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FIELD EMISSION AND FIELD IONIZATION IN A LIQUID METAL CESIUM  
FIELD-EFFECT SOURCE

J. Mitterauer

*Technische Universität Wien, Institut für Allgemeine Elektrotechnik,  
und Elektronik, 1040 Wien, Gusshausstrasse 27-29, Austria*

Résumé - Les paramètres d'émission d'une source à effet de champ à césium liquide ont été analysés soit en mode d'émission de champ, soit d'ionisation de champ, suggérant un processus d'ionisation de champ dans chacun des modes d'opération.

Abstract - Emission parameter of a liquid metal cesium field-effect source operating in both the field ionization and field emission mode were analyzed, suggesting field ionization as a common feature in both operating modes.

I - INTRODUCTION

Liquid metal field-effect sources may operate according to the polarity of the field generating voltage in both the field emission (FE) and field ionization (FI) mode. Field electron emission from a regenerative liquid metal field emitter may be considered as successive explosive electron emission due to thermal runaway like vacuum arcing /1/, while in the case of field ionization thermal runaway is prevented due to inherent negative feedback present in all regimes of ion generation /2/.

A physical model describing the cathode spot of a vacuum arc by successive explosive field electron emission from microscopic protrusions and therefore called 'dynamic field emission' was proposed by the author /3/; for quantitative treatment of this model the relevant physical effects (e.g. space charge generation, thermo-field emission, emission induced energy conversion, heat conduction) were linked by positive and negative feedback loops. In the meantime this model was developed considerably, allowing nowadays the computer simulation of the transient evolution of field electron emission in vacuum arc spots /4/. A similar model describing the quasistationary field ionization in the apex region of a liquid metal field ion source by feedback mechanism also was proposed previously by the author /5/.

In order to compare computational and experimental results, a large amount of data obtained in the course of numerous experiments on liquid cesium field-effect sources /6/ systematically was checked, comparing above all field emission phenomena with field ionization effects.

II - EXPERIMENTAL RESULTS AND DISCUSSION

The scheme of the experimental set-up together with the different diagnostic methods applied is shown in Fig 1.

The liquid metal source is of the pin and tube type; two emitter with apex radii of the pin of 2 $\mu$ m (E1) and 20 $\mu$ m (E2) respectively were used. The diagnostic methods include measurement of the emitter

voltage-current characteristics, probe measurements of the ion current, mass spectroscopic analysis of both ions and neutral atoms and spectroscopic analysis of the optical radiation emanating from the emission zone.

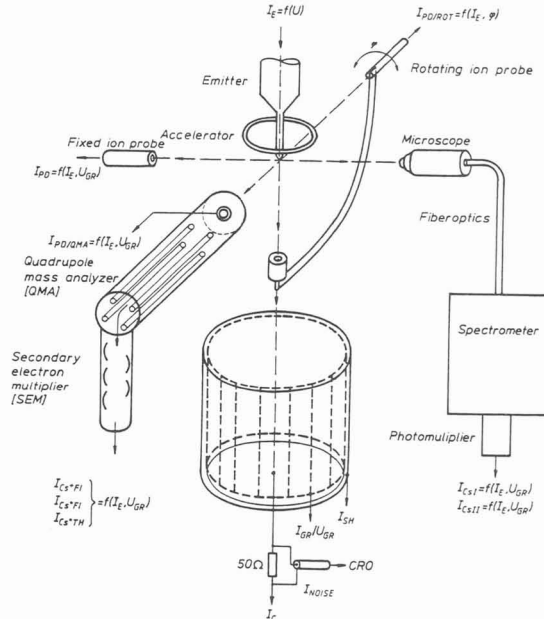


Fig. 1 - Scheme of experimental set-up and diagnostic methods.

### Emission characteristics:

The basic information on the emission performance of the source in both the FI- and FE-mode is by the dependence of the emission current  $I_E$  on the total voltage  $U$ , the latter being the sum of both the emitter voltage  $U_E$  and the accelerator voltage  $U_{ACC}$  towards common ground. Generally the emission characteristic depends on the actual geometry of the apex region of the Taylor-cone, the latter being influenced by the shape of the emitter tip, as well as on the geometrical position of the emitter tip against the accelerator electrode.

Typical emission characteristics for two emitter configurations E1 and E2 operating in FI- and FE-mode are shown in Fig.2. The general features of the emission characteristics are as follows:

- (1) For FI-emission, beyond a certain current level the emission characteristic is linear and obey the law  $I_E = c(U - U_C)$ .
- (2) For a distinct emitter geometry (E1, E2) the slope  $c$  is constant or varies only slightly.
- (3) The value of the voltage  $U_C$  depends on the emitter geometry, being higher for the 'blunt' emitter E2 than for the 'sharp' emitter E1, i.e.  $U_C$  increases with increasing truncation of the emitter tip.
- (4) Reducing the distance between emitter and accelerator, results in a similar behaviour as the transition from a sharp emitter E1 to a blunt emitter E2, i.e. an increase of the voltage  $U_C$

and shift of the emission characteristics towards higher voltages.

- (5) For FE-emission the general type of emission characteristic is similar to the case of FI-emission, the onset of emission being shifted to much lower voltages for identical emitter geometries.
- (6) For FE-emission, the general response of the emission characteristic is the same as in the case of FI-emission, i.e. both reduction of the emitter-accelerator distance as well as increasing truncation of the emitter tip result in a shift of the characteristic towards a higher total voltage.

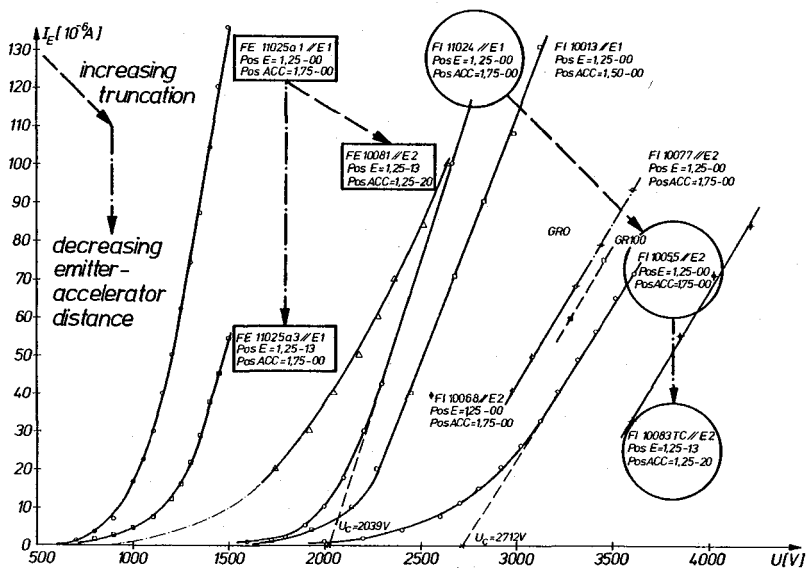


Fig. 2 - Emission characteristics for two different emitter configurations E1 and E2.

### Spectroscopic measurements

In both the FI- and FE-mode there exists a luminous glow in front of the apex region of the Taylor-cone. Spectra of this radiation were registered in a wavelength range between 3000 Å and 9000 Å. The general features of these measurements are as follows:

- (1) In both the FI- and FE-mode the spectra show identical qualitative results, i.e. they were pure line spectra showing no band spectra or continua.
- (2) In both the FI- and FE-mode, besides the four resonance lines of the neutral atom (CsI 4555, CsI 4593, CsI 8521, CsI 8943) no other CsI-lines were observed. The spectra show exclusively CsII-lines of the single ionized Cs-atom, the most intensive of these ion lines being CsII 4264, CsII 4277, CsII 4603, CsII 4616, CsII 4830, CsII 4870, CsII 4952, CsII 4972, CsII 5043, CsII 5227, CsII 5249.
- (3) For FI-emission, the intensities  $I_{CsI}$  and  $I_{CsII}$  of both the CsI and CsII lines depend on emission current  $I_E$  according the

law  $I = I_0 \exp(kI_E)$ , the value of  $k$  being nearly the same for CsI and CsII lines.

- (4) For FE-emission there exists an identical dependence except for the CsI lines which show a decreasing intensity at increasing emission current. Generally for identical CsII lines the intensity of the FE-CsII lines is somewhat lower compared with the corresponding FI-CsII lines.

The dependence of some characteristic spectral line intensities on emission current for the same emitter geometry (E2) are shown in Fig.3.

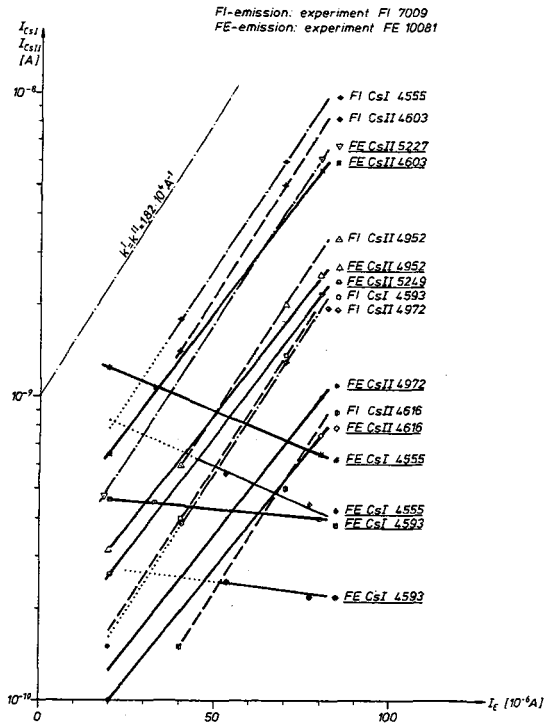


Fig. 3 - Dependence of spectral line intensities on emission current (emitter configuration E2).

III - CONCLUSIONS

(1) Analyzing the emission characteristics for both the FI- and FE-mode (Fig.2), the identical response on variation of emission parameters (e.g. total voltage, emitter tip geometry and emitter-accelerator distance) in both cases is obvious. Assuming for FI- and FE-emission Taylor-cone geometries (the latter being due to polarization effects only and being therefore unaffected by the polarity of the electrodes), for both emission modes one may conclude emission laws obeying the same tendency but operating in a quite different voltage-current relation.

(2) The striking result of spectroscopic measurements is the exist-

ence of CsII-ion lines also for FE-emission, showing nearly the same intensity and obeying the same intensity dependence on the emission current as the CsII-ion lines in the FI-mode. This suggests the existence of similar ionization mechanisms for both emission modes. The strange assumption of positive ions still created in the FE-emission mode is supported by mass spectroscopic evidence of  $\text{Cs}^+$  ions emanating from the emission zone.

(3) The occurrence of nearly similar intensities of the CsII-lines in both emission modes for the same emission current (the latter being sustained in the FI-mode by ions only, neglecting the effect of secondary electrons, while being sustained nearly completely by field emitted electrons in the FE-mode) suggests the same ion concentration within a space charge region surrounding the apex of the Taylor cone, while the voltages necessary to sustain equal emission currents differ quite considerably due to the specific mechanisms of field ionization and field emission.

(4) The common feature of both field ionization and field emission therefore seems to be tunneling of electrons through potential barriers yet into different directions according to the polarity of the applied electric field, as pointed out previously by Gomer /7/ concluding 'that field ionization is field emission in reverse'.

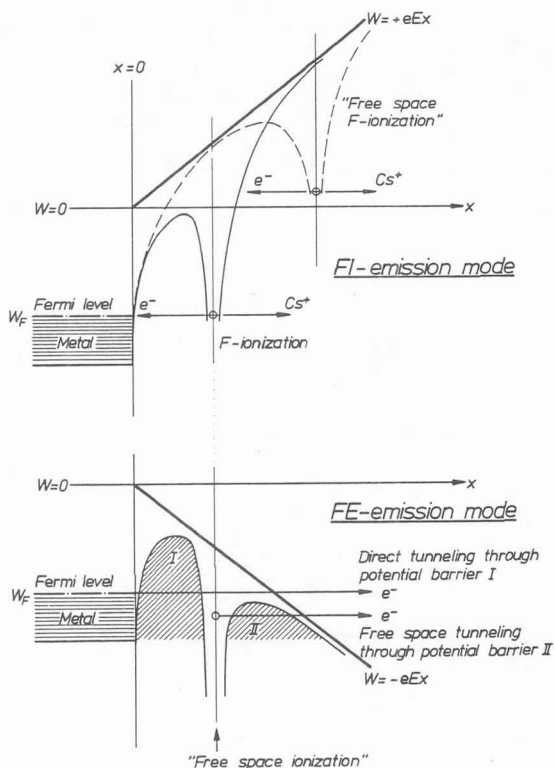


Fig. 4 - Potential energy diagram of an electron of an atom near a metal surface in the presence of a high electric field.

(5) Besides direct tunneling of electrons at the Fermi level one may suggest a mechanisms analogous to 'free space field ionization' /8/ of atoms evaporated from the apex region of the Taylor-cone; both mechanisms schematically are shown in Fig.4. In any case the emission of CsII-lines in both the FI- and FE-mode is due to tunneling of electrons through potential barriers, creating single ionized atoms which may be in a specific state of excitation, the latter being manifested by the multitude of CsII-lines observed.

(6) The occurrence of only the four CsI-resonance lines in the spectrum of both emission modes may be explained due to the rather short lifetime of the corresponding resonance states; therefore photon emission is much more probable than field ionization.

#### ACKNOWLEDGEMENT

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