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THE MEASUREMENTS OF SURFACE MIGRATION ACTIVATION ENERGY FOR EDGE POSITIONED ATOMS OF TUNGSTEN (011) PLANE

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Résumé

En se basant sur le phénomène des cycliques changements du courant de l'émission électrique sous à la constante pression qui extorque cette émission, observé en train des successives, incandescences / de courte durée / de l'émetteur à la température de 1135 - 1290 K, on a fixé l'énergie de l'activation pour le processus de l'élimination et de la migration des atomes de bord formant le disque de sommet de l'émetteur de tungstène à l'orientation [011]. En partant du principe que les changements du courant de l'émission sont provoqués par l'effet "patch-field", accompagnant le changement du diamètre du disque de sommet, on a obtenu pour les différents diamètres du disque l'énergie constante de l'activation $Q_e = 1.3 \pm 0.2 \text{ eV}$. L'agent pré-exponentiel $A_0$ à l'équation d'Arrhenius décrivant le processus étudié avait la valeur de $10^7 \text{ s}^{-1}$.

Summary

The activation energy on the removal and self-diffusion process of edge atoms of the top [011] oriented tungsten field emitter has been determined on the basis of the cyclic field emission current changes observed after the successive, short duration annealing of emitter. The consideration both the processes surface migration towards the base of emitter and so called "patch-field" effect permits to obtain the activation energy $Q_e = 1.3 \pm 0.2 \text{ eV}$ and preexponential factor $A_0$ of the order of $10^7 \text{ s}^{-1}$ from measurements in the effective temperatures range 1135 - 1290 K.

Apparatus

An all glass, seal-off valve, more detailedly described previously together with measuring system [1] has been used. The geometrical aperture angle $0.17^\circ$ permits to investigate a very small areas limited only by FEM resolution. All experimental chamber was placed in liquid nitrogen to obtain low pressure not exceeding $5 \times 10^{-11} \text{ hPa}$. The local field emission current was measured by using of channel electron multiplier KPE 7 operating in pulse mode. The [011] oriented tungsten tip with final radius about 1200 Å was used. The deflection of probe hole was realized by precise electrostatic system. The emitter temperature was controlled with $\pm 5 \text{ K}$ accuracy.

Experimental procedure and results

The local field emission current from the center of top disk,
structured as [011] plane was measured after the successive, short duration overheating of emitter without field. At constant voltage conditions a characteristic periodical changes of the field emission current, described by authors previously, were observed [1,2]. On the Fig.1 a typical dependence of field emission current, versus 5.0 ± 0.1 sec pulse overheating number is presented for temperatures 1180 and 1245 K. The measurements were made at effective temperatures 1135 K, 1180 K, 1225 K, 1245 K and 1290 K. Although overall length of cycles decreases when temperature increases, they shape is retained, so that standardized field emission current cycle / presented on the Fig.2 at co-ordinates N/N₀ versus x = t/ᵣ₀, where N₀ = counts for cycle beginning, ᵣ₀ = mean cycle length / can be constructed.

Discussion

The geometrical model of the apex part of [011] oriented tungsten emitter presents Fig.3. It may be constructed from concentric disks with thickness corresponding to interplanar space. For thermally smoothed emitter with tip radius ~1200 Å, the apex disk radius calculated from crystallographic relations is about 70 Å, the next one - about 110 Å. At high temperatures conditions, the edge atoms migrate on the next step towards the emitter base. Since the mean diffusion length per second of separate surface tungsten atom on the (011) plane, calculated after Graham and Ehrlich [3] for the temperature 1200 K is the order of 10⁻¹⁴ m, therefore all the edge atoms of apex disk removed in the course of heating pulse, are going toward the...
emitter base and apex disk grow small. This process was proposed and observed by Trolan and all [4]. The process of the apex disk collapse connected with "patch-field" effect, described by Young and Clark [5], can explain the observed cyclic field emission current changes. As suggested by Polizzotti and Ehrlich [6] the "patch-field" effect appear to be overestimated. Authors propose to calculate the field strength $F_0$ caused by "patch-field" effect from relation:

$$F_0 = \frac{\Delta \phi}{enR}$$

where $\Delta \phi$ - work function difference between (011) plane and next well developed plane, $n$ - number of net rings between this planes, $R$ - disk radius, $e$ - elementary charge.

If we assume the work function of (011) plane 5.6 eV [7] and take into consideration (012) plane with work function 4.34 eV [8] we can calculate, on the base of geometrical model / presented on Fig.3 /, $\frac{\Delta \phi}{en}$ ratio. Its value for 1200 Å radius emitter was 0.048 V.

The total field strength on the apex disk is the function of $R$ and can be denoted as $FR/R = F + F_0$, where $F$ is the average field strength evaluated for smooth (011) plane for example from van Oostrom tables [9]. For large disk size "patch-field" effect is negligible / $F_0 \approx 0$/7. Considering all above relations we can calculate from Fowler-Nordheim relation, the $j(F)/j(F)$ ratio as a function of $R$. Now on the base of above calculations and local current measurements results / presented on Fig.2/, the relation between apex disk radius $R$ and cycle phase $x$, showed on the Fig.4 was calculated. The apex disk radius shows linear changes to about 20 Å. The initial disk radius is 70 Å what is in excellent agreement with geometrical considerations.

Assumed, that the edge atoms number in disk is proportional to $\sqrt{N}$, where $N$ is the total number of disk atoms, we can describe the removing process of the edge atoms by expression:

$$-\frac{dN}{dt} = A_0 \exp\left(-\frac{Qe}{kT}\right)$$

where $Qe$ - an activation energy on the described process, $A_0$ - preexponential factor. If we have correlation between disk size and cycle phase, as well $T_e$ value at five constant temperatures, we can formulate the five equations system based on formula /2/. Its solution, obtained by least squares method, gives an activation energy and preexponential factor as a function of apex disk radius. Obtained values:

$$Qe = 1.3 \pm 0.2 \text{ eV}$$

$$A_0 \sim 10^7 \text{ s}^{-1}$$

are independent on disk radius $R$.

Comments

a/ In the papers of Barbour at all [10], Bettler and Charbonnier [11] and Bettler and Barnes [12] the surface migration activation energy of individual tungsten atom was measured by so called "disappearing rings" method using. On account of migration of the apprecia-
ble part of emitter tip material, together with destruction of relatively large micromonocrystal volume, the obtained value of activation energy 2.7 - 3.14 eV per atom can not be recognized as a surface migration energy on the individual net plane. Barbour at all and Bettler and Charbonnier [10,11] have suggested, that for the close packed (011) plane, the surface migration activation energy can be significantly smaller. The actual results obtained by FIM method [3,13,14] gives for activation energy on the self-diffusion process of tungsten atom on the (011) plane a value of 0.85 to 0.95 eV. The result obtained by authors for the remove of the outer atoms from the top disk for following diffusion on the next disk of (011) plane is the complement to previous results.

b/ The variation in the course of disk radius for final cycle stage / R ~ 20 A / can be caused by low resolution of FEM or by fact, that the assumption about proportional of the edge atoms number to square root N is not true for small disk radii.

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References