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Thermal Field Ionization Electron Emission

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It is known [1,2] that the theory of thermal field emission (TFE) does not provide a satisfactory physical interpretation for a variety of experimental data. Among them are: 1) non-linearity (in Fowler-Nordheim coordinates) of current-voltage characteristics (CVC) of vacuum diodes with single-crystal tip emitters in the region of strong electric fields (F_s) ($F_s \geq 0.45 \text{ V/\AA}$ for refractory metal emitters and $F_s \geq (0.3-0.4) \text{ V/\AA}$ for the p-type semiconductor or high resistance n-type semiconductor emitters), 2) existence of an extensive portion with the slope $n \sim 3/2$ in the "saturation region" of CVC for semiconductor emitters, and also complex kinetics and great inertia (up to tens of μs) of the current settlement process in the pulse mode of emission initiation, 3) significant differences between experimental spectra of emission electron energy distribution and those predicted using the theory of TFE, 4) substantial increase (up to $\sim (3-6) \text{ \AA}$) in resolving power of the Müller projector-microscope with a metal (W, Mo, Ta, Nb) emitter in the region of CVC departure from linearity [3], and, finally, 5) possible stationary emission current flow through a wide band gap semiconductor (ZnS, CdS) or dielectric (SiO_2 , SiC) microcrystal (MC) tip with a current density of up to $\sim 10^6 \text{ A/cm}^2$, and other.

The present work shows that these difficulties encountered when one tries to interpret the aforesaid data in the framework of TFE theory arise because in strong electric fields in the region where CVC plotted in the Fowler-Nordheim coordinates departure from linearity, the physical mechanism of electron emission alters and, hence, the theory of TFE becomes invalid.

The main reason of the change in the mechanism of emission in strong electric fields is a creation of high initial concentration of intrinsic neutral atoms of the MC material in the region of a potential trap [4] (at the MC apex), whose field ionization probability turns to be very high [5]. It is worth noting, however, that the mechanisms of injection into the potential trap region for the neutrals which, due to field ionization and interaction of thus produced ions with the MC surface, cause formation of microplasma completely (or partially) shielding the external field at the MC apex, for metal MC and semiconductor (dielectric) MC are different.

For metal MC, the neutrals injection is caused by the simultaneous processes of: a) MC apex heating by the high density TFE current, b) forming a high concentration of adatoms at the MC apex emitting surface [4] and thermally induced atom desorption stimulated by the excitation of the metal surface layer electron subsystem [6]. For semiconductor (dielectric) MC, the initial concentration of neutrals seems to be formed either by the mechanism similar to that for metal MC (relatively low-resistance n-type semiconductors) or due to trapping of the neutrals evaporated from the MC surface (or from a residual gas atmosphere), which are ionized by the field during their accommodation jumps, and then thus produced ions initiate further desorption of neutrals from the MC surface with subsequent microplasma formation (p-type semiconductors, dielectrics). Note that because of relatively low F_s values ($F_s \sim (0.3-0.4) \text{ V/\AA}$), field ionization of a neutral jumping over the semiconductor or dielectric surface,

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