

Contributions to the theory of Scandate cathode emission

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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] and a poster at this conference 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 $2.1\text{ }\mu\text{m}^*$. 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 $2.1\text{ }\mu\text{m}^*$ (*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 $\lambda_D = (\epsilon \epsilon_0 kT / (e^2 n_i))^{1/2}$, 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 n_i . With the following parameters $n_i = 3 \cdot 10^{17}\text{ cm}^{-3}$ similar to Chin et al. [9], $\epsilon(\text{Ba-scandate}) \approx 10$ and $T = 1260\text{ K}$ $\lambda_D = 14.1\text{ nm}$ 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 vanishes.

References:

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