetime and reliability of these field emission sources (FES) are still not sufficient to be used on a large scale in vacuum gauges. [2] To counteract these influences and extend the lifetime there are investigations to distribute the emission current across multiple integrated silicon field emission electron source chips to extend their lifetime. [3] This work aims to test whether a design featuring an electron source with multiple field-emission arrays (FEAs) is suitable for operating an ionization vacuum gauge. A Bayard-Alpert setup was therefore constructed with a developed silicon-based multi-chip FEA (Fig. 1). The study has shown that a Bayard-Alpert ionization vacuum gauge works with this configuration. To obtain a measurable ion-current in different pressure ranges, a max. current of 200 µA was required for the entire multi-chip-array. This is a fraction of the usual amount of current needed in an Bayerd Alpert setup with a hot cathode. The current could be distributed accordingly, and no significant degradation was observed. Further results are presented at the conference.

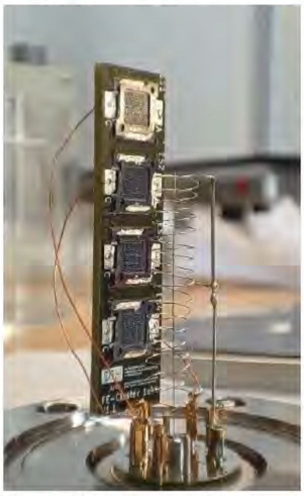

Fig. 1: Sensor assembly

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W32T, M. Langmantel, oral presentation (IVEW)

Field Emission Sources for Astro-Particle Physics Projects

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ABSTRACT

Vacuum and cryogenics are technologies employed by various large-scale experiments in the field of astro-particle physics. Electron sources in vacuum are used for detector calibration with e-guns for mono-energetic electrons and other purposes. Electron rates from fA to mA are required. Here we report on three projects where arrays of field emission sources (FES) are investigated as alternative to the usually used hot filaments or UV light illuminating a thin layer of metal. Both techniques produce light and heat that can be a problem for cold, light sensitive particle detectors.
The first project is the Karlsruhe TRItium Neutrino (KATRIN) experiment [1], which aims to determine the mass of neutrinos from high-precision spectroscopy of electrons from tritum beta-decay. A FES based e-gun (20 keV) operated close to the light-sensitive SDD detector array is being developed.
The second project is the Einstein Telescope (ET), the next generation gravitational wave observatory being planned in Europe [2]. The UHV cryostats for the 10-K mirrors of the low frequency laser interferometers require very good vacuum conditions that produce less than one monolayer of ice per year on the cold mirror surfaces. This may require regular in-situ cleaning of the mirrors, best without producing stray light or excessive heat. A working group started developing FE-based electron emitters (200 eV) for this purpose.
The third experiment (XLZD) is a next generation Dark Matter (DM) detector using 60 to 80 tonnes of liquid Xe in a time-projection-chamber (TPC) to detect the elusive signal of hypothetical DM particles, so-called WIMPS. Electrons from Xe atoms ionized by a WIMP are drifted in an electric field through the liquid Xe. They can be captured by electro-negative impurities before reaching the detectors. Continuously removing any trace of radioactive isotopes as well as electro-negative molecules from the Xe is mandatory to reach the required sensitivity of less than one background event per year. The use of FE sources is investigated to improve the cleaning process of the Xe.

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W1T, J. Wolf, oral presentation (IVEW)

Poster Presentation

Field Emission:

ON THE ADVANTAGES OF USING THE SCALED FIELD *f* AS THE AUXILIARY PARAMETER IN MURPHY-GOOD FIELD EMISSION THEORY

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The Murphy-Good zero-temperature field electron emission (FE) equation for local emission current density J, as a function of the local work function ϕ and the magnitude F of the local surface electrostatic (ES) field, can be written in two alternative (but numerically equivalent) mathematical ways. In the "legacy" (or "BKH") approach, the zero-temperature MG FE equation is written

$$J^{\mathrm{MG0}}(\mathrm{BKH}) \;=\; \{\mathrm{t}_{\mathrm{BKH}}(y_{\mathrm{F}})\}^{-2} \cdot a\phi^{-1}F^{2}\exp[-\mathrm{v}_{\mathrm{BKH}}(y_{\mathrm{F}}) \cdot b\phi^{3/2}/F], \tag{1}$$

where a and b are the Fowler-Nordheim universal constants, y_{F} is the Nordheim parameter defined below, and $\mathrm{v}_{\mathrm{BKH}}(y_{\mathrm{F}})$ and $\mathrm{t}_{\mathrm{BKH}}(y_{\mathrm{F}})$ are functions based on work by Burgess, Kroemer and Houston in 1953. In the "21st Century" (or "FD") approach, the equation is written

$$J^{\mathrm{MG0}}(\mathrm{FD}) \;=\; \{\mathrm{t}_{\mathrm{FD}}(f)\}^{-2} \cdot a\phi^{-1}F^{2}\exp[-\mathrm{v}_{\mathrm{FD}}(f) \cdot b\phi^{3/2}/F], \tag{2}$$

where f is the "scaled field" defined below. $\mathrm{v}_{\mathrm{FD}}(f)$ and $\mathrm{t}_{\mathrm{FD}}(f)$ are derived, by setting $x=f$, from a "purely mathematical" new special mathematical function (SMF) $\mathrm{v}_{\mathrm{FD}}(x)$ introduced by Forbes and Deane in the period 2006 to 2010. y_{F} and f relate to a Schottky-Nordheim tunnelling barrier of zero field height equal to the local work function ϕ, and are given by

$$f \;=\; y_{\mathrm{F}}^{2} = (e^{3}/4\pi\varepsilon_{0})\;\phi^{-2}F, \tag{3}$$

where e is the elementary charge and ε_0 is the electrical constant.

The SMF $\mathrm{v}_{\mathrm{FD}}(x)$ is a purely mathematical function that is a special solution of the Euler/Gauss Hypergeometric Differential Equation (HDE) Exact mathematical definitions of $\mathrm{v}_{\mathrm{FD}}(x)$ can be given in many different ways

The "BKH" and "FD" approaches both yield the same numerical results, and currently both are acceptable. However it is argued in this Poster presentation that the FD approach is *mathematically superior* and superior in practice, for the following reasons.

(1) In the precise series expansions for $\mathrm{v}_{\mathrm{FD}}(x)$ there are no terms involving $x^{1/2}$: this shows that x is the natural mathematical variable to use: hence using f is better than using y_{F}.

(2) The defining equation for $\mathrm{v}_{\mathrm{BKH}}(y_{\mathrm{F}})$ is more complicated than the defining equation for $\mathrm{v}_{\mathrm{FD}}(x)$ or $\mathrm{v}_{\mathrm{FD}}(f)$, and is less obviously a special case of the Euler/Gauss HDE.

(3) Basic algebra related to $\mathrm{v}_{\mathrm{FD}}(f)$ is simpler than basic algebra related to $\mathrm{v}_{\mathrm{BKH}}(y_{\mathrm{F}})$.

(4) In discussion involving an auxiliary parameter, it is usually easier to work with a parameter that is proportional to "field" F, rather than with one that is proportional to $\sqrt{F}$.

(5) The concept of "scaled field" is easier to understand than the Nordheim parameter.

(6) The orthodoxy test is already formulated in terms of f, rather than y_{F} .

(7) The theory of the Murphy-Good plot (which is more nearly straight than a Fowler-Nordheim plot) is already formulated in terms of f.

It is argued that, in the long term, it would be better for the subject area if FE researchers changed to using f rather than y_{F},

C19P, R. Forbes, poster presentation P1 (IVESC)

Tungsten-graphite cathodes as electron sources for 3D-printed field emission microscopes

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ABSTRACT

MEMS technology is used to build miniature electron microscopes, which is known as MEMS electron microscopes. In this technology, field-emission electron guns are used and designed to produce a stable and high field emission performance electron beam, which is crucial for obtaining high-quality images at the microscopic level [1, 2].

In recent studies, it was shown that traditional uncoated tungsten field emission cathodes have several limitations when operated outside of ultra-high vacuum conditions, such as high threshold voltages, short life and operation time, and widespread electron beam. However, it was also shown that coating the nano apex of such cathodes with graphene nano layers helped to improve their performance in scanning tunneling microscopy, along with excellent field emission performance and characteristics [3].

In this study, tungsten nano tips were prepared and cleaned following the electrochemical etching process described in [4]. The uncoated tungsten samples were attached to a 3D-printed field emission microscope that consists of a cylindrical sample holder, cylindrical extractor of 2 mm in aperture diameter, and cylindrical Einzel lens system of 4 mm in aperture diameter. Moreover, electrical conductivity was established by coating the electrodes with 60 nm of chromium followed by another 30 nm of gold. Then, the electrodes of the printed structure and the prepared tungsten nanotip were then coated by exfoliated colloidal graphite to ensure better electrical conductivity at the gold/tungsten-graphite interface, Figure 1 presents a schematic diagram for the tungsten-graphite cathodes.

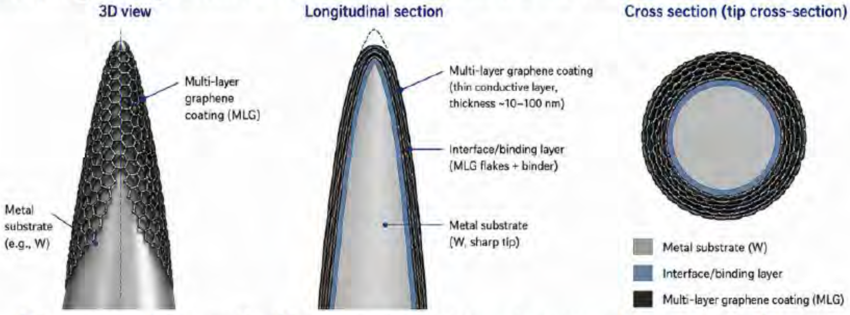

Figure 1: Schematic diagram for a tungsten-graphite electrode apex.

Acknowledgemnt

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W27P, M. Allaham, poster presentation P2 (IVEW)

MEMS INFINITY – MULTIPLE USE MEMS ADAPTER TO MEASURE FIELD EMISSION IN VACUUM ENVIRONMENT

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ABSTRACT

For more than 10 years, high vacuum MEMS devices were developed at Wroclaw University of Science and Technology [1]. Usually, during the development stage the systems and parts of the systems, e.g. electron emitters, are tested in vacuum chambers. However, to test the final device, all technological processes needed to be performed, including anodic bonding of the whole structure to ensure vacuum sealing of the device. This process is difficult and sometimes leakages are encountered, so the final device cannot be tested. Moreover, the anodic bonding is final, so there cannot be any changes in the structure of the device.

In this work, we present our solution of a MEMS structure with a vacuum adapter and a valve that can be placed on a desk to do easier measurements and tests, e.g. field emitters in the setup of a final device. We called it MEMS Infinity because it is a compact sized portable adapter, which can be reusable, that allows carrying out tests on manufactured silicon field emitters. Minuscule dimensions of this adapter allow measurements in a restricted space environment, and it also offers an easy way to replace the field emitter that is being studied, which improves replicability of measurements; moreover, it saves time during assembly of the measured structure. The components of the adapter, as well as the silicon tips that were tested with it, were manufactured using wet anisotropic silicon etching in aqueous solution of potassium hydroxide, similarly to that in [2]. As an electron detector, a flat silicon structure was used [3]. The structure of MEMS Infinity was integrated using anodic bonding, which ensures preservation of structural integrity and minimizes outside environmental factors that may significantly affect the occurrence of field emission phenomenon, such as accumulation of humidity, furthermore specially manufactured efferent canals, allowing for formation of vacuum inside the structure of MEMS Infinity in order to test the phenomenon of field emission. Further development of the vacuum adapter in the case of unambiguous as well as nondeviant from expected results would be based on further miniaturization while conserving the simplicity of cable connections.

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W41P, I Czerwiec, poster presentation P3 (IVEW)

THE STUDY OF HIGH AND LOW DOPED P-TYPE SILICON FIELD EMITTERS

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ABSTRACT

In this work, we present the results of our study on changes in occurrence of fields emission phenomenon depending on the amount of dopant in silicon wafer used in the emitter making process. Saturation level of current which appears in p-doped silicon field emitters [1] could be used to improve stability of generation of electrons in electron beam, which in term could result in better performance of electron microscopes. Analysing the influence of amount of dopant on the field emission phenomenon could open up new possibilities of designs and implementations of field emitters in vacuum MEMS electron devices [2]. Silicon tips were manufactured from both high (boron, 0.001-0.005 Ω·cm) and low (boron, 10-20 Ω·cm) doped p-type silicon wafers. In the process of making tips wet anisotropic silicon etching was used in aqueous solution of potassium hydroxide as well as photolithography using specially designed mask in order to increase the height to width ratio of the emitter [3]. The pyramids were used to induce and measure field emission in vacuum environment, taking into special consideration the voltage required for this phenomenon to happen and for a stable emission of electrons. In order to have a thorough comparison the experiment was repeated for n-type silicon wafers, same technological processes and measurements methods were used in order to replicate the environment of the first experiment. The results indicate significant differences in both the amount of voltage needed for a field emission phenomenon to happen between p-type wafers with different amounts of dopants as well as significant difference in the amount of time needed for wet etching.

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W42P, G. Malinowski, poster presentation P4 (IVEW)

Deposition of Carbonous Nanotips on Field Emitters
(POSTER)

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ABSTRACT

For efficient field emission electric fields in the range of 10^8V/m are required. Therefore miniaturisation of the field emitters can help to increase the efficiency of the devices, as well as the sharpness of the emitter tips leads to a specific local increase of the electric field (field enhancement) also increasing electron emission[1].

Based on the works of Yeong [2] and Nakahara [3], who grew extreme sharp carbon tips on metal emitters as for example tungsten emitters. Therefore, they used different organic gases to introduce carbon to the vacuum system. It was already known that thus grown sharp tips increased emission behaviour of the emitter cathodes. In our work we shifted the process to silicon field emitters and investigated their outcome current, stability and recoverability of the devices by growing carbon on degraded emitters. As shown in figure 1 the growth of the carbon nanostructures was documented by SEM imaging.

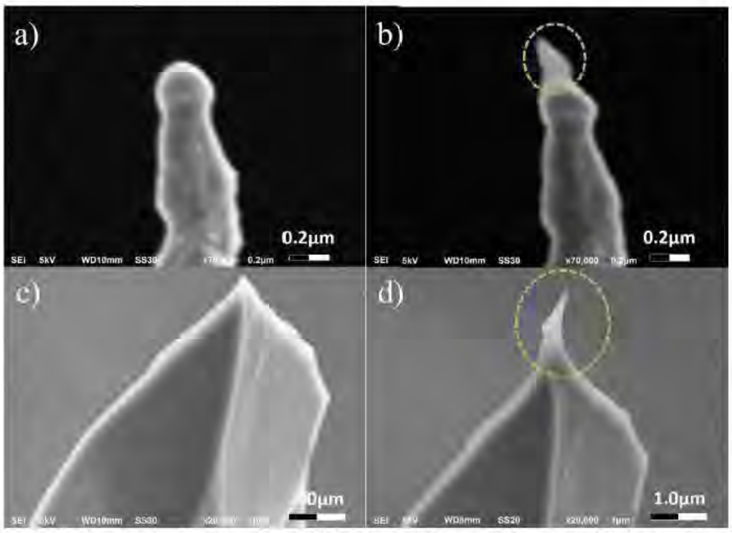

Fig. 1: a) Tungsten Emitter before and b) after Deposition; c) Silicon Emitter before and d) after Deposition

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W45P, F. Hecht, poster presentation P5 (IVEW)

Thermal and Photo Emission:

Evidence for semiconducting behavior of Scandate cathodes

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Poster contribution for IVESC 2026; modified by. G. Gaertner (Consultant, Aachen, Germany)

Abstract: A new theory of emission is offered for scandia doped dispenser cathodes [1, 2]. It is based on data collected at ebeam and the University of Kentucky from 2016 to 2024. The data confirms that scandate cathodes do exhibit certain features of semi-conductor cathodes, such as the anomalous Schottky effect in the temperature limited regime, which is much higher than expected from normal Schottky emission. But they also exhibit some of the features of metallic cathodes, such as insensitivity to duty factor variations. The conventional understanding [3, 4] is, that an approximately 80 nm thickness of scandium rich material lies on the surface of these cathodes, and this accounts for their semiconductor properties. However, this layer was not found on any of the cathodes constructed at ebeam. This finding is based on SEM/EDS, XPS, TEM and Auger in situ studies presented here.

However, a 4-6 nm layer of scandium-rich material was detected on the surface of all tungsten particles in the matrix of activated and emission tested cathodes. This layer was observed using TEM (transmission electron microscopy) on thin cross-sections. It was also detected on the emitting surface of activated cathodes operated at normal emission and temperature by in situ Auger studies.

As a result of these experimental results a new theory of emission is offered. It assumes a thin film semiconductor exists on each tungsten particle in the matrix. These particles in aggregate seem to constitute a thick film semiconductor such as is seen on oxide cathodes, theoretically described by Wright and Woods and Morgulis [5, 6]. This approach was used to fit the anomalous Schottky characteristic by M. Caplan [2], resulting in a Debye length of 1.5 µm.

Keywords: Scandate Cathodes, electron emission, electron guns, thermionic emission, vacuum electron devices.

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C22P, B.Vancil, poster presentation P6 (IVESC)

ELECTRON EMISSION FROM REFRACTORY AND NON-REFRACTORY CATHODES

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ABSTRACT

Electron emission from cathodes occurs when electrons in the conduction band of the cathode overcome a certain potential barrier. Depending on the physical conditions enabling the release of electrons from the cathode, the mechanisms of electron emission are categorized as resulting from individual events (ion bombardment) or collective effect [1].

This contribution is concerned with the emission of electrons from cathodes made of selected materials (Cu, W, Cd, Zn, Ir) that occurs by collective effects (high temperature in the cathode, high electric field on the cathode surface). These effects characterize the arc regime of operation of electric discharges that are relevant to cathodic arcs, electric arcs in switching devices to mention a few application fields. In order to obtain the electron emission current for operation with cathodes of the aforementioned materials, the transferred matrix method is applied [2]. This method is applicable to arbitrary shapes of the surface potential barrier. The selected materials considered in this work represent both refractory and non-refractory cathodes.

The results obtained indicate that cathodes made of Ir and W, which can withstand high temperatures before melting, provide a field-enhanced thermionic electron emission with current density of (10^6-10^7) Am^{-2} even for electric fields in the order of 10^7 Vm^{-1} (W) or 10^8 Vm^{-1} (Ir). For cathodes made of Cu, such current densities can be reached at temperatures below and slightly above the melting point of Cu (1358 K) provided the electric filed is in the range (2-3)$\times10^9$ Vm^{-1}. Cathodes made of Cd and Zn start melting at temperatures of 594 K and 692 K, respectively. For these materials, electron emission current density in the order of (10^6-10^7) Am^{-2} is predicted for electric field of about 3×10^9 Vm^{-1}. An increase of the temperature up to the corresponding values for melting or even up to the boiling point does not give a rise of the current density for weak electric fields since the main mechanism of electron emission is field emission.

The work is funded by the German Research Foundation (DFG) Project number 548964199.

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C3P, M. Baeva, poster presentation P7 (IVESC)

A Rapid Photoemission Model for Beam Optics Codes

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Photocathodes for future Vacuum Electronic (VE) applications such as x-ray Free Electron Lasers (xFEL's) and particle accelerators must satisfy metrics related to performance addressing [1, 2]: (*i*) the mean transverse energy of the beam, (*ii*) the effects of surface roughness, (*iii*) the nature and dependencies (*e.g.*, temperature) of scattering processes, (*iv*) the impact of non-uniform coverage of coatings, (*v*) the dependence on temperature, (*vi*) how degradation and damage due to dark current, desorption, and back-ion bombardment occur, and (*vii*) the dependence on the composition (*aka* stoichiometry [3]) of the photoemissive material. Beam optics codes used to design VE devices launch macroparticles from millions of surface elements for millions of time steps, and so prioritize algorithmic simplicity and rapidity of execution [4]. We present a high speed and flexible algorithm that gives QE based on the parameterization of the dielectric function $\hat{K}(\omega)$ using Lorentz-Drude-Resonant (metal, m) and Adachi-Drude-Resonant (semiconductor, s) schemes, and show how Nordheim's alloy scattering rule and Drude's model of conductivity allow composition to affect estimates of (E_g, E_a, r_e) for band gap, electron affinity effective electron mass that appear in the QE formulae [2, 4]

$$QE_m \approx [1-R(\omega)]F_\lambda[x_m, p]\ h_m\left[\frac{\hbar\omega}{\phi}, \frac{\mu}{\phi}\right]; QE_s \approx \left[\frac{1-R(\omega)}{1+p}\right]\ h_s\left[\sqrt{\frac{\hbar\omega - E_g - E_a}{E_a}}\right] \tag{1}$$

where the optical functions from which $R(\omega)$, $\delta(\omega)$ are found is

$$\hat{K}(\omega) = 1 - \sum_{j=0}^{N_b} \frac{f_j\omega_p^2}{\omega^2 - \omega_j^2 + i\omega\Gamma_j} \quad \hat{K}_a(\omega; = 1 + \frac{\mathcal{A}}{\hat{h}^4}\left(2 - \sqrt{1-\hat{h}} - \sqrt{1+\hat{h}}\right) \tag{2}$$

where the Drude term is such that $\omega_0 = 0$, $p = \delta(\omega)/\ell(\tilde{E})$ is the ratio of penetration depth to mean free path, $(f_j, \omega_j, \Gamma_j)$ are the weighting factor, the resonance frequency, and the broadening factor the j^{th} Lorentzian with $j \in (0, \cdots, N_b)$. For semiconductors, $\hat{K}_a$ is added, $\hat{h} = (\hbar\omega + i\epsilon)/E_g$ as $\epsilon \to 0$, and changes in composition affect $(E_g, \hat{K}, E_a, r_e)$ [5]: for substitutional binary alloys $A_{1-x}B_x$, the $P(x) = xP_A + (1-x)P_B - bx(1-x)$ for parameter P. It is therefore expected that composition will change these most important factors on which QE depends. We demonstrate the model's speed and performance as applied to measured QE from copper and Cs_3Sb and consequences of stoichiometric variation of the later.

Acknowledgements Interactions with D. Dimitrov, D. Finkenstadt, G. Wang, V. Pavlenko, N. Moody, S. Aryal, E. Batista, J. Petillo, E. Rocco, P. O'Shea gratefully acknowledged.

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C17P, K. Jensen, poster presentation P8 (IVESC)

Microscope Electron Sources:

Design of a thermal field electron gun immersed in the magnetic lens field

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Electron Emission Phenomena and Modelling, Thermionic and Field Emission, Poster

Scanning electron microscopes (SEM) are confronted with low speed[1, 2]. The thermal field electron gun immersed in a magnetic lens field can achieve high throughput and rapid imaging by enhancing the probe beam current of the SEM[3].
In this work, a magnetic field immersed thermal field electron gun was designed, which enables efficient collection of electrons emitted from the cathode, thereby increasing the effective emitted beam current. The optical characteristics of the magnetic field-immersed thermal field electron gun were analyzed theoretically. The performance of three different magnetic lens designs which are the single polepiece, the double polepiece with axial gap and the double polepiece with radial gap was simulated and compared. Based on the double-polepiece axial-gap lens, a magnetic field-immersed electron gun was developed, and the variations in beam spot size, beam current, and angular current density with respect to the magnetic immersion lens were systematically analyzed. The magnetic field distribution of the immersion lens and the effective emitted beam current of the gun were measured based on an experimental platform. The effective emitted beam current of the proposed magnetic field-immersed thermal field electron gun reached 44.97 nA at a low acceleration voltage of 3.3 kV and 638.12 nA at a high acceleration voltage of 23.5 kV, representing an approximately fourfold increase compared to that of a conventional thermal field electron gun (see Fig. 1).

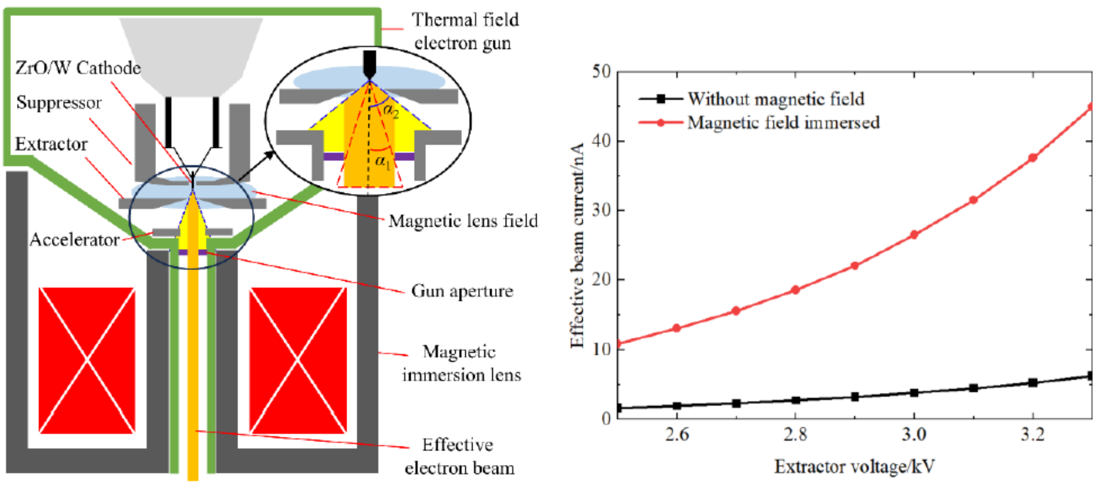

Fig 1 Left: Schematic design of the magnetic field immersed thermal field electron gun. Right: Experimental results of the effective beam current variation with the extractor voltage.

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C16P, Weixia Zhao, poster presentation P9 (IVESC)

PROOF THAT IN FIELD ELECTRON AND ION MICROSCOPES THE ELECTRON/ION PATH IS INDEPENDENT OF THE CHARGE/MASS QUOTIENT

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In normal circumstances, the path taken by a charged particle (electron or ion) moving in an electromagnetic or electrostatic field depends on the charge/mass quotient (q/m). However, in the contexts of the operation of field electron and field ion microscopes and the materials-analysis technique of atom-probe tomography (APT), it has been known for 70 years (and has been repeatedly confirmed) that electrons and ions (whatever their mass) follow *essentially* the same paths when moving in the electrostatic field associated with a needle-like emitter (although in APT there are some very small path differences associated with surface atomic structure of the needle). The technique of APT would not work if this were not the case. This result has also been confirmed (by more than one author) by trajectory simulations using finite-element methods. However, no clear theoretical explanation of this result is available in the literature of these techniques.

This Poster reports an analytical theoretical explanation of the above results, using theory based on Coulomb's and Newton's Laws. Details will be outlined on the Poster. Briefly, trajectory independence of q/m is to be expected if: (a) the particles are moving in a purely electrostatic field; and (b) particles start from the same point in space; and (c) particles start with zero kinetic energy; and (d) final velocities are non-relativistic. The time taken to traverse a given path, however, does depend on the quotient q/m. These conditions apply to the field electron and field ion microscopes and APT, and to various other situations involving electrostatic fields.

An implication of this result is that (for a given emitter shape) the field electron and field ion microscopes have the same magnification. This equality of magnifications is a key part of the theory of a new method of measuring emission area on field electron emitters, proposed by T. Shuai et al. [1].

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C20P, F. Dall-Agnol, poster presentation P10 (IVESC)

ELECTRON BEAM FOCUSING USING AN OCTUPOLE

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ABSTRACT

Achieving precise electron beam focusing is still a major challenge in MEMS-based electron microscopes [1]. These devices usually rely on Einzel lenses, which can introduce strong distortions and aberrations [2] and are very sensitive to voltage changes, lowering image quality. To improve this, the developed design uses an octupole as a focusing element: by adjusting the voltages on its eight electrodes, it can recreate the field of an Einzel lens while also allowing real-time correction of the beam. While traditional MEMS electron columns rely on high-risk, multi-step anodic bonding [3] that prevents component replacement, the implemented modular architecture restricts bonding to the component level. While this ensures a vacuum-tight seal, the process is permanent and risky, a single error during any of the numerous bonding stages can destroy the entire column, with no possibility of repairing or replacing individual components. This work presents a new approach of integrating MEMS electron columns by replacing the monolithic bonded architecture with a modular system. A key point of this design is the strategic use of anodic bonding: it is not entirely eliminated, but its role is shifted from system-level assembly to component-level fabrication. Specifically, anodic bonding remains essential for creating the octupole element. To function correctly, the octupole's silicon electrodes must be permanently joined to a glass insulator to maintain their precise radial positions and electrical isolation. However, once this "silicon-on-glass" component is finished, no further bonding is required to build the rest of the microscope. This modular approach replaces permanent bonding with a high-precision DLP 3D-printed housing and custom PCB interface, enabling precise axial alignment of MEMS components and the easy replacement of individual layers during prototyping. Design improves flexibility for research in high vacuum environments, discussed further in a separate abstract on this conference. Replacing the standard Einzel lens with an octupole can also improve performance. By adjusting voltages on its eight electrodes, the octupole can act as a focusing element, beam deflector, and shape corrector. This makes beam scanning possible, which is needed for Scanning Electron Microscopy (SEM). In this study, the focusing ability of the octupole is compared with a traditional Einzel lens. Beam spot quality is measured using a CMOS camera detector [4], enabling detailed image analysis and evaluation of focusing performance. By comparing the results 'before' (standard Einzel mode) and 'after' (octupole-based focusing), this research aims to determine the superior method for beam manipulation, providing a quantitative basis for the transition toward multifunctional MEMS electron optics.

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W40P, D. Opiela, poster presentation P11 (IVEW)

MODULAR 3D-PRINTED MEMS PLATFORM FOR A FIELD EMISSION SCANNING ELECTRON MICROSCOPE

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ABSTRACT

A novel approach to MEMS vacuum device design is presented, addressing limitations of conventional fabrication techniques, particularly anodic bonding, which is prone to leakage thus insufficient for maintaining the high vacuum required for stable field emission. The system is based on a MEMS scanning electron microscope architecture developed at Wroclaw University of Science and Technology [1].
A key limitation of such devices is the difficulty of testing fully integrated systems. To overcome this, a modular architecture is introduced, replacing permanent wafer bonding with a mechanically assembled structure that enables direct access to individual functional layers.
The proposed system combines a high-precision DLP 3D-printed housing with a custom PCB interface. Integrated sockets ensure precise alignment of the field emitter, extraction gate, and octupole electrode. The key contribution is a reconfigurable MEMS vacuum platform that eliminates anodic bonding [2] while enabling independent testing and replacement of components, which cannot be achieved in conventionally bonded MEMS architectures.
Experimental observations show that reduced vacuum accelerates emitter degradation, confirming the critical role of vacuum integrity. The proposed architecture provides a practical platform for iterative development of MEMS-based vacuum electronic devices.

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W43P, J. Rozum, poster presentation P12 (IVEW)

DESIGN AND ELECTROMAGNETIC ANALYSIS OF AN INPUT CAVITY FOR 648 MHz INDUCTIVE OUTPUT TUBES

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Primary topic: Vacuum Electronic and Discharge Devices and their Applications; Secondary topic: Microwave Tubes; Presentation: Poster

ABSTRACT

Inductive Output Tubes (IOTs) are widely used high-power RF amplifiers for accelerator and broadcast systems, where the input cavity must provide efficient electron bunching and stable RF coupling. This work presents the design and electromagnetic analysis of a 648 MHz input cavity with the anode attached to the shell, as shown in Fig. 1. The cavity incorporates key components including a loop coupler for input excitation, a 5 mm Al_2O_3 insulator, cathode, Window, focus electrode, and Grid, optimized using CST Studio Suite simulations.
The cavity was simulated under a cathode potential of -70 kV and a grid bias of 350 V, with a sinusoidal excitation at 648 MHz. Electromagnetic simulations reveal excellent impedance matching with a reflection coefficient S_{11} of -30.11 dB precisely at 648 MHz, indicating low return loss and effective power transfer into the cavity. Voltage monitors positioned at the cavity centre and 5 mm offset record peak values of 54.83 V and 59.02 V, respectively, suggesting a usable RF field distribution for beam modulation. Particle trajectory tracking in Fig. 3 shows current collision on the anode and grid. These results demonstrate the cavity's suitability for IOT applications, achieving high Q-factor potential and coupling efficiency suitable for multi-kW operation. Future work will integrate this input section with the output cavity for full device validation [1-2]. This work was Supported by National natural science foundation of China (Grant No.62527804).

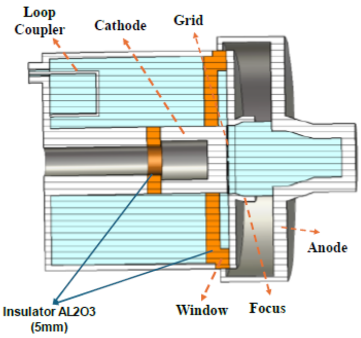

Fig.1. Proposed input cavity

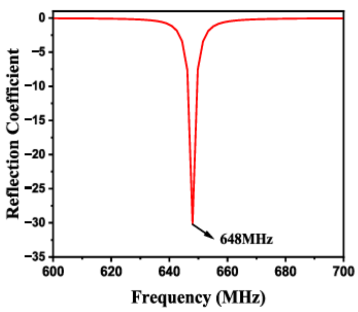

Fig.2. Reflection Coefficient at 648MHz

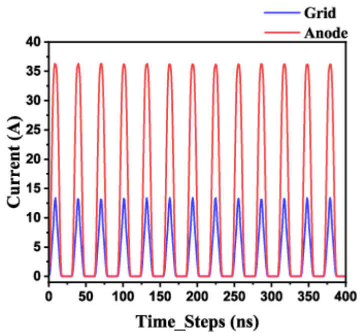

Fig.3. Current Collision on Anode & grid

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W10P, H. Alain, Y. Gong, poster presentation P13 (IVEW)

A SHORT PULSE RESONANT CAVITY FOR 915 MHz MAGNETRON

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Presentation：Poster
Primary Topic:Vacuum Electronic and Discharge Devices and their Applications
Secondary Topic:Microwave Tubes

ABSTRACT

This paper presents the Particle-in-Cell (PIC) simulation results of a 915 MHz pulsed magnetron. Through the electrical priming effect induced by the protrusions and recesses on the inner surfaces of the anode vanes,the magnetron effectively suppresses mode competition and achieves rapid oscillation initiation.

For solid-cathode magnetrons operating in the explosive electron emission regime, the start-up time is dominated by the duration required for the cathode-near electron cloud to propagate toward the anode. Upon the arrival of the electron cloud at the anode, the fringe direct-current (DC) electric field induced by the periodic anode structure perturbs the electron cloud and triggers the growth of magnetron oscillations [1]. In the protruding regions of the anode, the enhanced radial electric field accelerates the electron drift velocity, whereas the recessed anode regions correspond to a reduced electron drift velocity. Under π-mode operation, this spatial difference in field intensity results in azimuthal modulation of the electron drift velocity [2].

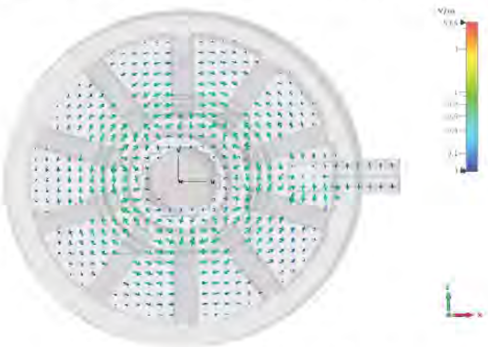

图 1 π-mode field distribution

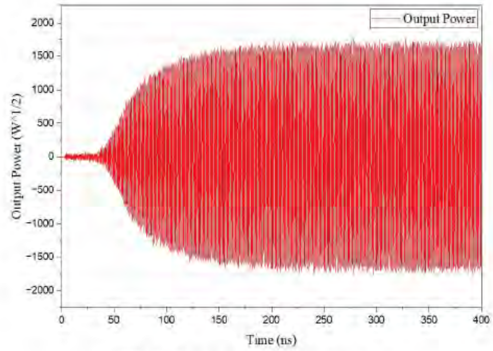

图 2 Output power signal

Figure 1 presents the π-mode electric field distribution, and Figure 2 presents the magnetron output signal. Operating at 45 kV and 0.225 T, the device starts oscillating at 50 ns, and the output power stabilizes at 180 ns to approximately 2.56 MW.

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W17P, Y. Gong, poster presentation P14 (IVEW)

Design of a Low Cathode Loading, High Compression Ratio Electron-Optical System for D-Band TWTs

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ABSTRACT

This paper presents the design of a D-band electron optics system (EOS) for geostationary orbit (GEO) satellite applications using CST Studio Suite. A Pierce-type electron gun with an area compression ratio of 204 was developed, generating a 74-mA beam with a cathode emission current density below 2 A/cm². A periodic permanent magnet (PPM) focusing system with a peak axial magnetic field of 5020 Gs was designed for beam confinement. Simulation results demonstrate stable, zero-interception transmission over a 40 mm distance with a 100% transmission rate. This design provides a viable solution for high-power, long-life D-band traveling-wave tubes.

PRIMARY TOPIC:
Vacuum Electronic and Discharge Devices and their Applications-Microwave Tubes (TWTs, Klystrons, Fast-Wave Devices ...)

SECONDARY TOPIC:
Electron Emission Phenomena and Modelling - Thermionic and Field Emission

C8P, K. Duan, poster presentation P15 (IVESC)

NUMERICAL INVESTIGATION OF 1 kW MICROWAVE HEATING APPLICATOR FOR ENHANCED POWER ABSORPTION IN ASPHALT PAVEMENTS

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ABSTRACT

The use of microwave energy for heating asphalt-based road construction materials in repair and rehabilitation applications holds practical importance due to its capability for rapid and volumetric energy delivery [1], [2]. However, microwave applicator systems employed for asphalt pavement heating often experience significant reflection losses and non-uniform electromagnetic power deposition due to impedance discontinuities between the antenna aperture and the lossy dielectric medium [3], [4]. In the present work, the influence of an impedance matching layer (IML) on the electromagnetic coupling and power absorption characteristics of a 1 kW horn antenna–asphalt slab system operating at 2.45 GHz is numerically investigated. A 3-D electromagnetic model consisting of a horn antenna, impedance matching layer and asphalt pavement was developed using CST Studio Suite. Parametric investigations were carried out to examine the influence of dielectric constant and layer thickness on the S_{11}, VSWR and volumetric power loss density distribution. The results demonstrated that the IML significantly improved impedance matching between the applicator and the asphalt slab. An optimum dielectric constant of 2.5 and layer thickness of 6 mm produced minimum VSWR values near the operating frequency of 2.45 GHz. The optimized configuration reduced the VSWR from 1.63 for the base configuration to approximately 1.28, indicating enhanced electromagnetic coupling and reduced reflection losses. To quantify the power absorption, threshold-based indices corresponding to power loss density levels of $P > 200$, $P > 400$ and $P > 800$ W/m^3 were evaluated. Compared with the base configuration, the optimized impedance matching layer increased the distributed power absorption region, indicating stronger localized field concentration resulting from enhanced microwave power coupling into the asphalt medium. The study demonstrates that impedance-engineered dielectric interlayers of the applicator can effectively improve microwave coupling and redistribute power.

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W33P, N. S. L. Aparna, poster presentation P16 (IVEW)

Dielectrophoresis and Electroporation:

Silicon-based Microfluidic Channel Structures for Future Human Cell Manipulation by Dielectrophoresis and Electroporation

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ABSTRACT

The controlled manipulation of human cells in microfluidic systems is a promising approach for cell biology, biomedical research, diagnostics and therapeutic development. Microfluidic channel structures provide defined geometries, small sample volumes, controlled flow conditions and optical accessibility, enabling reproducible cell guidance and observation [1]. Active cell manipulation can be achieved by acoustic, magnetic or electric fields [2]. This work focuses on electric-field based methods, as they can be integrated into microsystems and enable both dielectrophoresis cell control and electroporation-based membrane permeabilization.

The aim of this work is to establish a technological basis for such a platform by developing silicon-based microfluidic channels. At the current stage, the focus is on channel fabrication rather than biological cell experiments or active electrical manipulation. The realized structures provide defined fluidic pathways, inlet and outlet regions, observation areas and potential functional zones for later electrode integration (Fig.1, A and B).

Silicon-based fabrication offers high precision, reproducibility, mechanical stability and compatibility with microsystem technologies. Compared with polymer-based systems such as PDMS, silicon provides a dense, non-porous material platform with reduced absorption or loss of biologically relevant molecules into the channel walls [3].

Future work will include electrode integration, electric-field simulations, flow characterization and experiments with human cells using dielctrophoresis and electroporation.

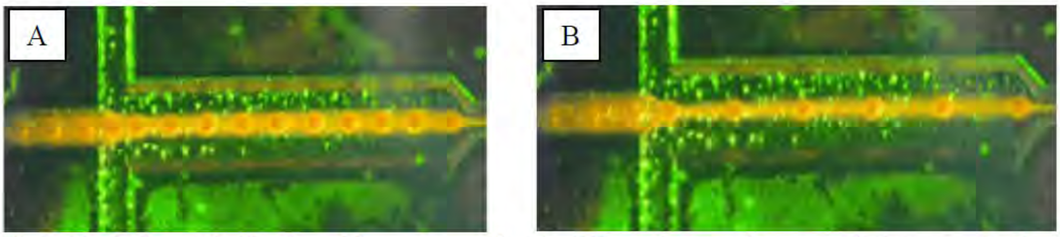

Fig.1: Identical microfluidic channel layout operated under different flow conditions, producing water-in-oil droplets with varying size and spacing in (A) and (B).

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W31P, J. Wiedmaier, poster presentation P17 (IVEW)

Electron-Beam Technologies:

TOWARDS HIGH-POWER PULSED ELECTRON-BEAM-SUSTAINED PLASMAS: A DEVELOPMENT PLATFORM FOR INNOVATIVE HIGH-VOLTAGE AND PULSED-POWER ELECTRONICS

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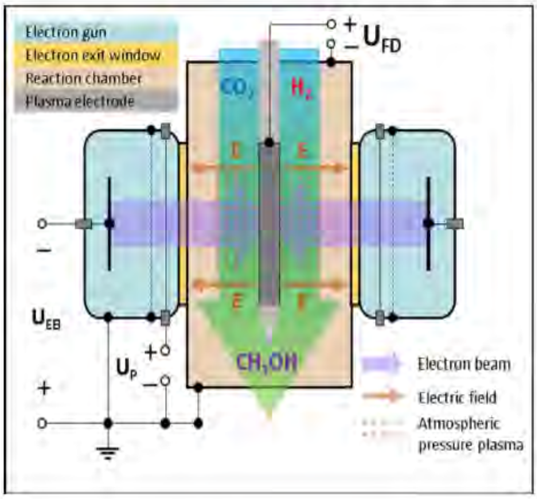
ABSTRACT

For the purposes of climate protection and resilience, Germany is undertaking the transformation of its energy system to solely regenerative sources. Efficient energy storage technologies, to equalize the daily and seasonal variation of the renewable electricity supply, are critical for the success of this "Energiewende". In that context, Fraunhofer FEP has set itself the goal to evaluate the conversion of carbon dioxide, e.g., with (future green) hydrogen, in electron beam-sustained, ambient-pressure plasmas and to proof the advantageous energy efficiency and conversion degree of this novel, industrially scalable Power-to-X process for the production of chemical energy storage materials and "green" platform chemicals. The conceptual approach relies on the fact that overcoming the energy barrier or the kinetic inhibition of chemical reactions is not only possible thermally, but in plasmas also by directly influencing the binding states of molecules. The key to superior energy efficiency is that the plasma species and degrees of freedom are thermodynamically in non-equilibrium, which allows the gas temperature to be kept low whereas the chemically active molecular vibrations are highly excited. Electron beam-sustained plasmas are also characterized by their uniform energy density and volume filling, which simultaneously promises high degrees of conversion.



However, exploiting these rewarding features in practice poses demanding challenges for the energy injection into the electron source and the plasma, which exceed the capabilities of current solid-state switching technologies: electrical pulses with some ns rise times and a few µs duration, kA currents at kV voltages, hundreds of kW/cm³ peak power densities, some J/cm³ deposited energy per pulse, and repetition rates in the kHz range. This poster introduces a pulsed-power development platform for evaluating advanced switches, current-regulation concepts, and pulse-forming architectures involving vacuum-electronic devices.

As one representative application, a SiC-JFET current-limiter stack shall be qualified to stabilize the wire-anode discharge of an SEE cold cathode EB gun, to prevent arcing, and to enable higher power-density operation.

Primary topic: *Laser-, Electron-Beam-, Ion-Beam- and Plasma Processing Systems*
Secondary topic: *Pulsed Power Switching*

W48P, A. Zschalig, poster presentation P18 (IVEW)

Gyrotrons:

FEASIBILITY STUDIES OF A 140 GHz, ≈ 2.4 MW, CW GYROTRON CAVITY

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ABSTRACT

Gyrotrons are high power millimeter wave/sub-terahertz sources capable of delivering hundreds of kilowatts of long-pulse to CW powers for a variety of Industrial-Scientific-Medical (ISM) applications that include plasma heating in thermonuclear fusion reactors, tokamaks and stellarators [1-2]. In this work, we present feasibility studies on a 140 GHz, ≈ 2.4 MW, CW, conventional cavity gyrotron, as a potential alternative for the existing gyrotron systems for W-7X type machines. This is a logical extension of our earlier work on similar gyrotron operating at 140 GHz [3-4]. During the course of these feasibility studies, we have first carried out the mode selection. Modes with eigenvalues, typically, between 65 and 85 are scanned keeping in view the basic design constraints and considerations. For the mode selection, two important rules are observed to choose a suitable mode. The first one is the mode which supports a dimpled wall quasi–optical mode converter with $\Delta m = 3$ perturbation for azimuthal focussing. For this, one should have a mode with $m/\chi_{m,p} \approx 0.5$ or $360°/\varphi \approx 3$. Another consideration is better stability with respect to competing modes. The numbers indicate that the modes $TE_{28,12}$, $TE_{31,11}$, and $TE_{33,12}$ would be a good choice to work with. In the next step, mode competition is studied and the design of a conventional cavity has been designed for all the three modes. In subsequent steps, single-mode self-consistent and multi-mode time-dependent computations are carried out for cavity output power and efficiencies for all the three modes considered. Glidcop with conductivity $\sigma_{gc} = 2.23 \times 10^7$ S/m (including surface roughness and temperature) as cavity material is used for calculations All the computations are carried out with the latest version of Gyrotron Design Studio [5]. Initial feasibility design studies indicate that such an operation is very much feasible to achieve cavity output powers up to around 2.4 MW with interaction efficiencies ≈ 40 % with the selected modes. Further studies on aspects of RF-behavior are in progress at present.

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W28P, M. Kartikeyan, poster presentation P19 (IVEW)

INITIAL DESIGN STUDIES OF A > 200 kW, 30/60 GHz, DUAL-FREQUENCY GYROTRON

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ABSTRACT

Gyrotrons offer a variety of Industrial, Scientific, and Medical (ISM) applications in millimeter-wave and sub-terahertz regimes starting from plasma heating in tokamaks to medical spectroscopy and industrial heating [1]-[2]. To address specific industrial-heating and plasma-diagnostic requirements in India, the feasibility of dual-frequency gyrotrons operating at 30 GHz and 60 GHz with output powers exceeding 200 kW is investigated. Both frequencies correspond to operation at the fundamental cyclotron harmonic (s=1). These requirements motivate the initial design studies reported in this work.

In the calculations, suitable mode pairs supporting the same cavity radius and caustic radius, while simultaneously satisfying the window transparency condition, are identified [3]. Also, the modes selected should support the same magnetron injection gun, interaction cavity structure and output system. After a careful mode selection calculation for dual frequency operation at 30/60 GHz, two modes, $TE_{4,2}$ mode at 30 GHz and $TE_{9,3}$ mode at 60 GHz are chosen.

In the next step, starting currents and diffractive quality factor times coupling coefficients are computed considering the main mode and the probable competing modes, to study the mode competition for a suitable cavity geometry supporting dual-frequency operation. These studies ensure that the chosen modes are well separated from their competing modes. In the succeeding steps, cavity design and self-consistent (single mode and time-dependent multi-mode) computations are carried out to estimate the output power and efficiency. All the computations are carried out with the latest in-house computational code Gyrotron Design Studio (GDS.V.2024) [4]. The initial feasibility design studies indicate that such a dual-frequency fundamental harmonic operation is feasible for achieving output powers (200 kW) with electronic efficiency ≈ 42 % using the selected modes. Further studies on RF-behavioral aspects are currently in progress.

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W25P, M. Kartikeyan, poster presentation P20 (IVEW)

DESIGN STUDIES OF A TRIODE MIG AND OUTPUT WINDOW FOR A 30/60 GHz DUAL-FREQUENCY GYROTRON

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ABSTRACT

This study presents a Triode Magnetron Injection Gun (TMIG) for a dual-frequency gyrotron, targeting operation at 30 GHz and 60 GHz, each with output power exceeding 200 kW. To achieve the gyrotron's specifications under various technological constraints, the $TE_{4,2}$ and $TE_{9,3}$ modes are chosen for operation. The selection of a TMIG is based on its effectiveness in controlling the beam parameters [1]. In the context of a dual-frequency gyrotron, while the physical dimensions of components designed for one frequency remain unchanged, parameters like beam radius and compression ratio vary with the frequency. Achieving the required beam conditions involves modifying the magnetic field strength and profile in the device, necessitating changes in currents applied to the solenoid coils. Precise optimization of both the TMIG and the magnetic field distribution is crucial to produce a high-quality beam with minimal electron velocity spread, thereby enabling efficient beam–wave interaction and power transfer to the desired operating modes. Initial determination of T-MIG parameters is carried out using the latest version of in-house code GDS.V.2024 [2]. Subsequent optimization is conducted through particle trajectory commercial code EGUN, ensuring accurate prediction of beam parameters while integrating the required magnetic field profile [3]. A four-solenoid magnet system is employed to generate the required magnetic field distribution, comprising a central main coil with two auxiliary coils to establish the required static magnetic field along the interaction cavity and a dedicated gun coil positioned in the emitter region for the initial formation of the quasi-laminar electron beam. The operating magnetic fields are 1.07 T and 2.14 T. Assuming a device efficiency of around 40 %, the required electron beam radii are estimated to be 4.98 mm and 7.68 mm to excite modes $TE_{4,2}$ and $TE_{9,3}$ in the cavity for this dual-frequency operation at 30/60 GHz, respectively. In addition, window design studies are carried out considering both sapphire and SiN as candidate window materials [4]. The window design is performed for a Gaussian beam with radial output coupling and an estimated window aperture radius of 50 mm.

References

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W26P, M. Kartikeyan, poster presentation P21 (IVEW)