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To cite this version:
M. Denizart, B. Hadef, J. Balladore. BUILD-UP OF MONOCRYSTALLINE TUNGSTEN TIPS FOR F.E.G.. Journal de Physique Colloques, 1988, 49 (C6), pp.C6-93-C6-97. <10.1051/jphyscol:1988616>. <jpa-00228113>

HAL Id: jpa-00228113
https://hal.archives-ouvertes.fr/jpa-00228113
Submitted on 1 Jan 1988

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Build-up of Monocrystalline Tungsten Tips for F.E.G.

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Résumé - Le remodelage de l’apex de pointes de tungsten monocristallines (111), (310) et (611) est étudié en fonction de la durée, de la température et de la tension de remodelage. Pour une même tension d’extraction le courant d’émission peut être multiplié par 103 à 106, l’angle d’émission étant divisé par 4 voire 7.5 dans le cas de pointes (611).

Abstract - The build-up of monocrystalline tungsten tips (111), (310) and (611) is studied as a function of the build-up duration, temperature and voltage.

For the same extraction voltage the emitted current can be increased by a factor between 103 and 106 when the emission angle is divided by 4 or even 7.5 for (611) tips.

1 - Introduction

The commercial development of F.E.G. has been subject to the solution of the problems related to the control of three kinds of parameters. 1. the vacuum. 2. the optical properties. 3. the emission of the electrons.

The vacuum conditions are dictated by the cathode design and the emission mode which are used: it is a technological choice but also a financial one.

So far as the optical properties are concerned the numerous studies which have been performed, as well from the theoretical point of view as from the experimental one, allow F.E.G.’s well adapted to each specific use. to be constructed.

On the other hand, the difficulties of obtaining high, stable and durable beam currents remain unsolved. They are directly related to the emission, more generally to the phenomena occurring in the diode region and particularly at the emitting area. We have therefore turned our attention to this last parameter and especially to the angular confinement of the emission.

In a first stage we have envisaged an electrostatic solution: the cathode is surrounded by a ring-shaped electrode (1, 2). The latter reduces the beam diameter in the plane of the anode (the operating conditions of the F.E.G. are not greatly affected), it protects the tip against breakdown, it can be used for outgassing the surface of the anode just in front of the tip which is outgased at the same time. It can be used in conjunction with any other method of confining the emitted beam.

In a second stage an extensive study of the tip build-up has been undertaken. The build-up of three monocrystalline tungsten tips (310, 111, 611) has been carried out. The results are reported here.

2 - Experimental

a. Why the build-up ?

Hitherto, different methods have been used to obtain angular reduction of the electron beam emitted from a tungsten tip. The principal techniques are as follows: the confinement by lowering the work function, confinement by oxygen processing and the confinement by remodelling the tip apex.

Among the numerous works concerned with the first technique, the results obtained by Swanson and Crouser (3) are interesting: the work function of the (100) plane of monocrystalline tungsten is lowered from 4.6 eV to 2.7 eV by absorption of Zr. Such zirconiated tungsten tips operated at a pressure of $2 \times 10^{-5}$ torr and at a temperature between 1350 K and 1450 K give a beam the current intensity of which can reach 100 μA, the emission being confined in a cone with a semi-angle between 7° and 10°.
The use of such tips presents a major practical disadvantage: the manufacturing technique has been patented and they are very expensive!
The second technique was first developed by Veneklasen (4) and revised by Troyon (5) and Tanura (6); the "recipe" in which the "ingredients" are the temperature, the pressure and the electrostatic field at the tip apex, results in a structuring of the (100) planes by oxygen absorption. A beam current of 40 \( \mu \text{A} \) is emitted in a cone the semi-angle of which is about 7.5°, the tip being heated at 1173 K.
The use of this process is far from easy and it requires much skill on the part of the experimenter as it must be done in the gun without the possibility of following the evolution of the emission pattern.
Owing to the disadvantages of these two methods we have turned our attention to the third technique, which allows the emission angle to be substantially reduced and can be performed simply in the F.E.G.. We have studied the parameters that govern the build-up of a tungsten tip.

b. The emitter

Although numerous works have been devoted to the study of new materials, tungsten remains the most widely used for the emitters which are used in F.E.G.. It is well known how to manufacture pointed cathodes of tungsten the radius of curvature at the apex of which is less than 1 \( \mu \text{m} \) but the use of monocrystalline tungsten is very expensive particularly, as in the case of our study, when a significant number of tips of each monocrystal is needed; We have therefore used the technique, described elsewhere (7), which allows us to obtain two tips simultaneously with a minimum amount of the precious crystal.

c. The devices

The study has been carried out using two experimental devices:

- The tip is placed alternately in front of a fluorescent screen and in front of an anode. The emission pattern is photographed through a window after each stage of the experiment and the emitted current is recorded. At every moment, the tip temperature can be measured through a window with a micropyrometer. The pressure at the tip is less than 10\(^{-6}\) torr.

- A minidiode is placed at the end of a special specimen holder of the 3 MeV microscope in the L.O.E. in Toulouse (8). A small tip holder is placed at the end of an insulated feedthrough. This allows the tip to be heated and polarized with regard to the anode which is fixed on an hollow copper cap locked to the feedthrough. The anode is earthed. The tip-anode distance can be adjusted before introducing the specimen holder in the microscope and the assembly can be moved in three orthogonal directions and tilted around the tip axis under the electron beam. During the experiments the pressure in the diode region is about 10\(^{-6}\) torr: (emission is not possible). The changes in the tip shape are either observed and photographed directly at the fluorescent screen level or visualized and recorded with a video system. Note that this kind of experiment could be performed only because of the very weak deflection of the electron beam when the electrostatic field is applied between the tip and the anode (see Gauby (9)).

d. The experiments

After formation, the tip is observed in a S.E.M. and its geometrical characteristics are determined particularly its initial radius of curvature. For a given tip, the build-up is performed as follows: at first, the tip is thermally cleaned by flash heating, then it is heated at the required temperature while an electrostatic field is applied (so that emission cannot occur). The process duration, the build-up voltage and temperature influence have been studied. For the same diode configuration and the same extracting voltage the intensity of the emitted current and the corresponding emission pattern have been recorded two minutes after the end of each build-up period. After each sequence of measurements, the tip is restored to its initial shape by flash-heating, another build-up is done using different conditions. Many tips have been used and the following results are representative of the average.
Fig. 1 – Current emitted by a (111) tungsten tip. Build-up temperatures and voltages: 1370 K and 4.5 kV (A) 4.8 kV (B), 5 kV (C); 1770 K and 4.8 kV (D). Emission patterns corresponding to curve B: 1 to a (before build-up); 2 to b; 3 to c and d; 4 to e and 5 to f and g.

Fig. 2 – Current emitted by a (310) tungsten tip. Build-up temperature: 1770 K. Build-up voltages: 3.2 kV (A) 3.4 kV (B), 3.6 kV (C), 3.8 kV (D). Emission patterns corresponding to curve D: 1 to a (before build-up), 2 to b, 3 to c and d, 4 to e and f and 5 to g.

Fig. 3 – Current emitted by a (611) tungsten tip. Build-up temperature: 1970 K. Build-up voltages: 4 kV (A), 4.2 kV (B), 4.4 kV (C), 4.6 kV (D). Corresponding emission patterns: 1 to a, 2 to b and c of curve A, 3 to c, 4 to d and e, 5 to f of curve C.
3 - RESULTS

Results obtained with the first device are illustrated in figures 1 to 3, which correspond respectively to (111), (310) and (611). Taking the case of the (611) tip, after a very short build-up duration, about 15 s, the intensity of the emitted current is increased from $10^{-4}$ A to $7 \times 10^{-4}$ A. For longer build-up durations, the intensity of the emitted current is not increased, as shown in each figure, a modification of the emission pattern is observed corresponding to different structures of the emitting area and particularly to field evaporation as in the case of pictures 5 of figures 1 to 3.

Considering figure 3, the curves A and C show that, for a build-up duration of 2 minutes, a build-up tension increase of 10% results in a doubled intensity of the emitted current (for the same emission conditions). At the same time, the emission angle is reduced from 20° to 8° (fig. 3 pictures 2 and 3).

Some results of the experiments on the 3 MeV electron microscope are illustrated in the micrographs obtained with (310) tips (fig. 4). They show the importance of the build-up conditions and particularly, for the same temperature, the influence of the field applied to the tip. When the field is increased the area of the (310) face decreases while the area of the (211) and (302) faces increases. For the same build-up voltage, the field on the (310) face will be greater for the tip build-up at 3.5 kV than for the build-up at 2.7 kV and the current will be higher. This is in good agreement with the results obtained on the first device. If the build-up voltage is decreased, the (310) face grows again and the (302) face is annihilated.

Note that a similar phenomena is observed with the (311) face of the (111) tips (fig. 5).

Fig. 4 - Profil of a (310) tungsten tip : a before build-up, b corresponding theoretical profil ; build-up voltages and temperatures : c 2.7 kV-1800 K, d 2.3 kV, e 3.5 kV-1970 K, f 3.0 kV-1970 K.

Fig. 5 - Profil of a (111) tungsten tip : a theoretical profil, b usual profil, c formation of (311) planes.

4 - CONCLUSION

The object of this study was to determine the conditions which have to be fulfilled to achieve build-up of the cathode in a F.E.G.. Our results show that the intensity of the emitted current can be easily multiplied by $10^3$ and $10^5$ and the emission angle reduced by 4 even 7.5 after short build-up durations. At the same time they show that if the controle of the parameter time is not crucial provided that the duration does not exceed 1 minute, the same is not true for the temperature and the voltage. It would hence be hazardous to build-up a tip in a gun if the ranges of required build-up temperature and voltage have not been previously determined.

Mean while, taking into account the good reproducibility of our results, it is reasonable to think that, with careful calibration of the cathode-anode system, the build-up could be reliably used in F.E.G.. This supposes a very good knowledge of all the parameters which govern the emission and the build-up : not merely the electrical parameters but also the geometrical dimensions such as the tip-anode distance and those of the cathode itself, particularly the tip radius.
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