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Influence of Oxygen on the Surface Ionization of Europium on Tungsten

Wpływ adsorpcji tlenu na jonizację powierzchniową europu na wolframie

Влияние кислорода на поверхностную ионизацию европия на вольфраме

INTRODUCTION

Surface ionization of europium on polycrystalline tungsten was investigated by using the Nier type mass spectrometer. Work function of polycrystalline tungsten was determined as a function of temperature on the basis of temperature dependencies of the ionization coefficient of europium. A special source of ions was used in which the rate of evaporation of the sample could be regulated independently of the temperature of the ionizing electrode. An additional oxygen dosing system was attached to the source of ions in order to investigate the influence of oxygen adsorption on the work function of tungsten.

It was observed that the presence of oxygen significantly increased the intensity of the ion current emitted by surface ionization sources.

The effect was observed when the temperature of the ion source anode was relatively low.

The obtained results may be useful in mass spectrometry and electromagnetic separation of isotopes.

APPARATUS AND METHOD OF MEASUREMENT

In the spectrometer used in our investigation a deviation angle was 90 degrees and resolving power $\frac{M}{\Delta M} = 300$. The pressure of residual gases was $27 \mu\text{Pa}$ ($2 \cdot 10^{-7}$ torrs). The temperature of the ionizing surface was measured by an optical pyrometer with ± 20 K precision. The temperatures varied from 1500 to 2850 K and oxygen pressure ranged from $1330 \mu\text{Pa}$ to $133 \mu\text{Pa}$ (10^{-5} to 10^{-6} torrs).

The europium atom stream of $10^{10} \text{ cm}^{-2} \text{ sek}^{-1}$ emitted from the evaporator was a result of dissociation of Eu_2O_3 at 1500 K. The stream was then directed through a slit in a tungsten cylinder to the surface of the tungsten ionizer (Fig. 1).

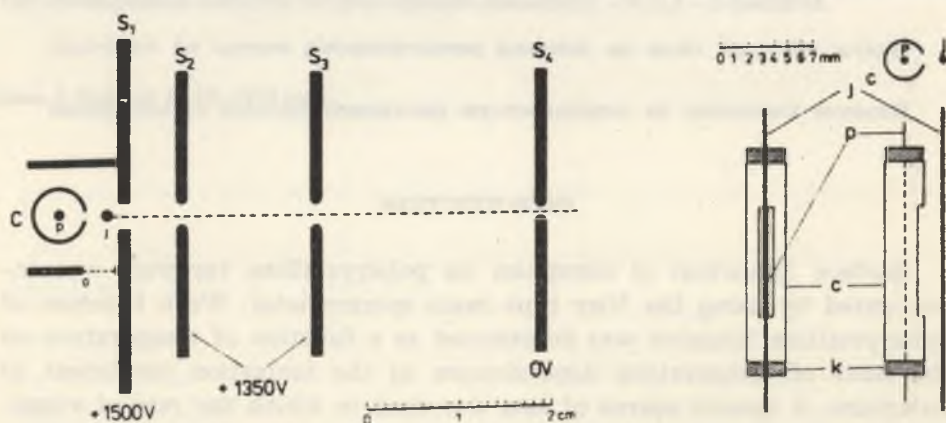


Fig. 1. Diagram of mass spectrometer ion source; C — tungsten cylinder, P — evaporator-tungsten wire $\Phi = 0.1$ mm covered with Eu_2O_3 , J — ionizer-tungsten band $10 \text{ mm} \times 1 \text{ mm} \times 0.02 \text{ mm}$, O — window for temperature measurements, S_1 — shield slit, S_2 , S_3 — focusing slits, S_4 — ion source outlet slit, K — quartz insulators

The ion current intensity was measured by a DC electrometer with output digital voltmeter.

The surface ionization phenomenon is described by the Langmuir equation [1, 2]. This equation expresses the dependence of the so-called ionization degree α on surface temperature T , work function $e\phi$ and

ionization potential of atoms V : $\alpha = \frac{n^+}{n^0}$

$$\alpha = \frac{g^+}{g^0} \exp \left[- \frac{e(V - \phi)}{kT} \right] \quad (1)$$

The following symbols are used in eq. (1):

- n^+ — number of ions emitted per unit time,
 n^0 — number of neutral particles evaporated per unit time,
 g^+/g^0 — ratio of the statistical weights of the ionic and atomic states,
 $e\varphi$ — work function of the surface,
 V — ionization potential of the element,
 k — Boltzmann's constant,
 e — electron charge.

Another parameter is often included in a description of this phenomenon — the so-called ionization coefficient β :

$$\beta = \frac{n^+}{n^+ + n^0}, \quad \beta = \frac{a}{1+a}$$

The inequality $V > \varphi$ applies to most elements (europium including) ionized on the surface of tungsten. In such case the ionization degree is small $a \ll 1$. As a result $a \approx \beta$.

Thus, the ion current intensity is: $i = n^+ e = n \beta e \approx n a e$,

$$i = n e \frac{g^+}{g^0} \exp \left[- \frac{e(V - \varphi)}{kT} \right] \quad (2)$$

From equation (2) follows that the logarithm of the ion current is a linear function of the reciprocal of temperature, with a slope of $-\frac{e(V - \varphi)}{k}$:

$$\ln (i/a) = - \frac{e(V - \varphi)}{k} 1/T, \quad a = n e \frac{g^+}{g^0} \quad (2.1)$$

If eV and $e\varphi$ are expressed in electronvolts and numerical values are substituted for e and k then:

$$\ln (i/a) = - \frac{11\,600}{T} (V - \varphi) \quad (2.2)$$

An increase of work function resulting from the adsorption of oxygen will cause an increase of the ion current.

If in case of the clean surface of the ionizer intensity

$$i_0 = a \exp \left[- \frac{e(V - \varphi)}{kT} \right], \quad \text{in case of adsorption } i = a \exp \left\{ - \frac{e[V - (\varphi + \Delta\varphi)]}{kT} \right\}$$

From both equations we can calculate $\Delta\varphi = \frac{\ln \left[\frac{i}{i_0} \right]}{\frac{11\,600}{T}}$ (3)

THE RESULTS

Figure 2 represents the dependence of the logarithm of ion current Eu^{153} on temperature, with oxygen pressure $270 \mu\text{Pa}$ ($2 \cdot 10^{-6}$ Tr). For temperature $T > 2400$ K this function is linear, which means that work function has a stable value $e\varphi = 4.50$ eV. When the temperature is lowered, the function reaches its minimum value at 2260 K, and its high maximum at 1800 K. When the temperature is further lowered, the ion current decreases.

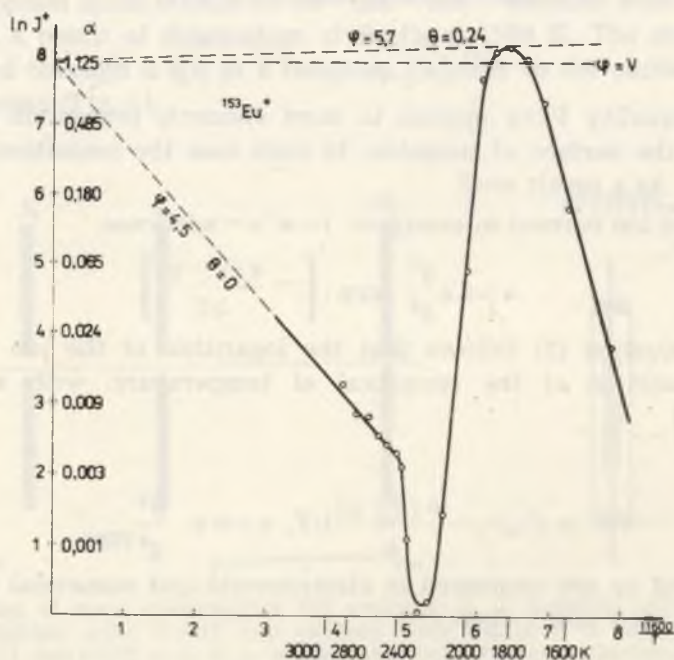


Fig. 2. Dependence of logarithm of ion current of Eu-153 on reciprocal temperature (i-picoamperes)

Figure 3 presents calculated values of work function of polycrystalline tungsten.

An increase of work function at $T = 1800$ K is $e\Delta\varphi = 1.19$ eV, while a decrease at $T = 2260$ K is $e\Delta\varphi = 0.38$ eV. For $T > 2400$ K, mean work function has a stable value $e\varphi = 4.50 \pm 0.20$ eV.

Work function at different oxygen pressures and a stable temperature of ionizer $T = 1800$ K was also measured (Fig. 4).

If oxygen pressure, heat of desorption and coefficient of reflection of oxygen molecules are known, it is possible to calculate an average

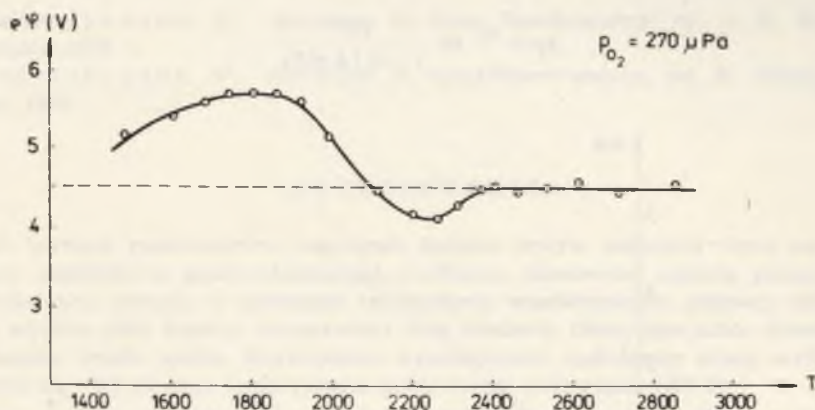


Fig. 3. Dependence of work function on temperature with oxygen pressure 270 μPa ($2 \cdot 10^{-6}$ Tr)

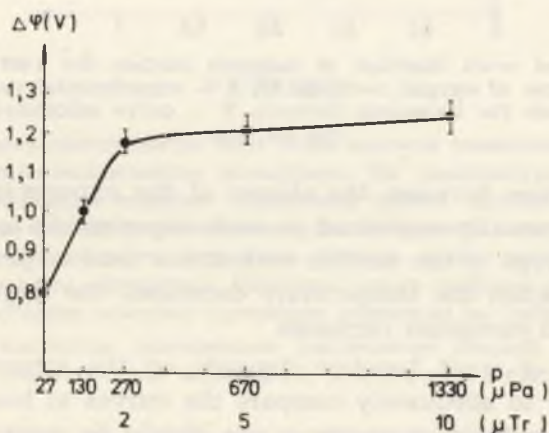


Fig. 4. Change of work function as a function of oxygen pressure

coverage of tungsten surface with oxygen at different temperatures of the ionizer [3]. This method was used to calculate the dependence of work function on the degree of coverage (represented by θ).

The values $\Delta\phi$ obtained from the Langmuir linear formula $\Delta\phi = \frac{\mu_0 \sigma_1}{\epsilon_0} \theta$ where μ_0 is the dipole moment of the individual dipoles (oxygen atoms), σ_1 — tungsten surface density, ϵ_0 — the dielectric constant of free space ($\mu_0 = 2.906 \cdot 10^{-30} C \cdot m$, $\sigma_1 = 1.45 \cdot 10^{19} m^{-2}$, $\epsilon_0 = 8.85 \cdot 10^{-12} F \cdot m^{-1}$), and from the Topping formula, which takes into consideration the depolarization effect of dipole moments, are also included in Fig. 5. According to the Topping formula:

$$\Delta\varphi = \frac{\sigma_1}{\varepsilon_0} \Theta \frac{\mu_0}{1 + 0.14 \Theta^{3/2}}$$

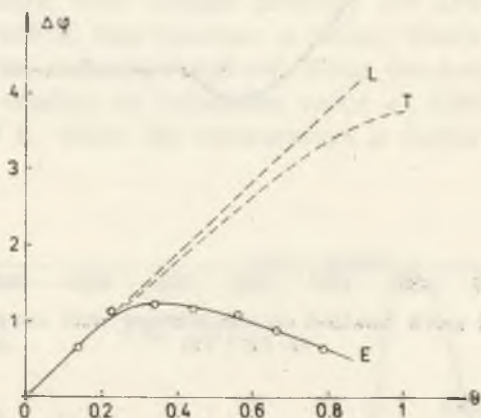


Fig. 5. Increase of work function of tungsten surface for $1480 \leq T \leq 2110$ K as a function of degree of oxygen coverage Θ ; E — experimental curve, L — straight line calculated from the Langmuir formula, T — curve calculated from the Topping formula

The differences between the shapes of the experimental and Topping curves are usually explained in such experiments as a result of an additional coverage of the surface with atoms used to probe this surface [4, 5]. Indeed, when the temperature decreases, the degree of coverage of tungsten with europium increases.

A decrease of work function depends on the stream of europium atoms. In order to adequately compare the curves at low temperatures, very small currents of europium atoms should be used.

Surface ionization efficiency of different elements decreases when an ionization potential of atoms increases, and it increases when surface work function also increases.

Our experiments point to a possibility of an effective ionization of atoms of different elements with high ionization potentials on oxidized surfaces of tungsten at $T \leq 1800$ K.

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STRESZCZENIE

Za pomocą spektrometru masowego badano wpływ adsorpcji tlenu na pracę wyjścia elektronu z polikrystalicznego wolframu. Stosowano metodę jonizacji powierzchniowej europu. Z zależności termicznych współczynnika jonizacji określano pracę wyjścia jako funkcję temperatury oraz ciśnienia tlenu, specjalnie dozowanego do obszaru źródła jonów. Stwierdzono występowanie maksimum pracy wyjścia na poziomie $e\phi = 5,7$ eV przy temperaturze powierzchni jonizującej 1800 K.

Ten znaczny wzrost pracy wyjścia elektronów z anody wolframowej źródła jonów umożliwi stosowanie tego typu źródeł do uzyskiwania przydatnych w spektrometrii masowej wiązek jonów nawet dla pierwiastków o wysokim potencjale jonizacji.

РЕЗЮМЕ

С помощью масс-спектрометра типа Нира изучена поверхностная ионизация европия на поликристаллическом вольфраме. Из температурной зависимости коэффициента ионизации европия определена работа выхода поликристаллического вольфрама как функция температуры. Использован специальный источник ионов, в котором скорость испарения образца может регулироваться независимо от температуры ионизатора. Источник ионов снабжен системой напуска кислорода для изучения влияния адсорбции кислорода на работу выхода.

Присутствие кислорода значительно увеличивает ионный ток полученный из источников с поверхностной ионизацией, работающих в сравнительно низкой температуре.

Результаты измерений важны для практики масс-спектрометрии и электромагнитной сепарации изотопов.

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