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TEMPERATURE DEPENDENCE OF IRIIDIUM FIELD EVAPORATION RATE

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Résumé - Différents auteurs ont suggéré la possibilité d'un effet tunnel ionique et quelques expériences ont conforté l'hypothèse d'un effet tunnel pour les ions W ou B à basse température.

Nous avons déterminé, par Microscopie ionique, la dépendance en température du flux d'ions évaporés par effet de champ (en plans évaporés par seconde). Les résultats montrent deux régimes différents à haute et basse températures, la température de transition étant comprise entre 35 et 40 K. A basse température le flux est beaucoup moins dépendant de la température. Ceci est interprété comme le résultat d'une désorption des ions iridium par un mécanisme d'effet tunnel en dessous de 35 K.

Abstract - The possibility of ionic tunneling has been suggested previously by several authors, and some experiments have been already reported giving indication for the quantum mechanical tunneling of W or B ions at low temperatures.

We performed FIM experiments on Iridium to determine the temperature dependence of the relative field evaporation rate (in layers per second). The results show two different regimes at high and low temperatures, with a transition temperature between 35 K and 40 K. The much more smaller temperature dependence at low temperature is interpreted as being indicative of a tunneling mechanism of field desorption of Iridium ions below 35 K.

I - INTRODUCTION

The quantum mechanical phenomenon of tunneling has been known for more than 50 years. Among the best examples of tunneling are α particle decay of nuclei /1/ and field emission of electron /2/. More recently the existence of a molecular tunneling has been reported for chemical reactions /3/.

The possibility that field desorption at low temperature would be the result of ionic tunneling has been suggested previously /4/, /5/, /6/, /7/, /8/, /9/, /10/. We have recently reported some experimental evidences showing that boron ions are field desorbed by ionic tunneling up to a temperature of 140 K /11/.

At high temperature the field desorption of atoms is a full thermally activated process while at very low temperature the desorption reduces to pure tunneling.

Between these two situations a transition temperature T_c exists, defined by the equality of the two desorption rate constants.

In this paper we present a FIM study of the temperature dependence of desorption rate for iridium at low temperature where tunneling is supposed to occur.

II - EXPERIMENTAL

We measured the desorption rate constant of iridium using a ring counting technique /12/. The desorption rates were obtained in layers per second.

The specimen was cooled down to 20 K using a close-circle cryogenerator. The temperature could be adjusted by heating the cryotip by means of electrical resistances. The temperature was measured at the base of the sample holder with a Fe Au-chromel Thermocouple with a reference at 77 K. The difference between the actual tip temperature and the measured one's has been estimated to be close to 10 K. The experimental protocole is as follows : the applied potential V_{DC} is first settled to a chosen value. Then the time required to evaporate one (or several) layer is measured. The potential is then decreased and afterwards the tip temperature is changed and stabilized before a new measurement.

Since the barrier height and width are field dependent it is necessary to hold the field constant during the whole measurements. Because the tip radius generally increase during the experiments it is necessary to compensate this phenomenon by increasing the applied voltage.

This can be achieved in a simple way since for a constant field there is a linear relationship between this potential increase $V_1 - V_2$ which is required and the number of evaporated planes n /13/. When the pole of interest is located at the tip axis :

$$V_1 - V_2 = n\Delta V (hkl)$$

with

$$\Delta V (hkl) = \frac{E\beta a}{\sqrt{h^2 + k^2 + l^2}} \times \frac{\sin \alpha/2}{1 - \sin \alpha/2}$$

where α is the cone angle of the tip, a the lattice parameter, E the applied field and β the field proportionality factor defined by $E = V/\beta R$ with R the tip radius.

The value of $\Delta V (hkl)$ can be accurately determined with a preliminary experiment. As the applied voltage is slowly increased the number of field evaporated planes is recorded. The figure 1 shows the results obtained for two different tips. The number n of field evaporated planes is plotted versus the applied voltage V . The linear relationship between n and V is well verified. The cone angles calculated from these data are respectively equal to 4.5° and 8.8° . As mentioned by D. Blavette /13/ the $\Delta V (hkl)$ parameter is only dependent upon the cone angle and the cristallographic plane, it does not depend on the increase voltage rate.

III - RESULTS AND DISCUSSION

The figure 2 gives the results obtained for three different applied field strengths. The logarithms of evaporation rates (measured in layer per second) are plotted versus $1/T$.

For the first experiment conducted at the lower field we did not succeed to go down in temperature below 58 K because the time required to evaporate one layer was yet greater than half an hour. For this experiment points are alined on a straight line corresponding to an activation energy $Q_n = 0.106$ eV.

The experiments 2 and 3 were performed at higher fields (for instance the increase in field is about 6 % between experiment 1 and 2). A sharp change in the slope occurs within 35-40 K. Two distincts regimes can be readily observed : above 40 K and below 40 K.

Several explanations have to be considered in the interpretation of such a change in the evaporation rates. Wada /14/ suggested the possibility of two different thermally activated processes : migration of an atom from a site to another prior evaporation. At low temperature below T_c the observed desorption rate would be controlled by the migration rate while above T_c the evaporation process would become rate-controlling.

However we think that the activation energy which is observed at low temperature is so small ($Q_n \sim 10^{-3}$ eV) that a tunneling effect is more likely.

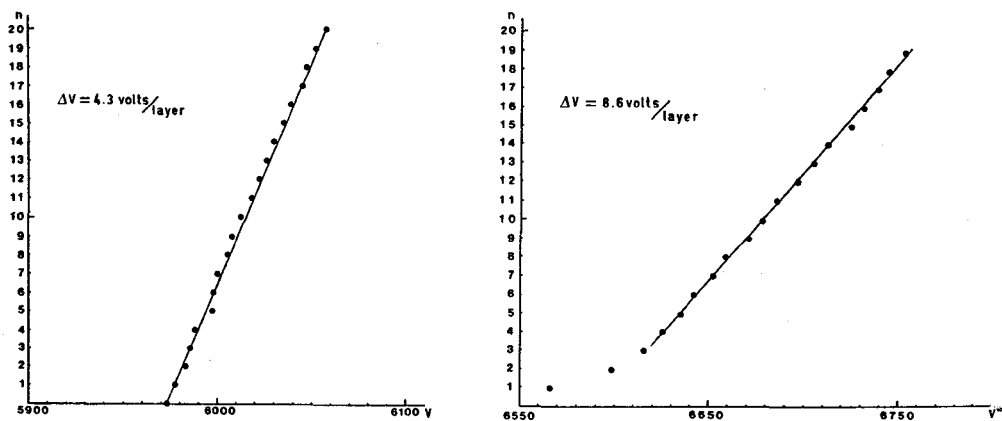


Figure 1 - Number of field evaporated planes as a function of the applied voltage for two different tips.

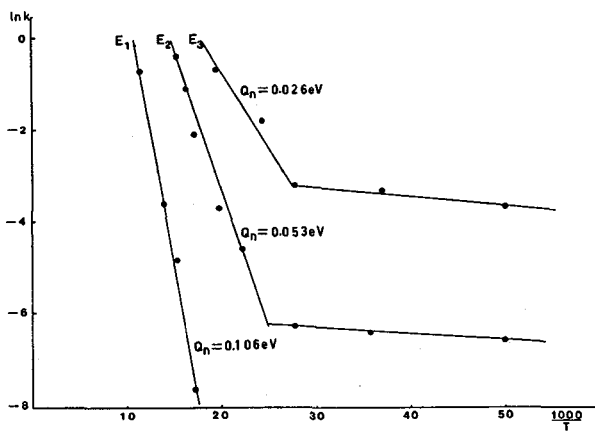


Figure 2 - Arrhenius plots for the field evaporation of iridium, for three increasing values E_1 , E_2 , E_3 of the applied field.

Tsong /7/ and Kingham /10/ estimates give a critical temperature T_c lying between 50 K and 75 K for iridium and for a barrier height and width respectively equal to 0.1 eV and 0.1 Å.

Considering a parabolic shape for the barrier

$$T_c = \frac{\frac{1}{2} \sqrt{2}}{\pi k_B} \left(\frac{Q_n}{M} \right)^{1/2} L^{-1}$$

when Q_n and L are the barrier height and width and M the ion mass. If we take as true the barrier heights observed above T_c for thermal activated desorption, the critical temperature 35-40 K is consistent with barrier widths of 0.1 and 0.13 Å for respectively $Q_n = 0.053$ and 0.026 eV.

Of course these experiments were performed with the presence of imaging gaz. Kellogg /15/ pointed out that the influence of gaz upon activation energy was significant even at a low background pressure of 5×10^{-10} Torr. This probably explains the low activation energies observed above T_c compared to Kellogg results.

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