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THERMAL EMISSION PROPERTIES OF Re-C THIN FILM SYSTEMS

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Abstract. The homogeneity of rhenium (Re) by work function has been investigated and some thermal emission constants were determined based on the changes on thermoelectric current and surface-ionization current of CsCl molecules, as well as In atoms. It was determined that, the Richardson constant of (Re-C) system did not change during transferring from pure surface of rhenium (Re) to thin film system as it was observed for another metal-film systems. Temperature dependences of various physical parameters were obtained and the mechanism of temperature dependence of these parameters was determined.

Keywords: *Thermal emission, thin films, Richardson constant.*

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1. Introduction

Recently, carbon based materials are considered one of the interesting research objects due to new physical properties (Suresh & Bandosz, 2018; Chavhan & Ganguly, 2019; Osman *et al*., 2020). It was determined that, in materials consisted of carbon atoms, different measurement effects, unique physical phenomena such as superconductivity is observed depending on the size (Rostamabadi *et al.*, 2019; Wang *et al.*, 2015; Yeoh *et al.*, 2007). Therefore nanotubes based on carbon as well as graphene is widely investigated.

To recrystallize polycrystalline tapes or wires is usually used AC heating method at high temperatures. It is known that in high vacuum, during prolonged heating, polycrystalline tapes of W, Rh, Ir, and other refractory transition metals turned into single-crystal samples (Fomenko, 1981). In (Zandberg & Tontogode, 1970) shown that a polycrystalline iridium tape with dimensions of 50×1×0.03 mm during heating using alternating current ($T\approx$ 2000 K) for t = 20 hours, it is recrystallized and a close-packed (111) material with a output work function of 5.8 eV is obtained. It was shown in (Fomenko, 1981) that during long heating time of polly crystalline volfram tape, a (100) face is formed with a work function of 4.50 eV.

It is know that it is possible to obtain effective cathodes with low output work function value, during Cs, Ba, Thetc. atoms thin film growing on the surface of metals. Usually, transition metals are used as substrate. Therefore, in high vacuum and in high temperature the surface of these metals are purified from absorbed particles. Then on the clean surface of metal is deposited the necessary atoms of Ba, Cs and etc.

The degree of homogeneity is associated with phase transition during absorption of atoms on the surface. Investigation of the dependence of the work function of metal-film systems on surface coatings for Sm, Ba, etc. no two-dimensional phase transition is

observed. However for the Mo-C, Ir-C, Pt-C as well as for another systems, it is observed two dimensional first order phase transition. A monolayer film is obtained on the surface of molybdenum after the formation of molybdenum carbide. It is clear from the above mentioned that, the main goal of the emission electronics is to obtain effective emitters with small value of output work function. For this purpose, in this research work emission properties of Rhenium and Rhenium with carbon surface were investigated.

2. Methods

The analysis of work function was investigated by thermo electron emission (TEE) and surface ionization (SI) methods. For the same mosaic surface, the output work function determined by the TEE and the PI is different. Studying thermo electron emission and surface ionization of difficult ionized elements in compensation "spot" field conditions the same time, it is possible to determine the value of practical emitter contrast over output work function $\Delta\varphi = \varphi_{max} - \varphi_{min}$. Under the conditions of the compensated contact field of "spots", the electron current mainly flows from those surface areas where the work function is minimal and expressed by

$$I = A_p^* S T^2 exp\left[\frac{-e\varphi_G^*}{kT}\right], \quad (1)$$

where

$$A_p^* = \frac{1}{S}\sum A_{pi}\, exp\left[\frac{-e(\varphi_i - \varphi_G)}{kT}\right] \quad (2)$$

A_p, S_i,φ_i -respectively the constant of Richardson, surface area and output work function, i - step, T - temperature of emitter, S - the total area of emitter , φ_G^*- effective or electronically averaged output work function.

$$\varphi_G^* = \sum \frac{\varphi_i^* I_i}{I} \quad (3)$$

After compensation of contact field "spot", this output work function can be determined from the slope of the dependency of $ln(I^-/T^2)$ on 1/T. In the case of compensation of the contact field, the ion current during PI according to (Zandberg & Tontogode, 1970) is determined by the formula

$$I^+ = evSB^* exp\left[\frac{e(\varphi_i^* - V + \sqrt{eE})}{kT}\right], \quad (4)$$

where

$$B^* = \frac{B}{S}\sum S_i exp\left[\frac{e(\varphi_i - \varphi_i^*)}{kT}\right] \quad (5)$$

v – atom flow falling on the surface of S area, $B^* = Q_+/Q_0$ the ratio of the sum of ion and atom states, S_i - area of "spot" with output work function φ_i, E – electric field of accelerating positive ions, T - Emitter temperature φ_i^* - effective or averaged output work function based on ion current

$$\varphi_i^* = \frac{1}{I^+}\sum \varphi_i I_i^+ \quad (6)$$

When contact field "spot" is compensated, so and a hard ionizing element will be selected from the "spots" with maximum work function. Therefore from (4) and (6), at $\varphi_i^* \cong \varphi_{max}$, the value of φ_i^* can be experimentally determined from tangens of angle of inclination of the dependence of the logarithm $lgI^+$of the ion current on 1⁄T. Thus, by studying the work function of the surface by the method of TEE and PI, we can

determine the contrast of the surface by the work function$\Delta\varphi = \varphi_I^* - \varphi_Э^* \cong \varphi_{max} - \varphi_{min}$. For homegenioussufaces on output work function $-\varphi_Э^* = \varphi_I^*$and $\Delta\varphi = 0$.

Beside TEE and PI methods for analysis of surfaces depending on output work function, was carried out qualitative – Electron Shotki effect metod. According to this method, if the surface is not homogeneous depending on output work function with increasing accelerating voltage, the electrical current increase and in the case of homogenous surface the current of TEE practically does not depend on the voltage outside of charge region.

3. Experimental results and discussion

Experiments were carried out in a high vacuum mass spectroscopy equipment a detail description of which is shown in (Fomenko, 1981).

Rhenium tape with 50×1×0.02 mm sizes firstly was polycristallic which explains with the presence of anomal Shotki effect. For obtaining homogeneous Re depending on output work function, the tape was firstly recrystallized on alternative current ($T \approx$ 2200-2500 K) during t = 30 hour. The experimental results showed that , the process of recrystillization leades to the reduction of anomal Shotky effect, which shows the increasement of output work function of Rhenium tape. After the disappearance of anomal Shotky effect, the dependence of electronic current on the tape temperature was removed. The relation of lg$lg\, I^-/T^2$ from 5400/T was show in Fig.1.

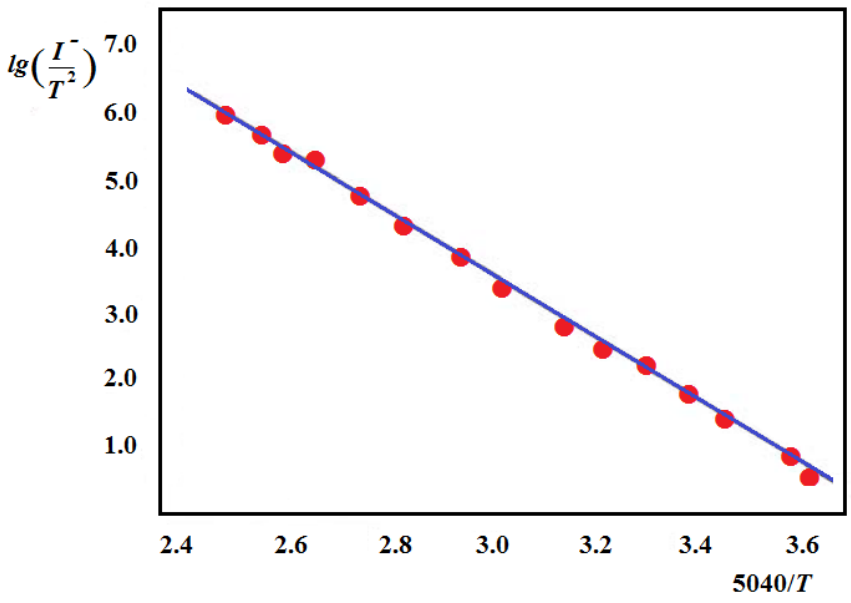

Fig. 1. The Richardson plot for the face (10$\bar{1}$0) of pure Rhenium

From the slope of the line the output work function was determined- $e\varphi_E$= 5.10±0.10 eV. Then, for the same tape, the output work function was determined by the PI of the hard-ionized element In. In ($V>\varphi$) case, the current of PI expressed by

$$I^+ = evS\frac{Q_+}{Q_0}exp\left[\frac{-e(V-\varphi_i)}{kT}\right], \quad (7)$$

Hence,

$$lgI^{+} = C - \frac{5040}{T}(V - \varphi_1) \quad (8)$$

$C = lg(evS\frac{Q_+}{Q_0})$ is the constant. Measuring the dependency of I_{In}^{+} from the temperature of the tape, we plotted the chart of lgI_{In}^{+} from 5040/T which was shown in Fig.2. Knowing the ionization potential of In atoms (V = 5.785 eV), from the slope of this dependence, we obtained that $e\varphi_i^*$= 5.00 ± 0.05 eV.

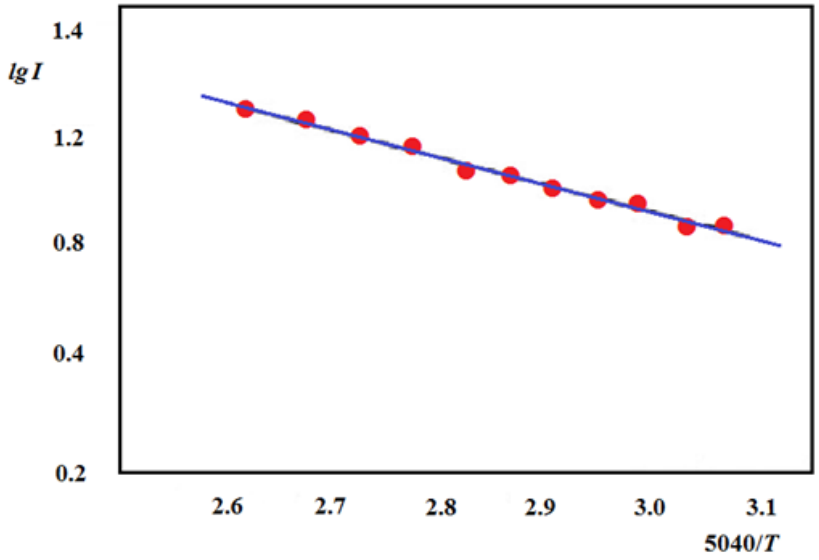

Fig. 2. Plot of the lgI_{In}^{+} from 5040/T dependency

It can be seen that the obtained values $e\varphi_E$and $e\varphi_I$are equal, it means the contrast is equal to zero. These values of output work function is suitable to densely packer face (10$\bar{1}$0) of Rhenium and consistent with another research results. The properties of graphite film were publicated in earlier research works, in this paper we considered some emission parameters of Re(10$\bar{1}$0) -C thin film system. Usually for determination output work function of metal – film systems it is suggested that the constant of Richardson does not change and in the same experimental conditions expressed by formula (9)

$$e\varphi = e\varphi_0 - kTln\frac{I}{I_0} \quad (9)$$

here $e\varphi_0$, I_0– output work function and current TEE for pure metall, $e\varphi$, I^{-}– these values are for metall-film systems. It is clear from this, for the output work function of the Re (100) with a graphite monolayer is $e\varphi$= 4.40 eV as well as the output work function determined by method of linear Richardson of Re(10$\bar{1}$0)-C system is 4.40 eV. It can be seen that the output work function of Re(10$\bar{1}$0)-C systems determined by (9), significantly differ from the output work function determined by linear Richardson method. This discrepancy is explained by us with a change of Richardson constant in transition from the face of Re(10$\bar{1}$0) to face Re(10$\bar{1}$0) with monolayer of graphite. Therefore, for such metal-film systems, when determining the output work function or its change by the formula of (9) and the method of total current, it is not possible to neglect the ratio of the Richardson constants A/A_0. Taking this into account we obtain the formula:

$$e\varphi = e\varphi_0 - kTln\left(\frac{I}{I_0}\cdot\frac{A_0}{A}\right). \quad (10)$$

For determination the ratio of the Richardson constants A/A_0, we were used the chart of dependency $lg(\frac{I^-}{T^2})$ from 5040/T for $(10\bar{1}0)$ face of Rhenium with monolayer of graphite (Fig. 3). The intersection of the Richardson experimental line with the ordinate axis is usually taken as the logarithm of the Richardson constant. In our opinion, this approach is wrong. It is possible only in the case, if the TEE current is measured from the entire emitting surface, i.e. if measured by the total current method. In these cases, when it is impossible to apply the method of full current, then it is possible to determine the ratio of Richardson constants A/A_0 using the linears of Richardson in the same experimental conditions. In this case, the constant values which include this expression, in both cases are decreased. Using this, from the linears of Richardson on the same temperatures for the ratio of Richardson we obtain the value of A/A_0~ 1.2. For metal emitters the value of A_0changes in the wide range (Fomenko, 1981). Using the value of A_0=(160±40) А/см^2·grad^2 for A we obtain ~133 А/см^2·grad^2. We should note that, the obtained values of A/A_0in $T = \infty$ is also coincide with this value, despite the fact that at high temperatures the sample is non determined.

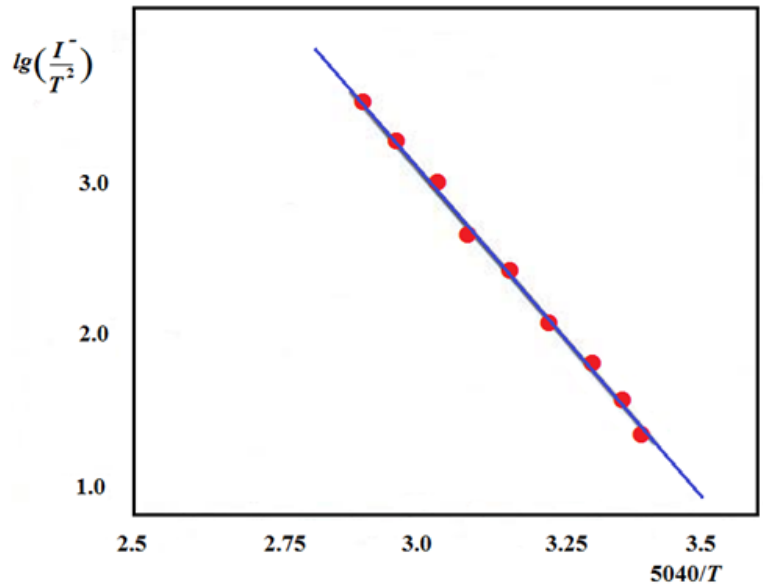

Fig. 3. The plot of Richardson for the $(10\bar{1}0)$ face of Rhenium with monolayer of graphite

In the 1400 K ≤ T ≤ 1800 K temperature range we obtained $e\varphi(T)$ and from comparison of Richardson output work function at T = 0 K, $e\varphi_p$= 4.5 eV, we determined temperature coefficient of output work function of $(10\bar{1}0)$ of Re with monolayer of graphite by formula

$$\alpha = \frac{\varphi(T)-\varphi_p(0)}{T} \qquad (11)$$

it was determined that the value of $\alpha = (1.95\pm0.10)\cdot10^{-4}$ V/K.

4. Conclusion

From the temperature dependence of the PI current of indium atoms on the $(10\bar{1}0)$ Re face, the temperature coefficient of the work function of the $(10\bar{1}0)$ Re face was estimated. In the wide temperature range 1400 K ≤ T ≤ 2300 K, the surface ionization

current of indium I^+ was not depend on temperature, which indicates about small value of temperature coeficient of output work function of Rhenium face $(10\bar{1}0)$. Assuming that the error in measuring the current of PI of In ions is about 1% of the measured current value, we estimated the temperature coefficient of the work function of the $(10\bar{1}0)$ rhenium face. Assuming that with increasing temperature the work function of the (100) rhenium face increases, from the expression of the currents at T = 1400 K and T = 2300 K, we estimated the temperature coefficient of the output work function of the (100) rhenium face and obtained $\alpha \approx 3 \cdot 10^{-6}$ V/K value. Therefore, we can assume that the temperature coefficient of the work function of the $(10\bar{1}0)$ rhenium face is $\alpha \leq 10^{-5}$ V/K and it is approximately one order less than for the $(10\bar{1}0)$ Re face with a graphite monolayer.

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