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], 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 1,5 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 1,5 µm. 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 $\boldsymbol{\lambda_D = (\varepsilon\, \varepsilon_0\, kT / (e^2\, n_i))^{1/2}}$ 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 thin semiconductor layers 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 two possibilities to explain the discrepancy between the very thin Sc and BaO layers on the cathode surface and the large Debye length. The first possibility is, that the large Debye length occurs only at larger oxide particles or at the oxides in the pores, which strongly contribute to high electron emission, in line with the model of G. Gaertner [8], based on the beamlet effect for small highly emitting dots.

The second possibility relies on the scaling of λ_D, which is decreasing with increased density of ionized donors $\mathbf{n_i}$. Since the theory of Wright et al. was derived for small band bending, in this case stronger band bending occurs and the derivation of their formulas based on the condition eV << kT no longer holds [6]. Since a solution of the Poisson equation in closed form is no longer possible, only numerical solutions can be obtained. F. e. with the following parameters $\mathbf{n_i}$ = 6.3*10^{16} cm^{-3} similar to Chin et al. [9], ε(BaO) = 14 or $\varepsilon(Sc_2O_3) = 4$ and T = 1300 K, λ_D = 37 nm or 20 nm respectively is obtained, consistent with the 20 nm oxide particles observed in the characterization [1].

The major advantage of scandate cathodes over oxide cathodes with their limited dc loadability still holds in both models, namely the conductivity limitation by the thick oxide layers disappears.

References:

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