Effect of concentration and temperature of cathode on arc plasma

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Abstract
the theoretical calculations and simulation data were presented to study the effect of the mixture Xe-Dy to study the effect of voltage concentration and temperature on the energy flux density on the properties of the arc plasma. The energy flux density and cathode temperature were studied. Different concentrations of dysprosium (0.005, 0.01, 0.05, 0.1, 0.5 mol) were used. The (NCBL) program was used in this work. The results showed a clear effect of concentration on plasma parameters, especially at the highest concentration, in addition to the effect of stress. We note that the energy flux density increases from (3500 - 5000 K) for all concentrations due to elastic and inelastic collisions due to the acceleration of electrons with increasing voltage.
Keywords: arc high pressure, flux density, concentration, temperature, voltag

الخلاصة
تم عرض الحسابات النظرية وبيانات المحاكاة على خواص بلازما القوس لدراسة تأثير الخليط Xe–Dy ودراسة تأثير الجهد ودرجة الحرارة على كثافة تدفق الطاقة. تم دراسة كثافة تدفق الطاقة ودرجة حرارة الكاثود. تم استخدام تراكيز مختلفة من الديسبروسيوم (٠.٠٠٥ ، ٠.٠١ ، ٠.٠٥ ، ٠.١ ، ٠.٥ مول). تم استخدام برنامج (NCBL) في هذا العمل. أظهرت النتائج تأثيراً واضحاً للتركيز على معاملات البلازما وخاصة عند أعلى تركيز بالإضافة إلى تأثير الإجهاد. نلاحظ أن كثافة تدفق الطاقة تزداد من (٣٥٠٠ – ٥٠٠٠ كلفن) لجميع التركيزات بسبب التصادمات المرنة وغير المرنة بسبب تسارع الإلكترونات مع زيادة الجهد.

Introduction

the Arc discharge Reverse glow discharge is a self-sustaining DC discharge when high heat is emitted from the cathodes emitting electrons [1]. When the surrounding gas insulator collapses, an arc discharge causes in a continuous discharge that leads to the flow of a current in a non-conductive medium [2]. Usually in arc discharge halides are used with gases in applications where the halides are the ionic forms of halogens. They are formed when the halogen gains an electron, so the halide is always negatively charged [3]. An arc lamp is an arc discharge application where an arc lamp is a lighting lamp that uses light emission at the time of arc discharge as the light source [4]. Xenon used in high-pressure arc lamps, as well as in optical projectors, research lamps [5]. Xenon and krypton arc lamps are used as pumps in solid state lasers, solar energy simulators [6], and study the properties of the plasma and gas produced in a vacuum arc discharge using scandium deuteride film cathode[7].

M D Cunha, et.al,(2019), Taking into account the deviation of the local thermodynamic equilibrium that occurs near the surface of the cathode, especially the space charge envelope near the negative electrode, the melting of the cathode and the movement of the molten metal under the influence of plasma pressure of the Lorentz force, gravity and surface tension .the plasma-electrode interaction model along with reality is still a bottleneck in the development of prediction models for high voltage arc equipment[8]. Evaluation of the unbalanced layer parameters of a hot arc cathode as a function of the cathode surface temperature is an integral part of the self-consistent modeling and the local cathode voltage drop [9]

This work is done using the NCBL model code. The model equations are summarized[10]. where the following conditions were used (room temperature (300 K) - cathode radius (1 cm) and height (1cm) and xenon gas was used where xenon was mixed with dysprosium for calculate the parameters of energy flux density, where different concentrations of dysprosium were added (0.005,0.01,0.05,0.1,0.5) mol. at two voltages 13and 25V

Theory

The cathode material has a thermal conductivity that is a function of heat[11].

$$K = k(T) \quad (1)$$

K is Boltzmann constant; T is temperature distribution in the cathode body

The intensity of the energy flux coming from the arc plasma and will collect part of it at the surface of the cathode in the thin plasma layer close to the cathode[12].

$$q = q(T_w, u) \text{ which is define for all} (T_w \geq Tc). \quad (2)$$

q is density of heat flux removed from the cathode surface into the bulk by heat conduction, Tc is temperature of the base of the cathode, Tw is temperature of the surface of the electrode.

Also $j = j(T_w, u)$ which is defining for all (T_w≥ Tc). (3)

Equations (2) and (3) describes the energy flux density and current flux density

The current transmitted in the layer near the cathode is in one dimension and varies with the surface temperature (Tw) and the low voltage (U) in this layer.

The modulus of the plasma layer in the region near the cathode (such as current flux density and energy flux density from the plasma to the cathode surface) is a function of temperature (Tw) and voltage (U).

The exchange temperature of the cathode with the gas or the radiation lost from the part of the surface in contact with the gas changes with the change of the surface temperature (Tw)[13]

$$\nabla \cdot (\kappa \nabla T) = 0 \quad (4)$$

$q(Tw, u)$ function describes the temperature distribution with in the cathode body on the surface by evaluating the thermal conductivity in the cathode body as the equation [14]

with boundary condition

$$\kappa \frac{\partial T}{\partial n} = q(T_w, U) \quad (5)$$

n is the portion of the cathode surface in contact with the arc plasma and with the

cold gas with boundary condition

$$T = T_c \quad (6)$$

the energy flux density at the surface of the cathode produced by the plasma describes by equation[15].

$$q_p = q_i + q_e - q_{em} \quad (7)$$

q_p is density of the plasma-related energy flux to the cathode surface, q_e is density of energy flux delivered to the cathode surface by fast plasma electrons, q_{em} density of losses of energy by the cathode surface due to thermionic emission

q_i is the energy flux density by fast plasma describes by equation[16].

$$q_i = j_i[z_e U_D + E - ZA_{eff} + k(2T_h + ZT_e/2 - 2T_w)] \quad (8)$$

The equation (8) can be written in the following form

$$q_i = j_i(z_e U_D + E - ZA_{eff}) + w_i + [j_i k\left(2T_h + \frac{ZT_e}{2}\right) - (j_i 2kT_w + w_i)] \quad (9)$$

j_i The density of the ion current arriving at the cathode surface.

T_e and T_h Heavy particle temperatures, (E) the average ionization energy in the layer near the cathode, low voltage in the envelope of space charge is (U_D)

$$q_p = ju - \frac{j}{e}(A_{eff} + 3.2kT_e) \quad (10)$$

Equation (10)has the meanings of different physical properties: The energy flow associated with the plasma to the cathode surface represents the difference between the electrical energy deposited per unit area near the cathode layer and the energy (electrons) transferred by current from this layer to the mass of the plasma[17].

Results and discussion

Ion energy flux density of concentration (0.005,0.01mol)

from the figures (1) and (2) at the voltage of $(U = 13V)$ we notice that pure Xe begins with an increase in temperature $(T_W = 3100K)$ and we note that the energy of the ions remains stable at a temperature of $(T_W = 4000\ K)$ due to reaching the saturation state .As for voltage $(U = 25\ V)$ for pure Xe it starts to increase at a temperature of $(T_W = 2800\ K)$ and reaches the highest rise at a temperature of $(T_W = 3700\ K$.When adding concentration (0.005,0.01) we do not observe an effect of concentration on the mixture. as we notice an increase in the qi for the period from (٢٨٠٠-3500K) that the table (1) shows that. as for at a temperature of $(3500 - 5000K)$ we note that the qi grows rapidly with the increase in the surface temperature T_W from $(3500 - 5000k)$ due to collisions between electrons and ions and these collisions are elastic or inelastic.

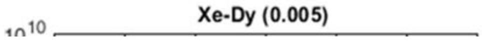

Table1. The energy flux density of the ion vs cathode surface temperature to Xe pure for each voltage (U=13V, U=25V)

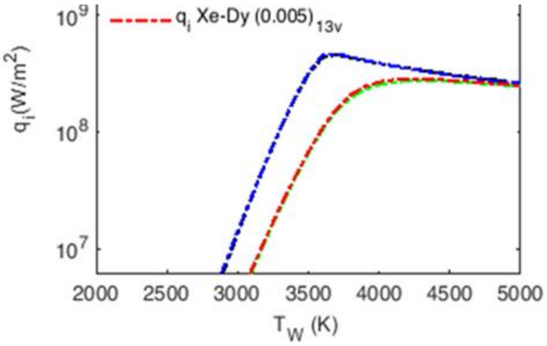

Figure1. The energy flux density of ion vs cathode surface temperature to concentrate (0.005) of voltage U=13V,U=25V

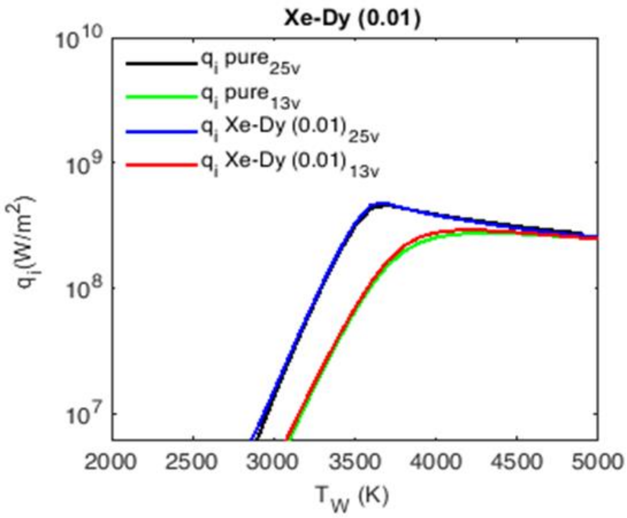

Figure2. The energy flux density of ion vs cathode surface temperature to concentrate (0.01) of voltage U=13V,U=25V

Xe pure at T_W $(2800-3500k)$			**Xe pure at T_W $(3500-5000k)$**		
Energy flux density	$U=13V$	$U=25V$	**Energy flux density**	$U=13V$	$U=25V$
q_i	$6.55*10^7$	$3.11*10^8$	q_i	$6.55*10^7$	$3.11*10^8$

Flux density of Ion energy for concentration (0.05,0.1mol)

from the figures (3) and (4) in the case of xe pure as is the case in each of the figure (1,2) but in the case of adding concentration (0.05,0.1) we notice a slight effect of concentration as we notice an increase in the qi for the period from $(2800-3500K)$ that the table (2) and (3) shows that. as for at a temperature of $(3500-5000K)$ we note that the $q_e$grows rapidly with the increase in the surface temperature T_W due to collisions between electrons and ions and these collisions are elastic or inelastic.

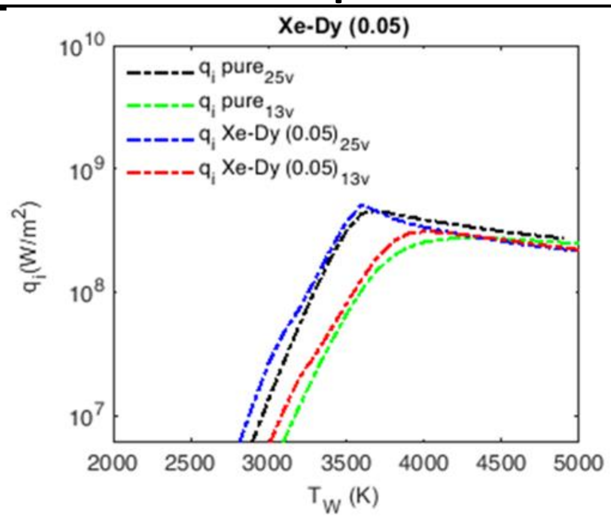

Figure3. The energy flux density of ion vs cathode surface temperature to concentrate (0.05) of voltage U=13V, U=25V

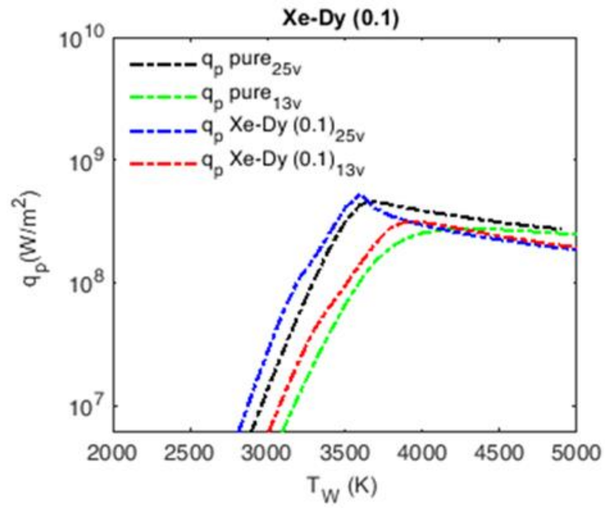

Figure4. The energy flux density of ion vs cathode surface temperature to concentrate (0.1) of voltage U=13V, U=25V

Table2. The energy flux density of the ion vs cathode surface temperature to concentration (0.05) for each voltage (U=13V, U=25V)

Concentration (0.05) at T_W $(2800-3500k)$			**Concentration (0.05) at T_W $(3500-5000k)$**		
Energy flux density	$U=13V$	$U=25V$	**Energy flux density**	$U=13V$	$U=25V$
q_i	$7.99*10^7$	$3.68*10^8$	q_i	$2.21*10^8$	$2.16*10^8$

Table3. The energy flux density of the ion vs cathode surface temperature to concentration (0.1) for each voltage (U=13V, U=25V)

Concentration (0.1) at $T_W(0-3500k)$			Concentration (0.1) at $T_W(3500-5000k)$		
Energy flux density	$U=13V$	$U=25V$	Energy flux density	$U=13V$	$U=25V$
q_i	$9.41*10^7$	$4.05*10^8$	q_i	$1.94*10^8$	$1.86*10^8$

Flux density of Ion energy for concentration (0.5mol)

From the figure (5) in the case of xe pure as is the case in each of the figure (1,2) but in the case of adding concentration (0.5) we notice a clear effect of concentration as we notice an increase in the qi for the period from $(2800-3500K)$ that the table (4) shows that. As for at a temperature of $(3500-5000K)$ we note that the qi grows rapidly with the increase in the surface temperature T_W from $(3500-5000k)$ due to collisions between electrons and ions and these collisions are elastic or inelastic.

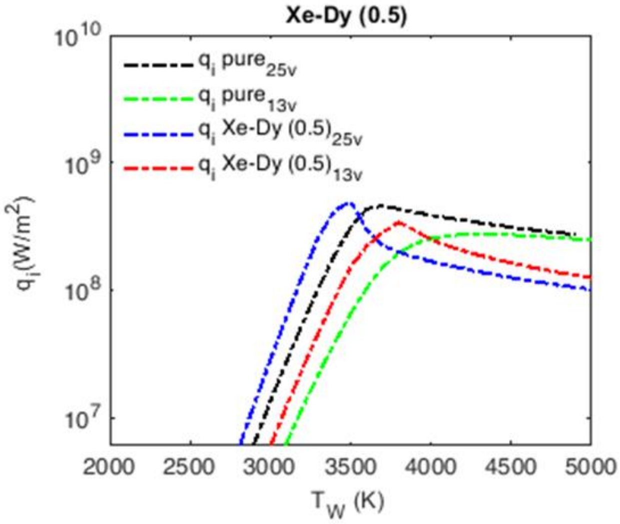

Figure5The density of flux energy ion vs cathode

Table4. The energy flux density of the ion vs cathode surface temperature to concentration (0.5) for each voltage (U=13V, U=25V)

Concentration (0.5) at Tw $(0-3500k)$			Concentration (0.5) at Tw $(3500-5000k)$		
Energy flux density	$U=13V$	$U=25V$	Energy flux density	$U=13V$	$U=25V$
q_i	$1.52*10^8$	$4.95*10^8$	q_i	$1.24*10^8$	$1.01*10^8$

Energy Flux Density of Plasma

Energy Flux Density of Plasma of concentration (0.005,0.01mol) from the figure $(6,7)$ that the plasma energy at the $(U = 13V)$ of Xe pure begins to increase from the temperature $(T_w = 3200k)$ and continues to increase with increasing temperatures and reaches the highest rise at the temperature $(T_w = 3700k)$ and then begins to decrease gradually. As for at $(U = 25\ V)$ Xe pure starts to increase at a temperature of $(T_w = 2800K)$ and continues to increase with an increase with the increase in temperature and reaches the highest rise at temperature $(T_w = 3300k)$ and the is from a temperature of $(4000 - 45000\ K)$ it is stable due to reaching the saturation state, then it starts to decrease, and when adding concentration $(0.005,0.01\ mol)$ we do not notice an effect of concentration on the mixture. as we notice an increase in the $q_p$for the period from $(2800 - 3500K)$ that the table (5) shows that.

As for at a temperature of $(3500 - 4000K)$ we note that the $q_p$grows rapidly with tincrease in the surface temperature T_W due to collisions between electrons and ions and these collisions are elastic or inelastic.

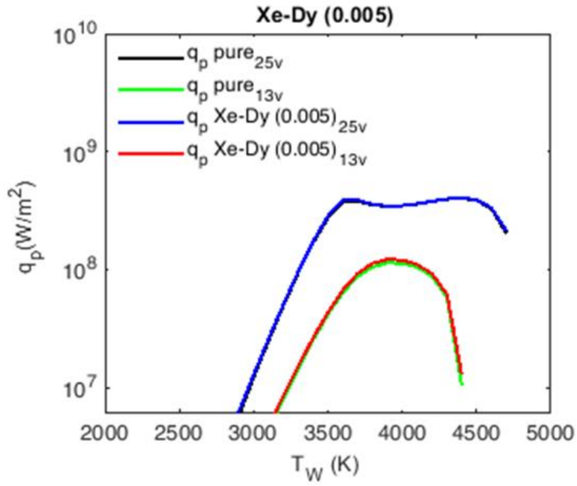

Figure6. The energy flux density of plasma vs cathode surface temperature to concentrate (0.005) of voltage $U = 13V, U = 25V$

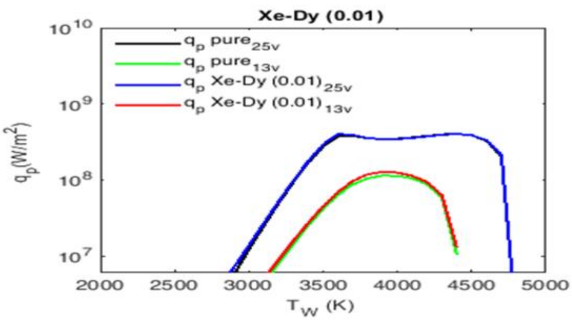

Figure 7. The energy flux density of plasma vs cathode surface temperature to concentrate (0.01) of voltage $U = 13V, U = 25V$

x density of the plasma vs cathode surface temperature for Xe pure a
voltage ($U = 13V, U = 25V$)

Xe pure at T_w $(2800 - 3500k)$			**Xe pure at T_w $(3500 - 4000k)$**		
Energy flux density	$U = 13V$	$U = 25V$	**Energy flux density**	$U = 13V$	$U = 25V$
q_p	$4.18 * 10^7$	$2.75 * 10^8$	q_p	$1.13 * 10^8$	$3.48 * 10^8$

Energy Flux Density of Plasma for concentration (0.05,0.1mol)

From the figure (8,9) in the case of xe pure as is the case in each of the figure (6,7) but in the case of adding concentration (0.05,0.1) we notice a slight effect of concentration as we notice an increase in the q_p for the period from (2800−3500K) that the table (6) and (7) shows that. As for at a temperature of (3500−4000K) we note that the q_p grows rapidly with the increase in the surface temperature T_W due to collisions between electrons and ions and these collisions are elastic or inelastic.

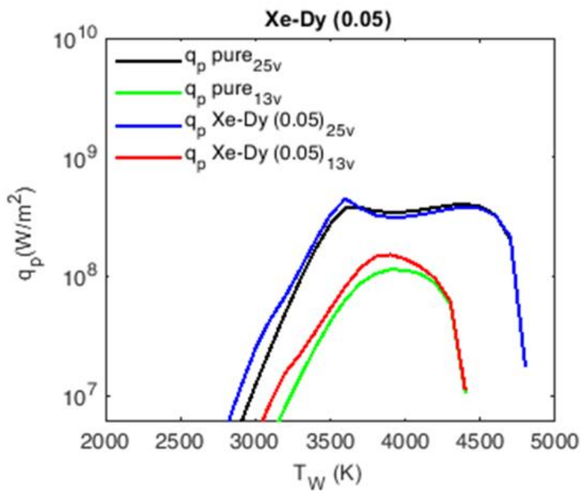

Figure 8. The energy flux density of plasma vs cathode surface temperature to concentrate (0.05) of voltage $U = 13V, U = 25V$

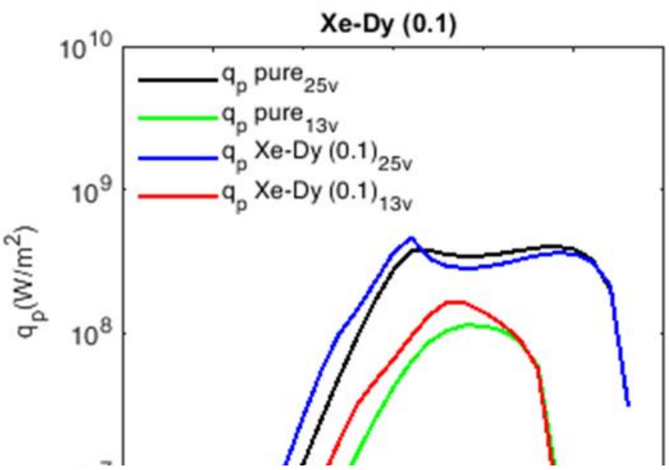

Figure 9. The energy flux density of plasma vs cathode surface temperature to concentrate (0.1) of voltage $U = 13V, U = 25V$

Table 6. The energy flux density of the plasma vs cathode surface temperature for Concentration (0.1) at each voltage ($U = 13V, U = 25V$)

Concentration (0.1) at T_w $(0 - 3500k)$			Concentration (0.1) at T_w $(3500 - 4000k)$		
Energy flux density	$U = 13V$	$U = 25V$	Energy flux density	$U = 13V$	$U = 25V$
q_p	$6.56 * 10^7$	$3.64 * 10^8$	q_p	$1.41 * 10^8$	$2.90 * 10^8$

Concentration (0.05) at T_w $(0 - 3500k)$			Concentration (0.05) at T_w $(3500 - 4000k)$		
Energy flux density	U=13V	U=25V	Energy flux density	U=13V	U=25V
q_p	$5.37 * 10^7$	$3.29 * 10^8$	q_p	$1.40 * 10^8$	$3.16 * 10^8$

Table 7. The density of the flux energy plasma vs cathode interface temperature for Concentration (0.05) at each voltage $(\mathrm{U} = 13\mathrm{V}, \mathrm{U} = 25\mathrm{V})$

Energy Flux Density of Plasma concentration (0.5mol)

From the figure (10) in the case of xe pure as is the case in each of the figure (6,7) but in the case of adding concentration (0.5) we notice a clear effect of concentration as we notice an increase in the q_p for the period from $(2800 - 3500K)$ that the table (8) shows that. As for at a temperature of $(3500 - 5000K)$ we note that the qp grows rapidly with the increase in the surface temperature T_W due to collisions between electrons and ions and these collisions are elastic or inelastic.

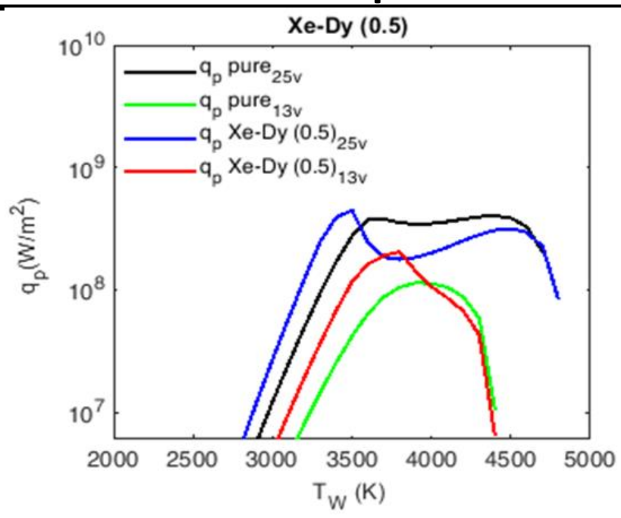

Figure10. The energy flux density of plasma vs cathode surface temperature to concentrate (0.5) of voltage $U = 13V, U = 25V$

Table 8.The density of the flux plasma energy vs cathode interface temperature for Concentration (0.5) at each voltage $(U = 13V, U = 25V)$

Concentration (0.5) at Tw $(0 - 3500k)$			**Concentration (0.5) at Tw (3500-4000k)**		
Energy flux density	$U = 13V$	$U = 25V$	**Energy flux density**	$U = 13V$	$U = 25V$
q_p	$1.16 * 10^8$	$4.48 * 10^8$	q_p	$1.07 * 10^8$	$2.00 * 10^8$

Conclusion

1. When Tw increases due to the rate of increase in electron temperature the energy density will increase.
2. The energy gained by the ions from the electric field increases if the voltage is increased, and free electrons and ions are generated.
3. The ionization process doubles by increasing the number of electrons and ions.
4. At a higher voltage of 25 V the energy flux density is higher than that of 13v.due to the rapid increase in heating of the ions.
5. Electrons and ions take energy from the applied electric field and transfer it through collisions with other particles. These collisions are elastic and inelastic.

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