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The effect of cathode work function on plasma parameters produced by radio frequency magnetron plasma sputtering

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Abstract : In this work, the spectra for glow discharge produced by RF magnetron plasma were studied, with argon gas using planner electrode with different target material (Cd, Ag, Pb, Zn, Sn and Cu) atcertainworking pressure and applied voltage with two space between electrodes 2cm and 4cmto study the effect of metal work function and the inter-electrode distance on plasma parameters by comparing the produced lines with neutral and ionic standard lines for usedtarget materials and argon.

Keywords : RF magnetron; spectroscopy; work function, secondary electron emission coefficient.

Introduction

RF magnetron sputtering is widely used both in the laboratory and in manufacturing. During sputtering an applied voltage is used to generate a plasma that is confined, by magnetic field, close to the target material which ejects particles then deposited on substrate. This technique has low cost and effective for industry [1]

Optical emission spectroscopy**(OES)**used to obtain information about plasma parameters, such as plasma density, electron temperature and the chemical compositions within plasma [2].

Electron temperature is an important parameter for plasma characterization. Line-ratio method using optical line emissions is one of technique used to determine electron temperature the electron temperature of plasma can calculated using ratio method between atomic and ionic lines for same species depending on the equation[3].

$$I\_1/I\_2 = g\_2/g\_2 \ \ A\_1/A\_2 \ \ \lambda\_2/\lambda\_1 \ \ e\hat{}([-((E\_1 - E\_2)/kT))$$

……………………………………………….. (1)

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The Stark broadening, Doppler broadening, and pressure broadening will affect the observed line widths. The Stark broadening can used to measureof the electron density while the Doppler broadening and ionic broadening is so small that can be neglected [4]. So the electron density can be given by the formula[5]:

$$n_e(cm^{-3}) = \left[\frac{\Delta\lambda}{2\omega s(\lambda, T_e)}\right] N_r$$

………………………………………..… (2)

Where Δλ is the FWHM of the line, and ωs is the Stark broadening parameter, that can be found in the standard tables, Nr is the reference electron density which equal to 10^{16} (cm^{-3}) for neural atoms and 10^{17} (cm^{-3}) for singly charged ions.

The secondary electron emission coefficient has high effected on plasma parameters[6]. It is reversely depend on targets work functions and directly on ionization energy of used gas[7].The work function is defined as the minimum energy required to remove an electron from the interior of a solid to a position outside the solid. In electronic structure calculations this translates to taking the energy difference between the Fermi level and the vacuum level[8]. Table (1) shows the work functions for used metal

Table 1: the work functions for used targets[9]

Metal	Work function (eV)
Cd	4.22
Ag	4.24
Pb	4.25
Zn	4.33
Sn	4.42
Cu	4.65

Experimental part

Plasma magnetron sputtering system involve of cylindrical glass chamber, and two circular electrodes separated with 2cmand 4 cm, the ground electrode made of stainless steel with radius 4 cm. The powered electrode with radius 4 cm, made of six different metals (Cd, Ag, Pb, Zn, Sn and Cu) at constant working pressure (0.4 mbar). The chamber is evacuated by double stage rotary pump and the pressure was noticed by pressure gauge (perani type Edward) and controlled by needle valve by varying Ar flow. Cathode prepared with two circular concentric magnets to confine the plasma on the cathode for sputtering enhancement. RF power supply of (4 MHz) frequency and applied voltage were used in the experiment. The optical emissions were collected and transfer by fiber to photo spectrometer device, connected with a computer, to record the plasma emission spectra in argon gas with different target material.

Results and discussion

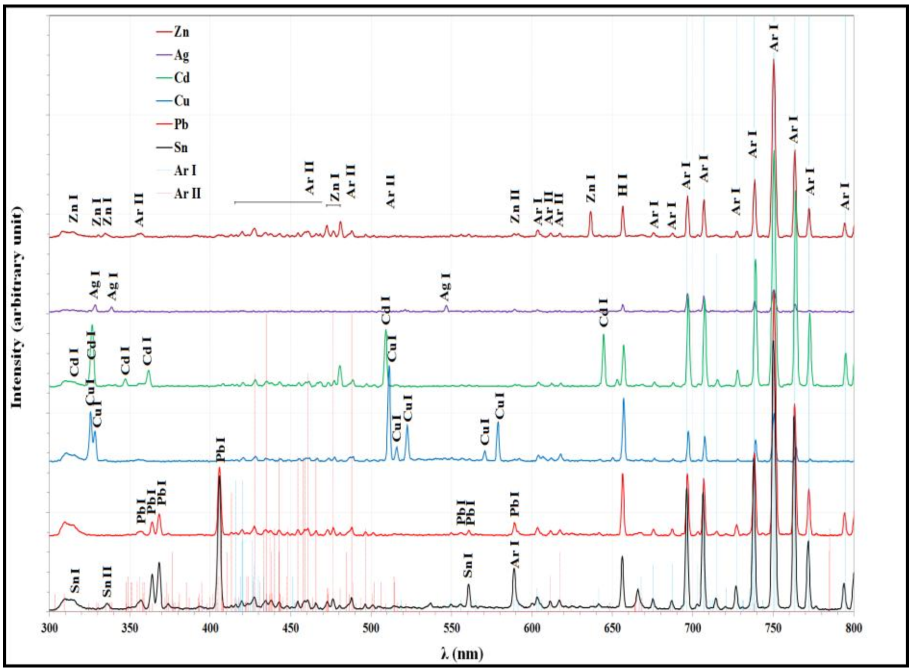

Fig. 1: Emission spectra for RF plasma in Ar with targets with 2 cm inter electrodes distance.

Fig. 1 shows The optical emission spectra for Rf magnetron plasma sputtering using argongasat constant working pressure (0.4 mbar) by different targets and 2cm inter-electrodes distance, which recorded by optical emission spectrometer. This figure shows the spectroscopic patterns and the standard lines for (Ar I, Ar II)[10]. There are many atomic and ionic peaks corresponding to argon and some of metal targets. One peak for Hα emission appears at about 656.3 nm in all samples as a result of the presence of water vapor desorbed from discharge chamber walls. It can be noticed that the intensity varies with different used targets.

The value of T_e is calculated by ratio method using two lines (Ar I at 750.38 nm and Ar II at357.66 nm) for different targets. The selection of these two lines because they are isolated and presence in all curves, also because of the high difference of their upper energy levels seeking more measurements accuracy[4].

Fig. (2) shows the 750.38 nm Ar I peak profile where full width at half maximum found by using Gaussian fitting to calculate electron density (n_e) at different targets Stark effect depending on the standard values of broadening for this line [11]. It can be seen that the full width decrease with increasing work function of used targets.

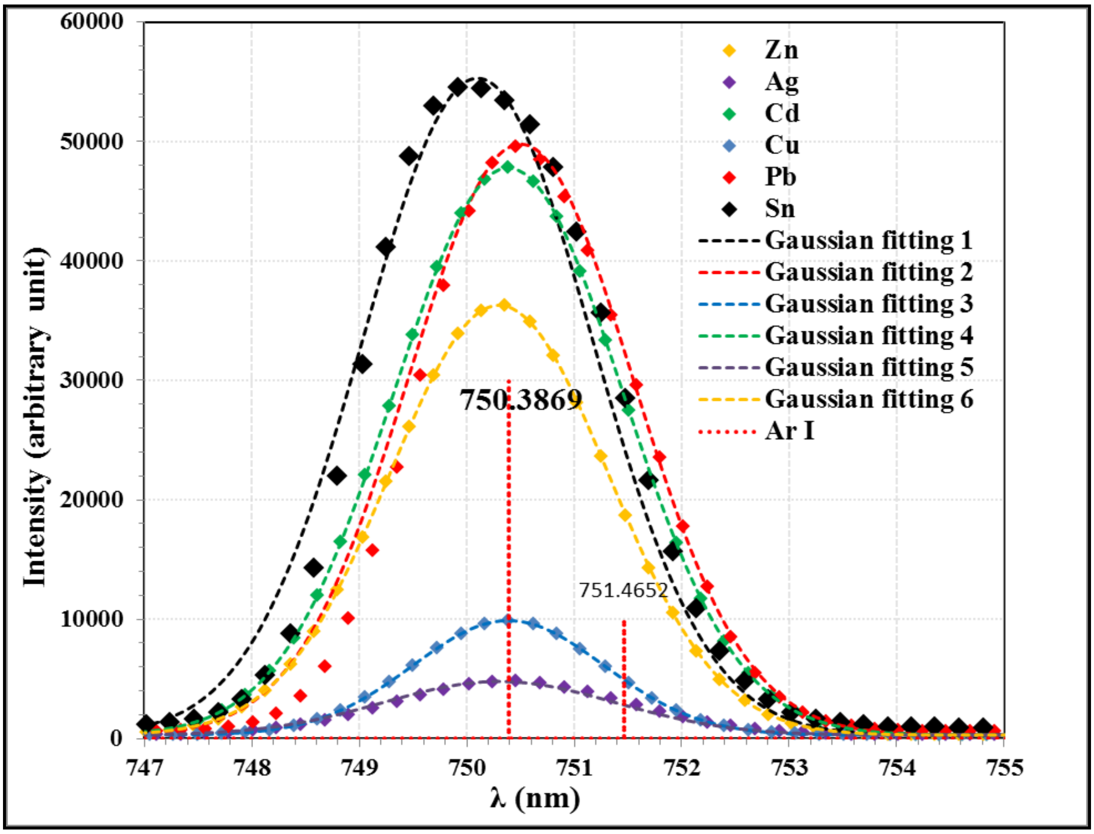

Fig. 2: Ar I:750.38 nm peaks profile and their Gaussian fitting at different targets with 2 cm inter electrodes distance.

The variation of electron temperature (T_e), calculated by ratio method, and electron density (n_e), using Stark broadening effect with deferent target material work function were shown in Fig. 3. This figure shows that the n_e decrease with increasing work function from Cd to Cu as a result of decreasing the secondary electron emission coefficient, which cause to reduce the emitted electrons from target. The decrement in n_e caused to reduce the electron-neutral collision, which responsible for the transfer of energy to the atoms, as a result of increasing their mean free bath[12].

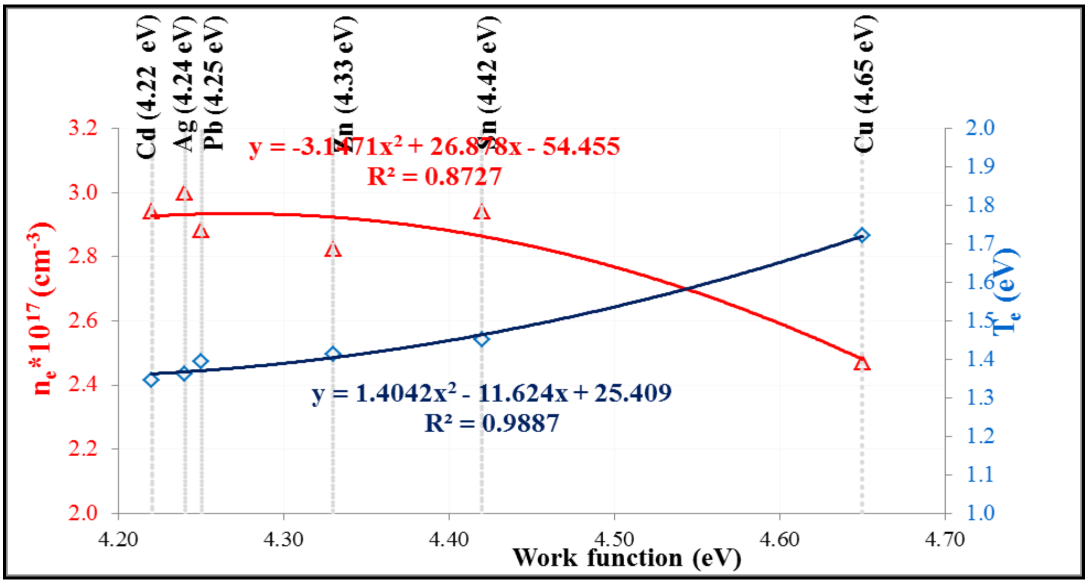

Fig. 3: The variation of (a)T_e and (b) n_e for RF plasma in Ar with target work function using 2 cm inter electrodes distance..

Table 2 shows the calculated values of Debye length (λ_D), plasma frequency (f_p) and Debye number (N_d) for RF plasma in argon with different targetsat d=2 cm.

Table 2: plasma parameters for RF plasma in Ar with different work function using 2 cm inter electrodes distance.

Target	φ (eV)	T_e (eV)	n_e*10^{17} (cm^{-3})	f_p(Hz) *10^{12}	λ_D *10^{-5}(cm)	N_d *10^4
Cd	**4.22**	1.346	2.94	4.870	1.589	0.495
Ag	**4.24**	1.362	3.00	4.919	1.577	0.493
Pb	**4.25**	1.394	2.88	4.821	1.627	0.520
Zn	**4.33**	1.414	2.82	4.772	1.656	0.537
Sn	**4.42**	1.452	2.94	4.870	1.644	0.547
Cu	**4.65**	1.722	2.47	4.464	1.954	0.772

Fig. 4 shows The optical emission spectra for Rf plasma in argon gas at constant working pressure (0.4 mbar) using different targets, which recorded by optical emission spectrometer, using (d= 2 cm) inter-electrodes distance. Also, there are many atomic and ionic peaks corresponding to argon and some of metal targets. One peak for Hα emission appears at about 656.3 nm in all samples. It can be noticed that the intensity of atomic lines less than that at d= 4 cm, as a result of decreasing the applied electric field due to increasing the distance between electrode (d). The electric field is responsible for energy delivers to electrons, reducing the energy cause to reduce the excitation reaction collisions, cause to reduce the emitted light.

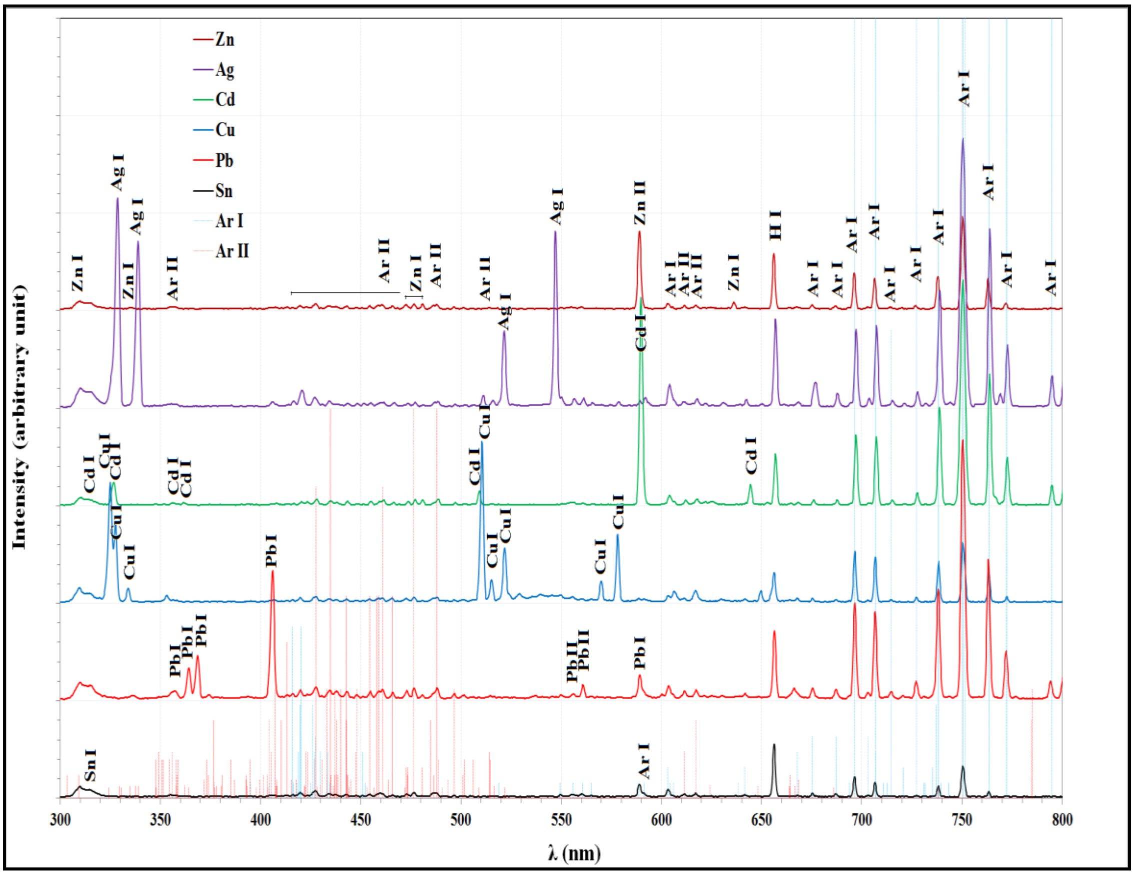

Fig. 4: Emission spectra for RF plasma in Ar with targets with 4 cm inter electrodes distance.

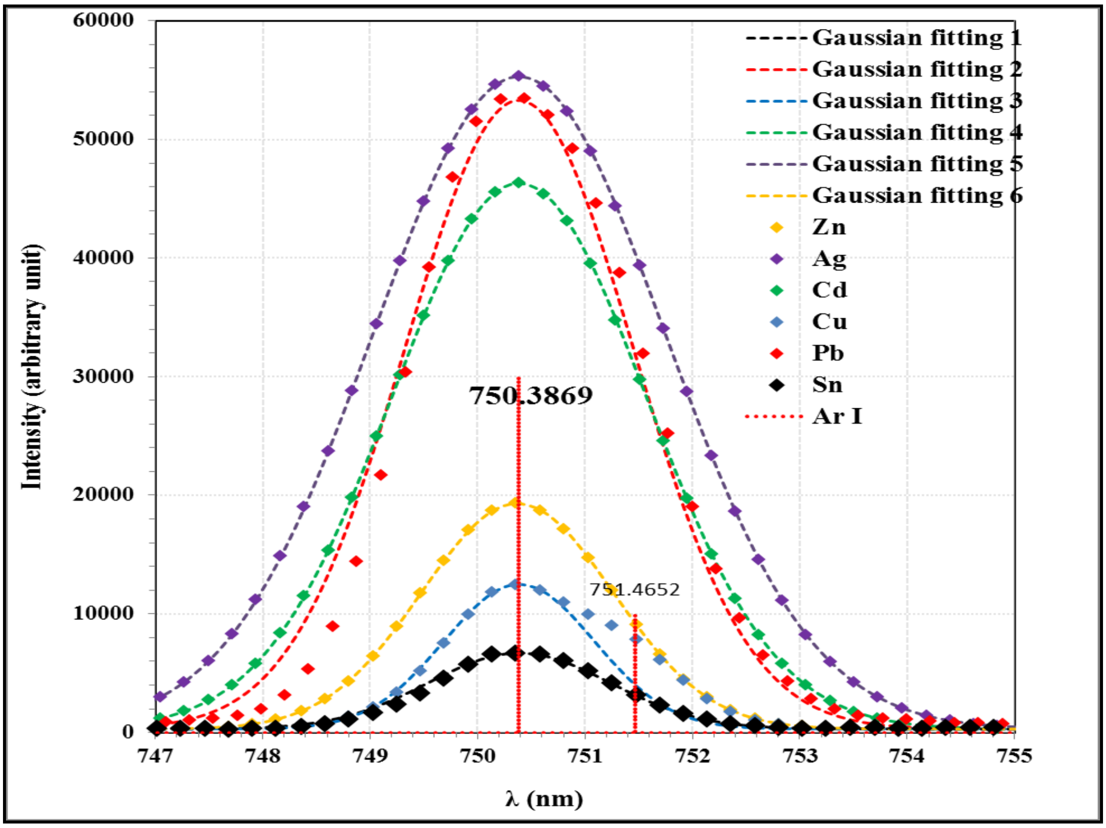

Fig. 5: Ar I: 750.38 nm peaks profile and their Gaussian fitting at different targets with 4 cm inter electrodes distance.

The value of T_e is calculated by ratio method using two lines (Ar I at 750.38 nm and Ar II at357.66 nm) for different targets, while the electron density calculated by stark broadening effect. Fig. 5 shows the 750.38 nm Ar I peak profile where full width at half maximum found by using Gaussian fitting to calculate electron density at different targets Stark effect depending on the standard values of broadening for this line [11]. Also, it can be seen that the full width decrease with increasing work function of used targets.

The variation of electron temperature (T_e) and electron density (n_e) with deferent target material work function, in case of d=4 cm, were shown in Fig. 6. This figure shows that the $n_e$decrease with increasing work function from Cd to Cu. The decrement in n_e caused increase the mean value of electron temperature (T_e).

It can be seen that the electron temperature doesn't have high variation with varying the inter-electrode distance from 2 to 4 cm, while, there is a clearly increment in electron density.

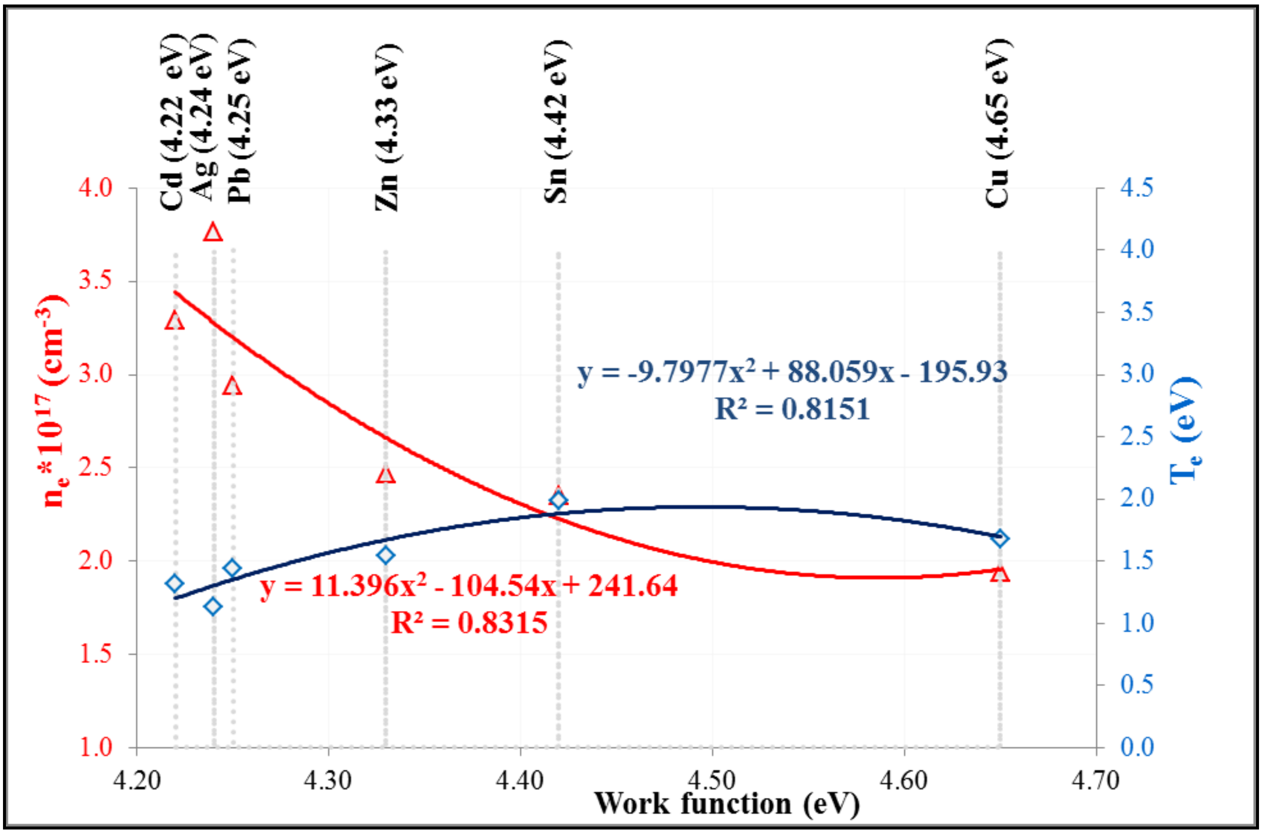

Fig. 6: The variation of (a)T_e and (b) n_e for RF plasma in Ar with target work functionusing4 cm inter electrodes distance.

Table 3 shows the calculated values of Debye length (λ_D), plasma frequency (f_p) and Debye number (N_d) for RF plasma in argon with different targets at d= 4 cm.

Table 3: plasma parameters for RF plasma in Ar with different work functionusing 4 cm inter electrodes distance.

Target	φ (eV)	T_e (eV)	n_e*10^{17} (cm^{-3})	f_p(Hz) *10^{12}	λ_D *10^{-5}(cm)	N_d *10^4
Cd	**4.22**	1.319	3.29	5.154	1.487	0.453
Ag	**4.24**	1.131	3.76	5.510	1.283	0.333
Pb	**4.25**	1.446	2.94	4.870	1.641	0.544
Zn	**4.33**	1.539	2.47	4.464	1.847	0.652
Sn	**4.42**	1.990	2.35	4.356	2.152	0.982
Cu	**4.65**	1.682	1.94	3.956	2.178	0.840

Conclusions

Study the effect of cathode work function and inter- electrode distance on plasma parameters produced by radio frequency in argon shows many points as follows:

- Electron density inversely proportional with target work function, i.e. direct proportional with secondary electron emission coefficient. While the electron temperature have opposite behavior.
- The separation energy not has high effective on plasma temperature but increasing it from 2 to 4 cm cause to increase the plasma density

References

1. S. Calnan, “Applications of Oxide Coatings in Photovoltaic Devices,” *Coatings*, vol. 4, pp. 162–202, 2014.
2. D. M. Devia, L. V Rodriguez-Restrepo, and E. Restrepo-Parra, “Methods Employed in Optical Emission Spectroscopy Analysis,” *Eng. Sci.*, vol. 11, no. 21, pp. 239–267, 2015.
3. Y. K. Pu, Z. D. Yu, and Z. G. Guo, “Effect of wall reflection on the determination of electron temperature by the line-ratio method in inductively coupled plasmas,” *Phys. Plasmas*, vol. 12, no. 11, pp. 1–3, 2005.
4. A. Mohmoud, E. Sherbini, A. Aziz, and S. Al, “Measurement of Plasma Parameters in Laser-Induced Breakdown Spectroscopy Using Si-Lines,” *World J. Nano Sci. Eng.*, vol. 2, pp. 206–212, 2012.
5. X. F. Li, W. D. Zhou, and Z. F. Cui, “Temperature and electron density of soil plasma generated by LA-FPDPS,” *Front. Phys.*, vol. 7, no. 6, pp. 721–727, 2012.
6. M. Khalaf, I. Agool, and S. Abd, “Influence of Inter-Electrode Distance , Gas Mixing , Magnetic Field and Cathode Material on Breakdown Voltage of Lab-Made DC Magnetron Sputtering Device,” *Iraqi J. Appl. Phys.*, vol. 10, no. 4, pp. 21–25, 2014.
7. Y. P. Raizer, *Gas Discharge Physics*. Berlin Heidelberg: Springer-Verlag, 1991.
8. H. W. Hugosson, O. Eriksson, U. Jansson, and A. V Ruban, “Surface energies and work functions of the transition metal carbides,” *Surf. Sci.*, vol. 557, pp. 243–254, 2004.
9. Herbert B. Michaelson, “The work function of the elements and its periodicity The work function of the elements and its periodicity,” *J. Appl. Phys.*, vol. 4729, no. 1977, pp. 1–6, 2013.
10. J. E. Sansonetti and W. C. Martin, “Handbook of Basic Atomic Spectroscopic Data,” *Am. Inst. Phys.*, vol. 34, no. 4, 2005.
11. A. Lesage, “Experimental Stark Widths and Shifts for Spectral Lines of Neutral and Ionized Atoms,” vol. 31, no. 3, 2002.
12. F. Hall and B. Hill, “Introduction to gas discharges,” *Plasma Sources Sci. Technol.*, vol. 9, pp. 517–527, 2000.

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