Na AND K IONIZATION ON POLYCRYSTALLINE Ir (*)

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ABSTRACT — The results of experiments on the ionization of thermal beams of Sodium and Potassium atoms by polycrystalline Iridium are presented. From the experiments we determine the work function of Iridium to be 5.34 ± 0.07 eV. The thermal electron emission method gives the value 5.25 ± 0.05 eV. These two methods and their results are discussed with reference to the «patch model» of ionization on heterogeneous surfaces.

INTRODUCTION

Surface ionization phenomena are important because of their vast area of application. Some of the important applications are in the fast neutral atom sources, ion sources, ionic motors. leak detectors for vacuum systems and semiconductor doping.

In surface ionization an electron in the valence band of an atom passes to the conduction band of a metal by tunnelling [1] and the resulting adsorbed ion remains on the surface for a certain time. This average residential time depends upon the heat of desorption of the ion at the surface. However, it is the probability of electron exchange between the atoms and the metal that dominates the phenomenon and this probability depends essentially upon the energy balance between the ionization potential of the atom and the work function of the metal (so positive surface ionization is more probable when the work function of the metal is higher).

(*) Results presented at the Conference of the Portuguese Physics Society (Lisbon, February 1978).

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Despite its high work function, Iridium, until now, has not been used widely in surface ionization applications. This may be partly due to the fact that its thermionic properties have not been studied systematically. In fact the number of materials which have been used so far as ionizers is small. Essentially the following have been commonly used: W, Pt, Re and 8% Pt-W and, in some applications, Ta, Mo, Ni, Sn, Ir, Os. Alloys of W-Re and W-Th have also been used.

In the following we present the result of our study on the ionization characteristics of thermal beams of Sodium and Potassium by polycrystalline Iridium.

EXPERIMENTAL

The experiment essentially consisted in generating a thermal beam of Sodium (or Potassium) and sending it onto a polycrystalline sample of Iridium placed in high vacuum ($\simeq 10^{-7}$ torr). The current due to ionization of the incident atomic beam was studied as function of the temperature of the surface of Iridium, the temperature being measured by an optical pyrometer. The effect on the ionization current due to the adsorption of foreign gases on the surface of Iridium was also analysed.

The experimental set up is schematically shown in Fig. 1. The atomic beam is produced in a charge-exchange type source; its intensity was controlled by measuring the ions which were not neutralised in the source. The beam, after collimation, hits the sample surface arranged in the form of a Langmuir-Taylor detector. A mechanical chopper and associated lock-in circuitry was used to measure the ionization current.

In the measurement of surface ionization, the incident beam particles themselves may contribute towards lowering the work function. In order to minimise this error the temperature of the filament was raised above 2000 K between each reading of the ionization current.

From the data obtained we can calculate the work function of Iridium and also the coefficient of ionization of Sodium or Potassium at thermal energies in the surface of Iridium. The work function was also measured by the thermal-electron emission method. The value obtained can be compared with the one obtained by the surface ionization method.

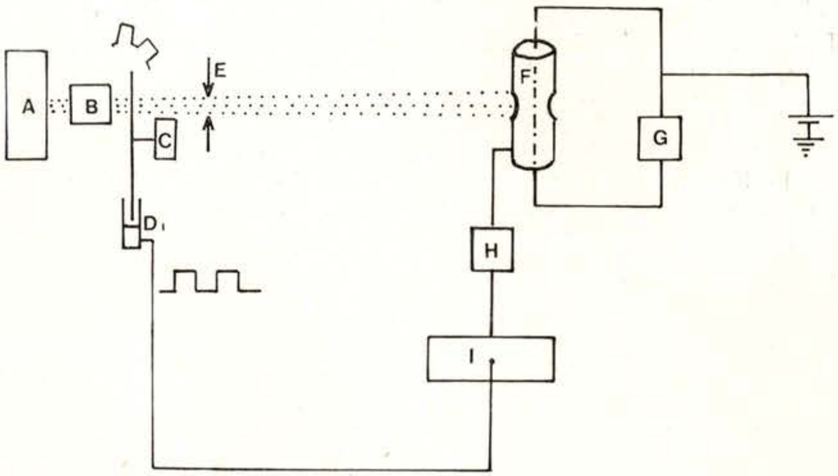

Fig. 1 — Schematic diagram of the apparatus

A — Charge-exchange source
B — Deflection plates
C — Chopper and rotor
D — Photodetector
E — Slit
F — Langmuir Taylor detector with Iridium surface
G — Direct current generator
H — Preamplifier
I — Lock-in amplifier.

DISCUSSION OF THE RESULTS

1 — *Thermal emission of electrons*

The electron current is given by the well-known Richardson-Dushman equation.

$$i = \mathrm{AT}^2 \exp(-\phi_e / k\mathrm{T})$$

where ϕ_e is the work function and T the temperature. It follows that the graph $ln\ i/\mathrm{T}^2$ vs. 1/T is a straight line (Richardson line) and the slope gives the value of ϕ_e; in our case we obtained the value 5.25 ± 0.05 eV. This value is close to the one obtained by other authors using this method: Alekseev and Kaminskii [2] (5.3 eV), Hushman [3] (5.4 eV), and Zandberg and Tontegode [4] (5 30 eV).

The influence of adsorption of oxygen and methane on the surface results in an increase of the work function in one case (oxygen) and a decrease in the other (methane).

In Fig. 2 are shown Richardson lines for the three cases: clean Iridium, Iridium in oxygen, and Iridium in methane atmosphere. In the case of oxygen the work function increased to 5.4 ± 0.11 eV. This value is, however, less than that obtained by Hurkmans et al [5] (5.6 eV). Probably the difference is due to the lower oxygen pressure employed by us; the pressure was low enough to ensure that only a monolayer was adsorbed on the surface. The pressure dependence of the work function has already been pointed out by other authors [6]. The difference between the value obtained with and without oxygen is explained, in general, by assuming the formation of a homopolar bond between the adsorbed atom and the sample surface. Using this model Slachter derived the expression for this difference [7] which, in our case, turns out to be 0.25 eV.

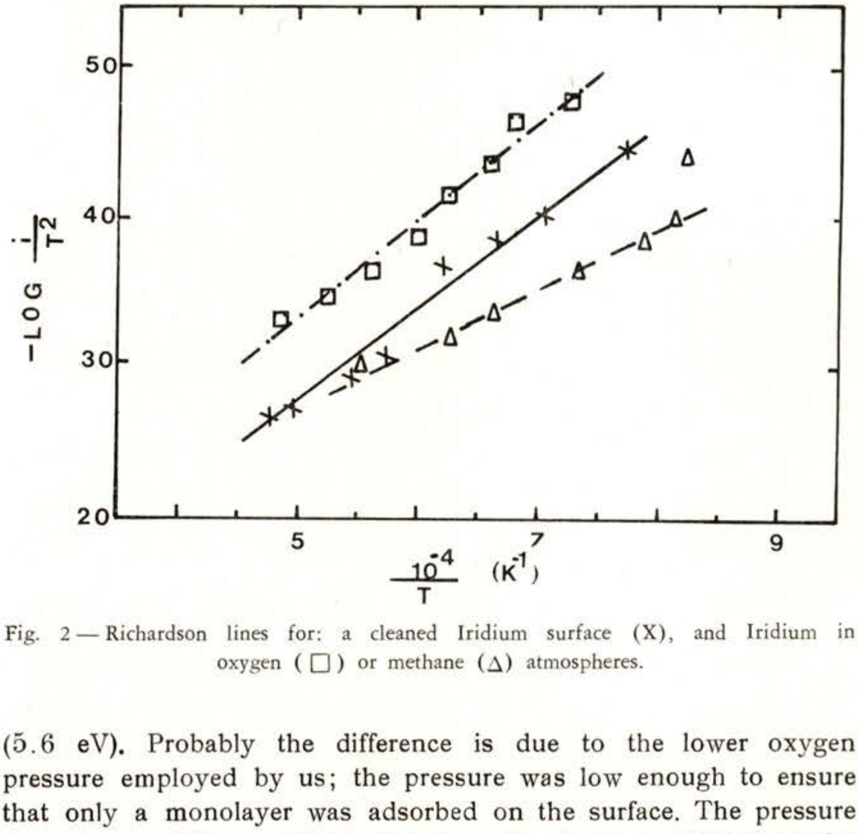

Fig. 2 — Richardson lines for: a cleaned Iridium surface (X), and Iridium in oxygen (□) or methane (Δ) atmospheres.

In the case of methane the work function is strongly dependent upon the temperature (see Fig. 2). The lowering of the work function in the region of 1250 K to 1700 K to approximately 4.4 eV should be noted.

2 — *Ionization of Sodium and Potassium on Iridium*

The typical data for the ionization current vs. temperature for Sodium and Potassium are shown in Fig. 3. The data indicates that the ionization starts at about 1050 K. Comparison between the two curves (Sodium and Potassium) shows that the surface ionization of Sodium is a little more strongly temperature dependent than that of Potassium. This is consistent with Saha-Langmuir equation

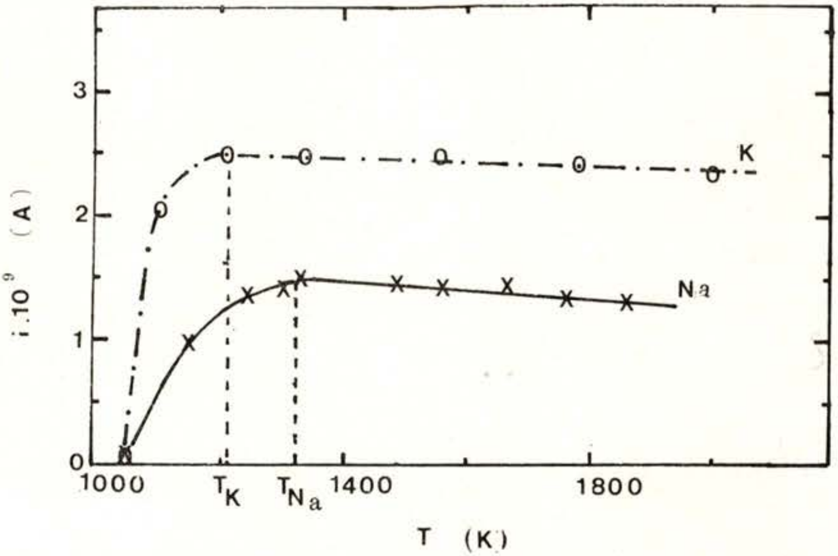

Fig. 3 — Ionization currents for a Sodium (X) and Potassium (O) atomic beams from a cleaned Iridium surface.

$$\beta = \left[1 + 2 \exp \left(\frac{\mathrm{I} - \phi_i}{k \mathrm{T}} \right) \right]^{-1},$$

where β is the coefficient of ionization and I the ionization potential of the incident atoms. From the same Fig. (and from other runs), the temperatures at which maximum ionization takes place for the two atom beams are $T_K = 1200$ K and $T_{Na} = 1320$ K.

The work function of the polycrystalline Iridium for positive surface ionization was calculated by fitting experimental values of $i(T)/i(2200$ K) to the Saha-Langmuir equation. As shown in Fig. 4 we obtain a value of $\phi_i = 5.34 \pm 0.07$ eV for Sodium using this method. For Potassium the method is less accurate and permits only to conclude that $(\phi_i - I) > 0.85$ eV and $\phi_i > 5.25$ eV. These values are qualitatively in agreement with the «patch model» of the positive ionization from a nonhomogeneous surface. In this model the surface is composed of patches each one with its own value of

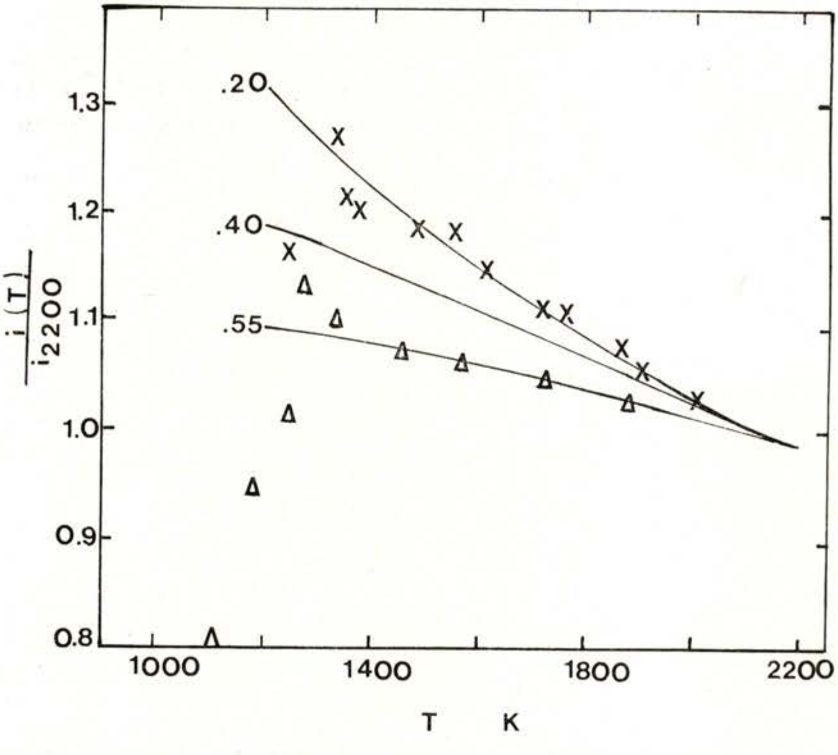

Fig. 4 — Data for Sodium ionization on cleaned Iridium surface (X) and on Iridium with adsorbed oxygen (Δ). Lines represent the theoretical behaviour of i(T)/i(2200 K) for several values of $\phi_i - I$

work function. The effective work function of the whole surface is then the weighted average of the contributions from the individual patches. The patches can be divided into two types: some having work function $\phi_{\min}$ and some $\phi_{\max}$. In the thermal emission of electrons the patches with $\phi_{\min}$ contribute predominantly, therefore $\phi_e \simeq \phi_{\min}$. It follows then that the effective work function for surface ionization ϕ_i lies between ϕ_e, and $\phi_{\max}$, that is, $\phi_e < \phi_i < \phi_{\max}$. From the thermal emission experiment we obtain $\phi_e \approx \phi_{\min} = 5.25$ eV and we verify from surface ionization experiments that ϕ_i lies between this value and $\phi_{\max} = 5.8$ eV measured for the (1,1,1) surface [8] and confirmed by others [9], [10].

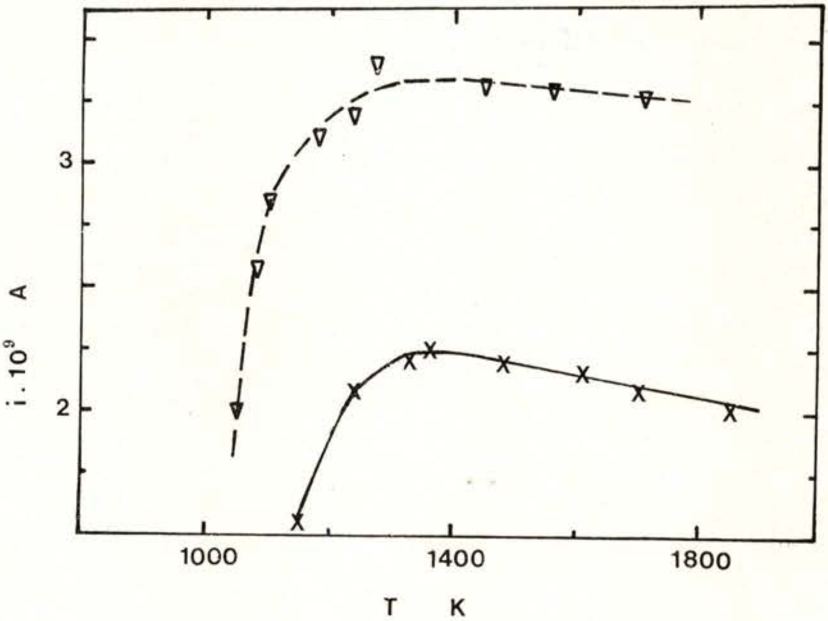

Fig. 5 — Ionization currents for Na: cleaned Iridium surface (X), Iridium in the presence of oxygen (▽).

From the knowledge of the effective work function we can estimate that the coefficient of ionization β maximises (100 %) for Potassium in the region of 1200 to 1500 K, and takes the value of about 80 % for Sodium at 1300 K.

3 — *Effect of oxygen and methane adsorption*

Adsorption of oxygen raises the ionization coefficient in the case of Sodium to approximately 100% (see Fig. 5), while results on Potassium are unaffected. The method described before gives the value of the work function as $\simeq 5.7$ eV for Iridium in oxygen atmosphere.

Methane has the effect of lowering the coefficient of ionization. For example, at 1250 K, the ionization of potassium decreases to 55%, and the ionization of Sodium is negligible. From the calculations on the work function in the case of Potassium, in the presence of methane, it was not possible to obtain an accurate value but only to ascertain that it lies between 4.5 and 4.7 eV.

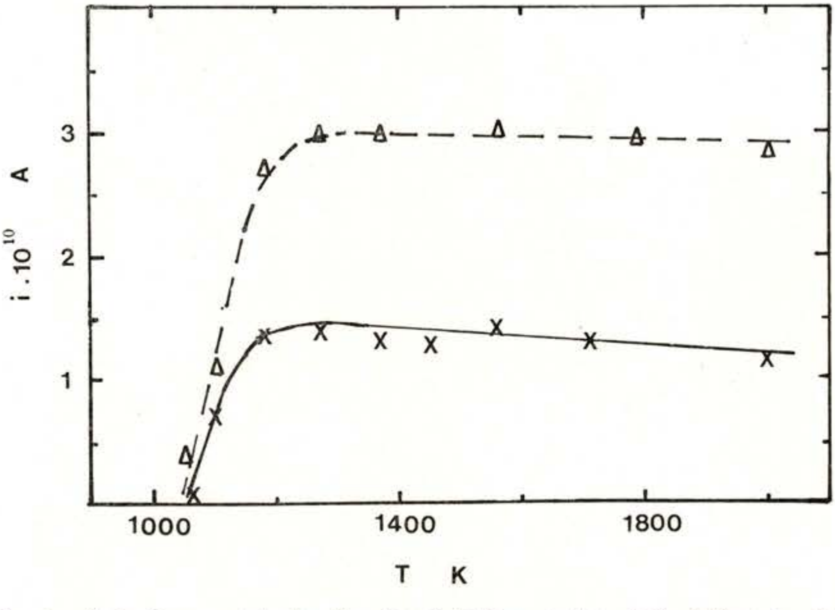

Fig. 6 — Ionization currents for K: cleaned Iridium surface (Δ), Iridium in the presence of methane (X).

The values of the work function in the presence of oxygen and methane are higher than those obtained from the thermal emission of electrons in identical conditions. This agrees with the patch model.

CONCLUDING REMARKS

From our experiments we observe that the work function is extremely sensitive to the presence of oxygen and methane. This points towards a good adsorption of these gases on the Iridium surface.

Globally, from the results obtained we can conclude that Iridium wire or Iridium wire covered with oxygen may be used as 100% eficiency detectors for Potassium and Sodium atomic beams respectively.

The financial support of INIC is gratefully acknowledged. The authors would like to thank Dr. M. Maneira and Eng. Isidro Pedro for cooperation in measurements; their help is gratefully recognised.

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