

TOWARDS HIGH-POWER PULSED ELECTRON-BEAM-SUSTAINED PLASMAS

A DEVELOPMENT PLATFORM FOR INNOVATIVE HIGH-VOLTAGE AND PULSED-POWER ELECTRONICS

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Germany's transition toward renewable energy requires efficient storage technologies to balance fluctuations in electricity supply. Fraunhofer FEP investigates CO₂ conversion, e.g. with future green hydrogen, in electron beam-sustained, ambient-pressure plasmas as an industrially scalable Power-to-X process. Thermodynamic non-equilibrium enables strong molecular excitation at low gas temperature, while electron beam-sustained plasmas provide uniform energy density and volume filling. Exploiting these advantages requires electrical pulses beyond current solid-state switching capabilities: few-ns rise times, few-μs duration, kA currents at kV voltages, high peak power densities, several J/cm³ per pulse, and kHz repetition rates. This poster presents a pulsed-power development platform for advanced switches, current regulation, and pulse-forming architectures, demonstrated by a SiC-JFET current limiter for stabilizing the electron-gun and preventing arcing.

1 Why high-power EB-sustained plasmas?

- Electron beam provides field-independent gas pre-ionization and promotes a uniform, volume-filling discharge
- External gas ionization enables independent control of electron density and reduced electric field
- Operation around 20 Td favors efficient vibrational excitation of CO₂, enabling dissociation via ladder climbing

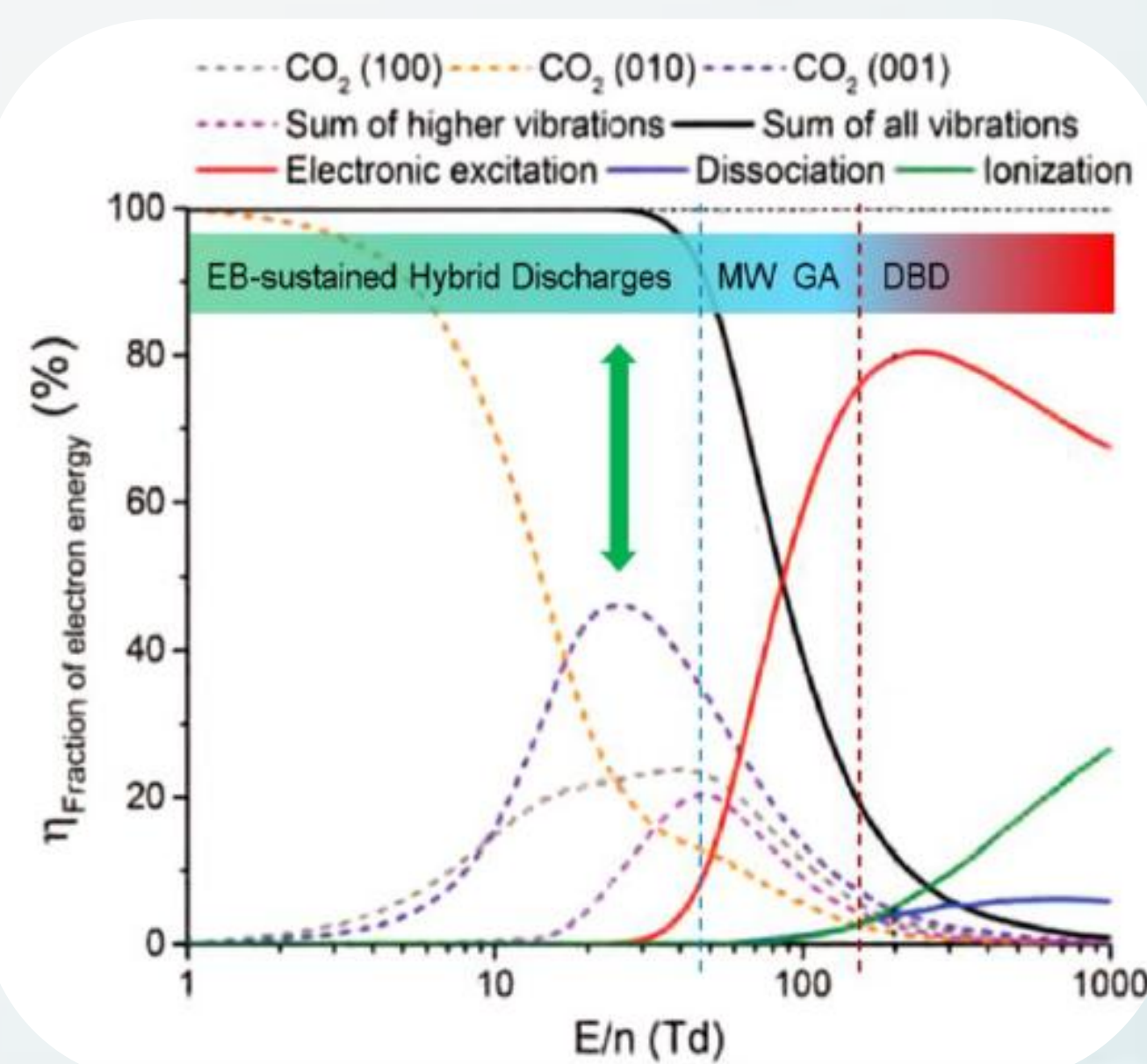


Figure 1. Electron energy loss fractions for CO₂ [1].

Potential Power-to-X pathways

- CO₂ Splitting - CO for synthetic fuels & chemicals
 $2 \text{ CO}_2 \rightarrow 2 \text{ CO} + \text{O}_2$
- Methane Pyrolysis - H₂ for energy & chemical processes
 $\text{CH}_4 \rightarrow \text{C} + 2 \text{ H}_2$
- Nitrogen Fixation - NO for fertilizer production
 $\text{N}_2 + \text{O}_2 \rightarrow 2 \text{ NO}$

2 Development objective

Enable efficient plasma-chemical activation through the development of fast, high-power pulsed components

few ns

rise time

few μs

pulse length

MW - class

Peak power

kHz

repetition

10 kA

current

10 – 30 kV

voltage

3 Vacuum-electronic core: TORUS

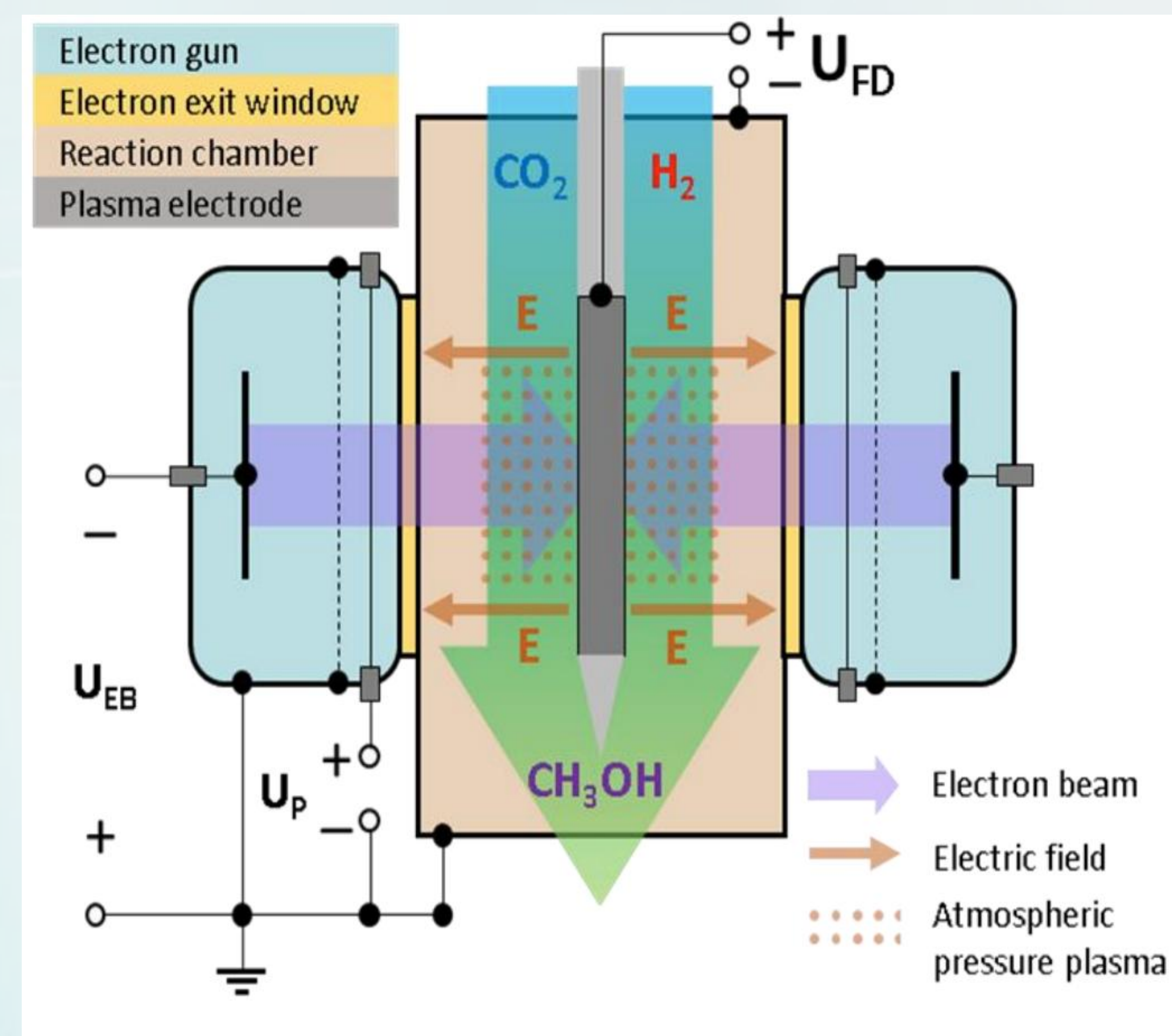


Figure 2. Cold-cathode gun with plasma anode [2].

1 WIP Discharge - U_P

- IGBT Pulse Generator up to 3000 V / 50 A
- Plasma anode for beam amplification
- Fast EB on/off switching

β_1

2 SEE (Cold-cathode) - U_{EB}

- 120 kV / 100 mA
- 55 nF energy buffer
- 10-A, 10-μs pulses @ 1 kHz ($\Delta U = 1.8 \text{ kV}$)

3 Field Discharge - U_{FD}

- Thyatron / PFN / passive discharge
- Target: kV-, kA-range, MW peak
- Flat-top μs pulses, impedance matched

Two-stage current amplification β turns a comparatively small control / beam current into the high plasma current.

4 SiC-JFET based WIP and EB Stabilization

Problem: Unstable, non-stationary electron beam causes process instability

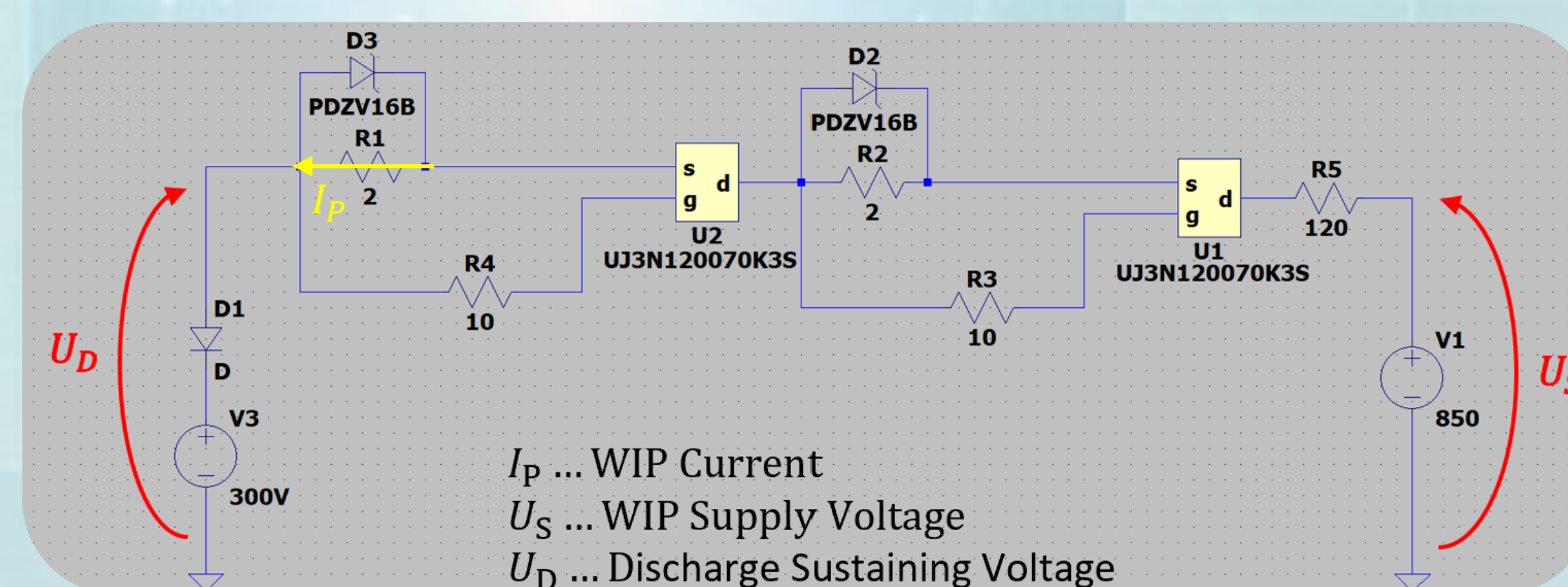


Figure 3. LTspice schematic of two series-connected current-regulating diodes.

- Depletion-mode SiC-JFET stack acts as a self-stabilizing current limiter
- High bandwidth (~1 MHz) enables suppression of fast current spikes
- Provides a defined current plateau for the glow discharge
- Robust against voltage spikes from plasma-induced transients [3]

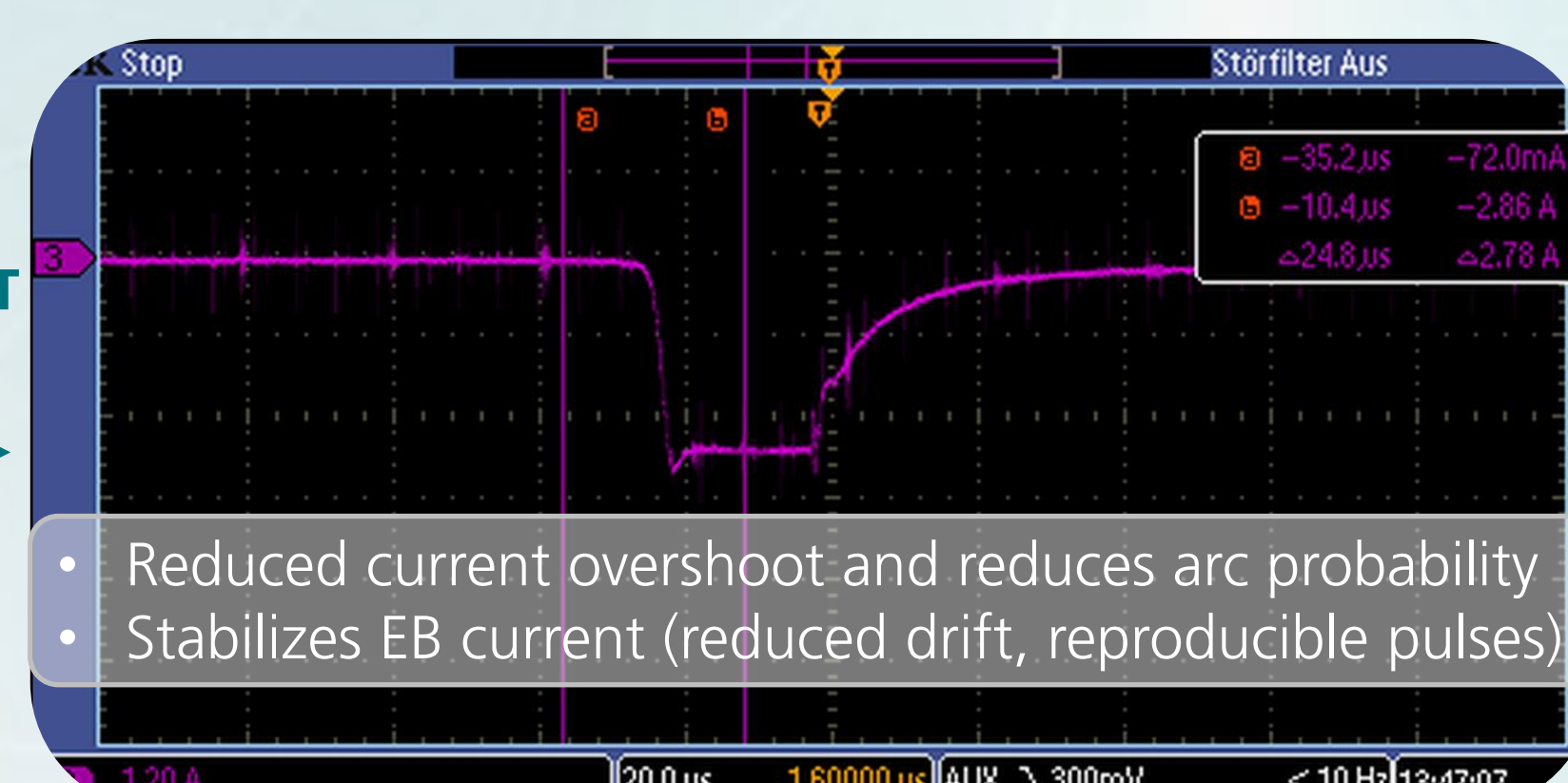
$$I_P = \frac{U_S - U_D}{2 * R_{FET} + R_5 + (2 * R_{Shunt})}$$

5 Results

- No current limiting (EB current 1.3 A)
- 60-μs EB pulse with a 3.6 A overshoot
- Current Limiting to 2.8 A
- 20 μs EB pulse with reduced overshoot



with JFET limiting



- Reduced current overshoot and reduces arc probability
- Stabilizes EB current (reduced drift, reproducible pulses)

6 Outlook

Scale up energy deposition

- increase power density → ~100× higher energy deposition

Field-discharge power supply

- evaluate a dedicated pulsed-power system

Arc control

- Implement a reliable fast arc-shutdown system

CO₂ benchmark experiments

- Investigate the effect of increased energy deposition on CO₂ dissociation