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Diffusion Mode of Arc Plasma under Atmospheric Pressure

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Abstract

The importance of the research is represented in the manufacture of lighting lamps by selecting the ideal cathode quality for these lamps.

To investigate how argon gas affects the arc flow plasma properties, various cathodes were used in this study, including hafnium (Hf), niobium (Nb), tungsten (W), and molybdenum (Mo). The cathode's surface temperature and the ion current were investigated in relation to temperature and voltage. Data from simulations and theoretical computations were provided. The program has helped this work (THERMOCAD).

Regarding the distribution of temperatures at various distances from the center, we observe that for all metals, the highest temperature and electron density are found at the radius (r=0.001mm), and that temperatures drop as one gets closer to the center. Recombination (electrons and ions) as a result of electron energy loss from collisions is what accounts for the variance in the distribution of the cathode metals.

As we took measurements, we observed that the cathode metal's edge temperature was higher than its center temperature, due to the ionization process of the argon gas, which leads to the gathering of argon ions at the edge, and thus causes the temperature of the cathode center to decrease and the cathode edge to increase.

The aim of the research is to manufacture high brightness lamps by the quality of the cathode material.

Keywords: Arc Discharge, Gas Discharge, Surface of Cathode

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وضع انتشار قوس البلازما تحت الضغط الجوي

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المستخلص

تتمثل اهمية البحث في صناعة مصابيح الاضاءة من خلال اختيار نوعية الكاثود المثالي لهذه المصابيح.

لاستكشاف كيفية تأثير غاز الأرجون على خصائص بلازما تدفق القوس ، تم استخدام كاثودات مختلفة في هذه الدراسة ، بما في ذلك الهافنيوم (Hf) والنيوبيوم (Nb) والتنغستن (W) والموليبدينوم (Mo). تم فحص درجة حرارة سطح الكاثود والتيار الأيوني بالنسبة لدرجة الحرارة والجهد. تم توفير بيانات من عمليات المحاكاة والحسابات النظرية. وقد ساعد البرنامج هذا العمل (THERMOCAD).

فيما يتعلق بتوزيع درجات الحرارة على مسافات مختلفة من المركز ، نلاحظ أنه بالنسبة لجميع المعادن ، توجد أعلى درجة حرارة وكثافة إلكترونية عند نصف القطر (r = 0.001mm) ، وأن درجات الحرارة تنخفض كلما اقترب المرء من المركز. إعادة التركيب (الإلكترونات والأيونات) نتيجة فقدان طاقة الإلكترون من الاصطدامات هو ما يفسر التباين في توزيع معادن الكاثود.

أثناء إجراء القياسات ، لاحظنا أن درجة حرارة حافة معدن الكاثود كانت أعلى من درجة حرارة مركزه ، بسبب عملية تأين غاز الأرجون ، مما يؤدي إلى تجمع أيونات الأرجون عند الحافة ، وبالتالي يتسبب في درجة حرارة الكاثود مركز لتقليل وحافة الكاثود لزيادة.

الهدف من البحث هو تصنيع مصابيح ذات اضاءة عالية من خلال نوعية مادة الكاثود.

الكلمات المفتاحية : تفريغ القوس ، تفريغ الغاز ، سطح الكاثود

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معلومات البحث
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Introduction

Discharge is created when a non-conductive material, like a gas, is exposed to a strong electric field [1]. This causes the material to break down electrically, increasing the medium's conductivity [2]. The goal of this investigation is to identify key characteristics of gas discharge plasma and models for their description [3]. It is demonstrated that the tau-approximation, which forms the foundation of the gas dynamical plasma model, causes a mistake in the assessment of plasma parameters [4]. For the investigation of gas discharge plasma, the self-consistent nature of atom excitation is crucial depending on plasma properties and the nature of plasma processes, gas discharge plasma can exist in a variety of regimes. Recently, there has been a lot of interest in arc discharge [5]. How to create group plasma related to the electrode regions is the goal of this research, which also takes into account the unique space charge layer (shell) on the cathode [6]. Describe the research done on the properties and composition of metal gas plasma during the vacuum arc evaporation of a molybdenum cathode in the plasma assist mode [7]. This work used uniform one-dimensional modeling to examine the first quarter period following AC arc ignition on cold electrodes in argon at atmospheric pressure, the entire electrode gap up to the electrode surfaces was solved, including the particle energy calculations and Poisson's equation [8]. In terms of applications, it is used for arc lamps, welding, plasma cutting, movie screens, lighting, and other things [1-5]. In this work, we will investigate how the cathode temperature T_w affects the of various cathode metals, including Hafnium (Hf), Niobium (Nb), Tungsten (W), and Molybdenum (Mo), under various conditions, including the use of argon gas Ar, distance between them electrodes (r=0.01m), cathode diameter (D=0.001 m) and pressure (1 atm).

Theoretical part

Through the cathode body's heat conduction equation being solved, it is possible to determine the temperature distribution both within and outside if function $q(T_w, U)$ is known:[9]

$$\boldsymbol{\nabla}.(\boldsymbol{k\nabla T}) = \mathbf{0} \quad (1)$$

The border condition is present

$$\boldsymbol{k}\frac{\partial \boldsymbol{T}}{\partial \boldsymbol{n}} = \boldsymbol{q}(\boldsymbol{T_w}, \boldsymbol{U}) \quad (2)$$

At the area cathode's surface where the arc plasma, cold gas, and boundary condition are in contact. Here, n is a local direction pointed away from the cathode that is orthogonal to its surface:[10]

$$\boldsymbol{T} = \boldsymbol{T_c} \quad (3)$$

The following expression equation describes the energy flux's density, q_p produced by plasma at the surface of the cathode within the context of this model:[11]

$$\boldsymbol{q_p = q_i + q_e - q_{em}} \quad (4)$$

$$\boldsymbol{q_i = J_i\left[ZeU_D + E - ZA_{eff} + k\left(2T_h + \frac{ZT_e}{2} - 2T_w\right)\right]} \quad (5)$$

$$\boldsymbol{q_e = J_e(2kT_e + A_{eff})} \quad (6)$$

$$\boldsymbol{q_{em} = J_{em}(2kT_w + A_{eff})} \quad (7)$$

The energy flux densities given ions and quickly moving plasma electrons are transported to the surface of the cathode, respectively, are denoted here as q_i and q_e. The cathode surface's rate where energy is lost because of thermionic emission is known as q_{em}. J_i, J_e and J_{em} the numerical densities of the corresponding flows; $j_i = ZeJ_i$ is the quantity of ions that deliver a flow of electricity across the cathode's surface; $j_e = eJ_e$ is the quantity of ions that deliver an electric current to the surface of the cathode; $j_{em} = eJ_{em}$ is the density of thermionic emission current; The layer of near-cathode plasma temperatures for ions and neutral atoms as well as electrons are T_h and T_e, respectively; Within the cathode layer Z and E stand for the average ionization energy and quantity of charges on the ions, respectively; U_D the difference in voltage inside of the space-charge sheath; A_{eff} actual work function that was calculated taking the Schottky correction into consideration.is the

It is possible to rewrite equation (5) as: [12]

$$q_i = J_i(ZeU_D + E - ZA_{eff}) + W_i + \left[J_i k\left(2T_h + \frac{ZT_e}{2}\right) - (J_i 2kT_w + W_i)\right] \qquad (8)$$

Thus, equation (8) should have the final term on the right side removed, and the following form has been given to this equation: [13]

$$q_i = J_i(ZeU_D + E - ZA_{eff}) + W_i \qquad (9)$$

The ionization layer's electron energy balance equation is written as follows: [14]

$$j_e = \left(2\frac{kT_e}{e} + U_D\right) + 3.2j\frac{kT_e}{e}J_i E = j_{em}\left(2\frac{kT_w}{e} + U_D\right) + W_e \qquad (10)$$

Here $j = j_i + j_{em} - j_e$ The density of the net electric current leaving the plasma and moving to the surface; W_e is caused by the electric field's impact on the electrons in the ionization layer.

Equation (4) is changed by substituting equations (5, 6) and (9), adding the result to equation (10), and applying the formula $W_e + W_i = jU_i$ one shows up at: [15]

$$q_p = jU - \frac{j}{e}(A_{eff} + 3.2kT_e) \qquad (11)$$

The diffusion approximation's assessment of the ion current density, which was discovered using the formula, is shown by the dashed line: [16]

$$j_i = \left(1 + \frac{T_e}{T_h}\right)\frac{D_{ia} n_{i\infty}}{d} \qquad (12)$$

$n_{i\infty}$ Is the ion number density near the ionization layer's edge (in equilibrium); D_{ia} is the binary diffusion coefficient for ions and atoms, and d length of ionization.

Combining the results of the correlation between the cathode surface area where the arc plasma and cold gas are in touch: [17]

$$IU = Q_c + Q_r + \frac{I}{e}(A^*_{eff} + 3.2kT^*_e) \qquad (13)$$

where

$$Q_c = \int q\, dS \qquad (14)$$

$$Q_r = \int q_r\, dS \qquad (15)$$

$$A^*_{eff} = \frac{1}{I}\int jA_{eff}\, dS \qquad (16)$$

$$T^*_e = \frac{1}{I}\int jT_e\, dS \qquad (17)$$

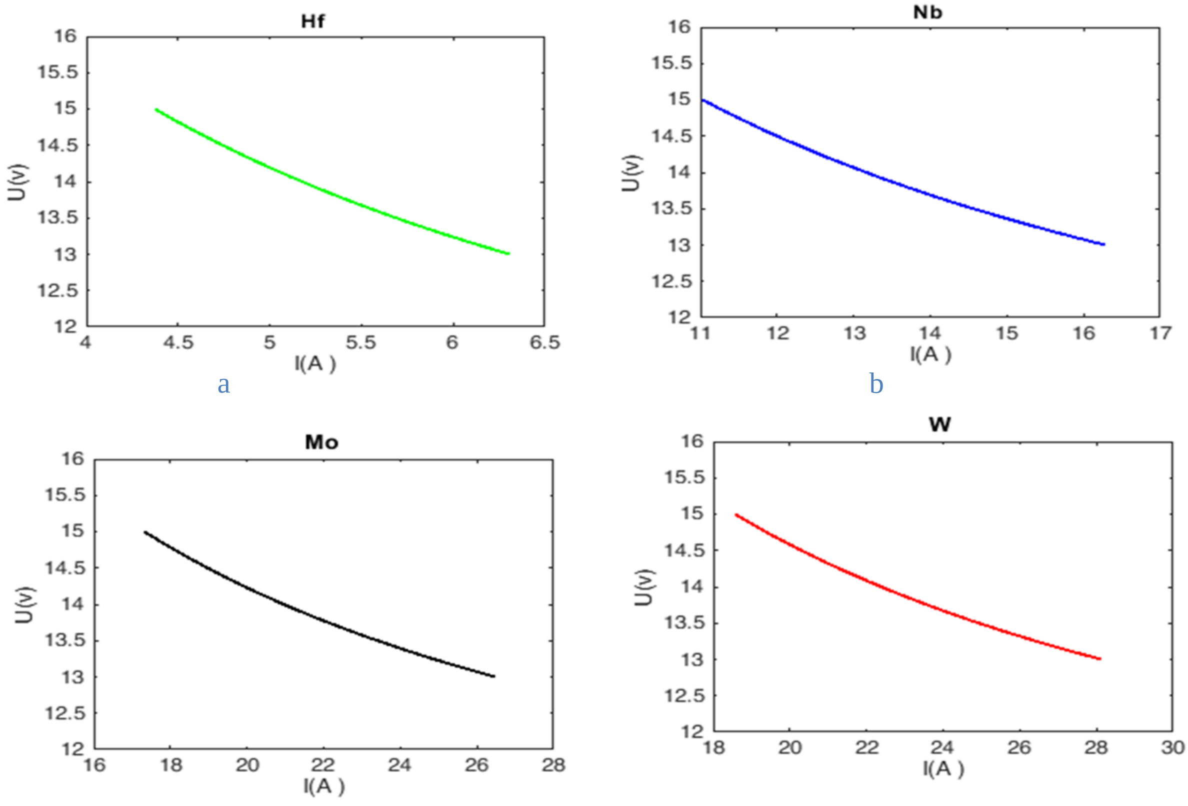
The surface of the cathode area that reaches out to both the cold gas and the arc plasma are covered by the integrals. You should be aware that Q_c reflects the total power lost as a result of heat being transferred from the cathode body's surface to the cooling medium. Power output from the surface of the cathode as a whole is known asQ_r. A^*_{eff} , T^*_e are averaged over weighted values for the electron temperature and the effective work function.

Results and discussion

Figure 1 (a, b, c, and d) show that the values of the current in the diffusion mode are that the metal (Hf) is less than the metal (Nb) and the metal (Nb) is less than the cathodes of other metals (W, Mo) due to the convergence of the work function for each, and that the cause of this is adsorption for (Hf) before (Nb) before (W) and then (Nb) before (W, Mo).

We note from the figure (1-a) the value of the current for (cathode-Hf)starting from (4.4-6.4A) through a potential difference(15-13V) whereas in figure (1-b) we notice an increase in the value of the current (cathode-Nb) from (11-16.5A) through a voltage difference (15-13V) while the form (1-c) we notice the growth in the current's value (cathode-Mo) and for the same period of the voltage difference (15-13 V) from (17-27A) while form (1-d) the value of current (cathode-W) rises from (18.5-28A) for the same period of voltage difference (15-13 V).

Where we notice through the diffusion pattern of the plasma that the current value of the cathode is inversely proportional to the work function and the reason for this is adsorption, and this case leads to a higher value of the work function than the original value due to the accumulation of electrons on the surface of the cathode.



c d

Figure (1): Current–voltage characteristics of (Hf, Nb, Mo, and W) cathodes

Figure 2 shows the temperature distribution for various distances from the center (r), where we can see that the highest temperature value is at the radius (r=0.001 mm) for all metals and in the case of approaching the center, the temperatures decrease because the difference in the distribution of the various cathode metals is caused adsorption. As the ions usually tend to the less hot areas and the gathering of ions at the edge of the cathode leads to a rise in the temperature of those areas.

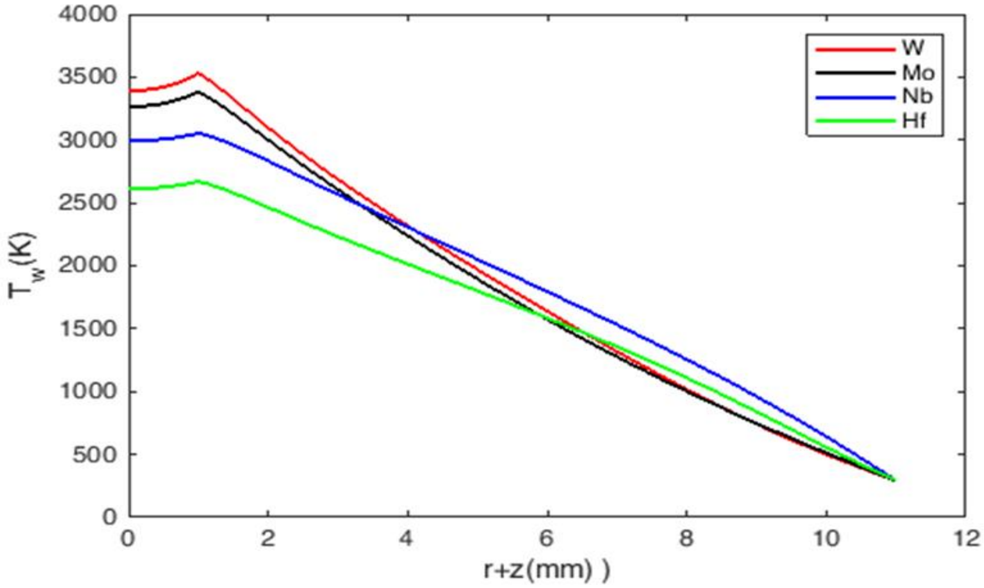


Figure (2): Distribution of temperature of cathode at different distances from the center r

Figure 3 shows the density of electric current distribution at different distances from the center r, is also similar to temperature at the surface distribution, except that the current density (at constant U) is strong the T_w function exhibits a more pronounced contrast along the length the cathode's front surface is decreasing faster along lateral surface. Distribution of cathode temperature with radius (r) due to the transfer of argon ions to the cathode edges. As ions typically gravitate toward cooler regions, the accumulation of ions along the cathode's edge raises the temperature of those regions.

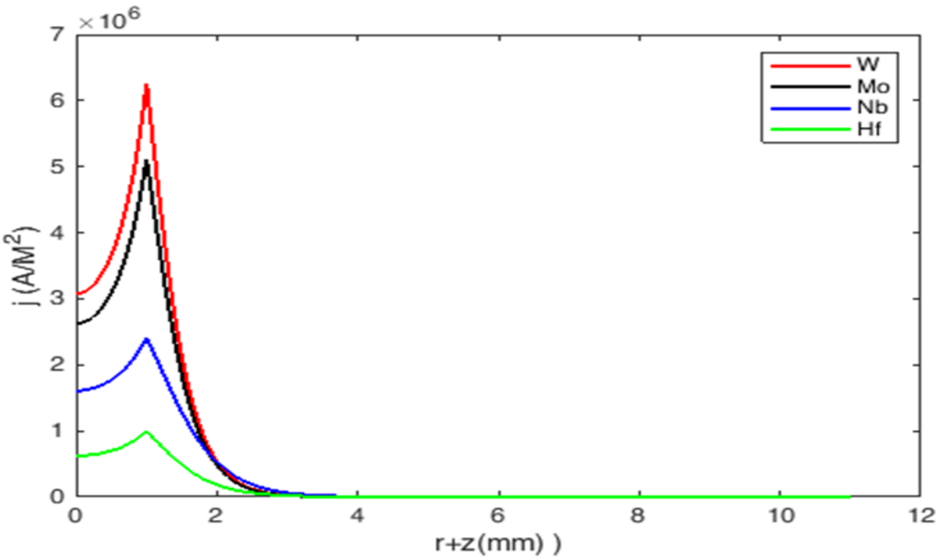


Figure (3): Distribution of electron density of cathode at different distances from the center r

It can be seen from the figure (4, 5, 6 and 7) that the temperature of the cathode metal at the edge is higher than it is in the center. This is because the ionization of the argon gas causes ions to collect at the edge, which raises the cathode's temperature edge while lowering the temperature of the cathode center. The difference in the temperature measurements of the center and the edge is due to adsorption as a result of the collision and the work function .

Where we notice from the figure (4) the current value (cathode-Hf) starts to increase from (4.4-6.4A) with the temperature of the center (2549-2611K) whereas in the figure (5) we notice an increase in the value of the current (cathode-Nb) from (11-16.5A) through a temperature of the center (2913-2993K) while the form (6) we notice the rise in the current's worth(cathode-W) from (18.5-28A) with the temperature of the center(3110-3206K) while form (7) the value of current (cathode-Mo) rises from (17-27A) for the temperature of the center (3165-3264K). This confirms what is in the form (1, 2, and 3) where the edge of the cathode has higher temperatures than the center.

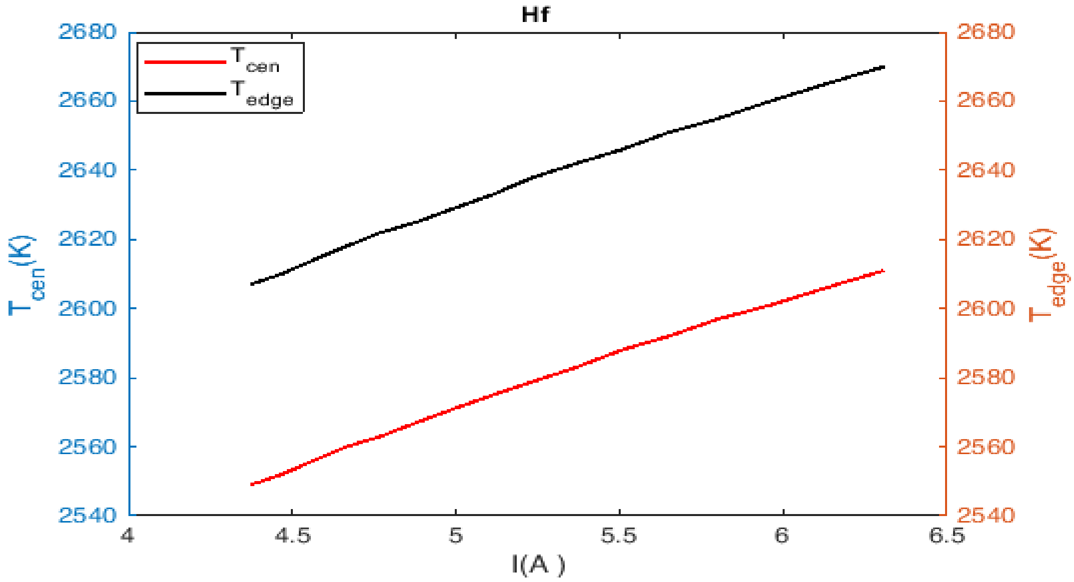


Figure (4): Center temperature-edge temperature characteristics of Hf cathode

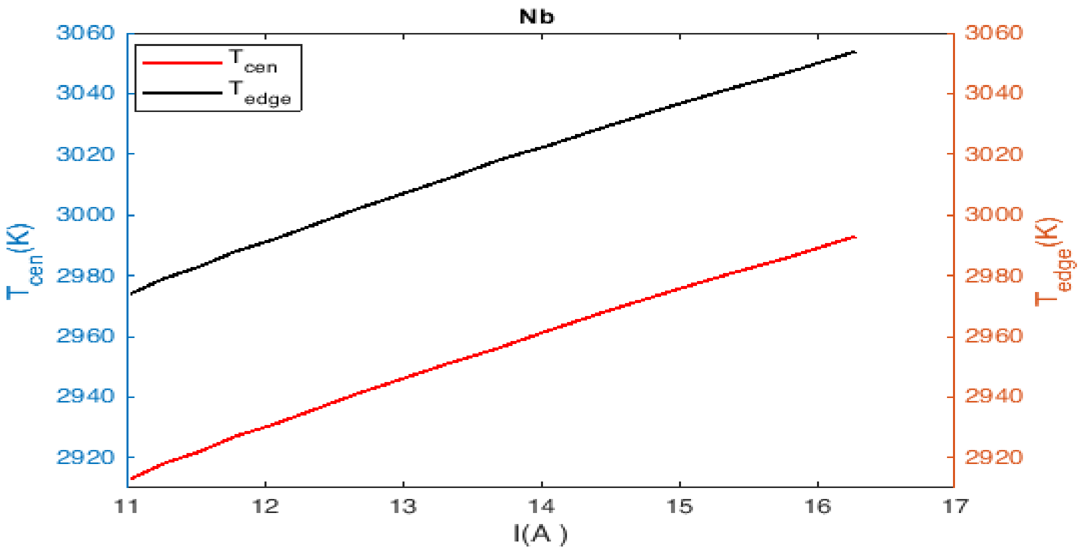


Figure 5: Center temperature-edge temperature characteristics of Nb cathode

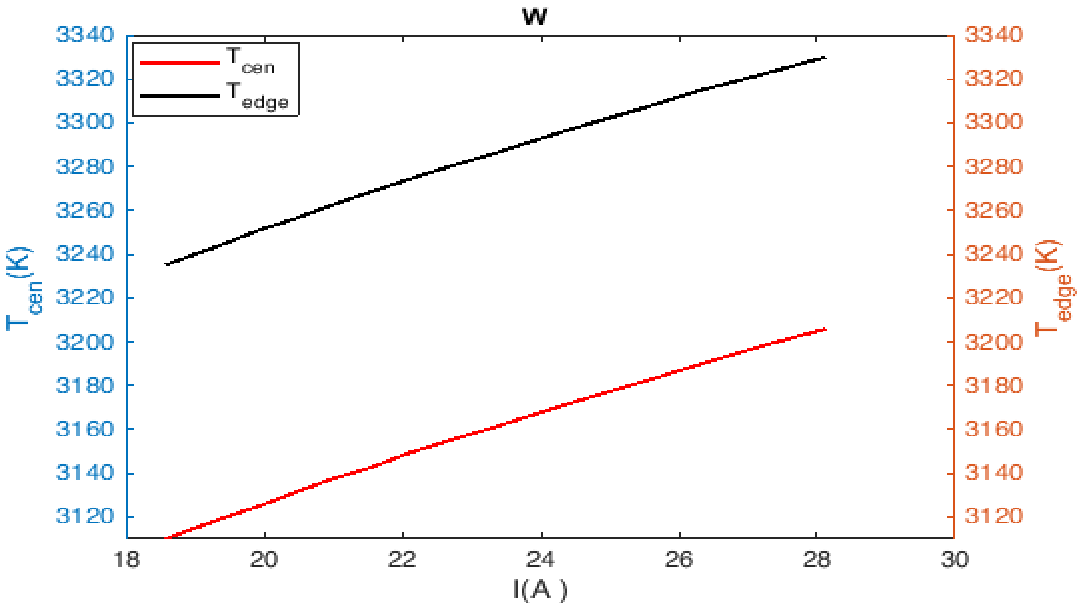


Figure (6): Center temperature-edge temperature characteristics of W cathode

Conclusions

We have concluded that the current values in the case of the diffusion pattern of the metal (Hf) are less than the cathode of other metals, and the reason for this is due adsorption where the process of liberating the electrons collected on the surface of the cathode reduces the emission electrons due to the increase in the work function.

As for the distribution of temperatures at different distances from the center r, we note that the highest value that the temperature and electron density reach is at the radius (r=0.001 mm) for all metals, and when approaching the center, the temperatures decrease. This difference in the distribution of the cathode metals is caused by recombination (electrons and ions) due to loss Electrons energy as a result of collisions.

Through the research, it is clear to us that the ions tend to move towards the less hot areas (the edges), and the accumulation of ions raises the temperature of those areas.

Also, the diffusion state leads to an increase in the value of the work function of the cathode as a result of the accumulation of ions on the surface of the cathode.

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