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Influence of the homogeneous magnetic field of the laser-induced breakdown spectroscopy of copper plasma

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Abstract
Copper plasma is generated with the existence of an external magnetic field and without its presence utilizing Nd:YAG laser (1064 nm ,9 ns) in different pulse laser energy which ranges from(100 to 400) mJ in a vacuum. Plasma parameter beta (β) is least than 1, this indicates that the existence of magnetic field confinement effect is proven. Note that both the electron temperature and electron density increases with the laser pulse energy increasing , Both are higher in the presence of a magnetic field.

Keywords: LIBS, magnetic field confinement, electron density, OES, electron temperature.

تأثير المجال المغناطيسي المتجانس في بلازما النحاس باستخدام التحليل الطيفي المستحث بالليزر.

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الخلاصة
تم توليد بلازما النحاس بوجود مجال مغناطيسي خارجي وبدون وجوده باستخدام ليزر Nd: YAG(1064 نانومتر ، 9 نانو ثانية) في طاقة ليزر نبضي مختلفة تتراوح من (100 إلى 400) مللي جول في الفراغ. المعلمة بيتا (β) هي أقل من 1 ، وهذا يدل على أن وجود تأثير حصر المجال المغناطيسي . لاحظ أن كلا من درجة حرارة الإلكترون وكثافة الإلكترون تزداد مع زيادة طاقة نبض الليزر ، كلاهما أعلى في وجود مجال مغناطيسي.

Introduction
New technicality a comparatively for elemental analysis and description of solids, liquids, gases and aerosol it is laser-induced breakdown spectroscopy (LIBS) [1]. LIBS is an atomic emission spectrum analysis technicality. Which is a high pulsed laser energy is localized onto a small target volume leading to a breakdown of analytical into ions and free electrons, resulting to a plasma identify by both continuum and atomistic emission[2,3].The parameters of the Laser-generated plasma is progress quickly and are strongly related on irradiation conditions like Intensity of laser incident on a surface of the target and pulse laser duration, the wavelength of the laser, the spot size of radiance, gas ambient installation, and ambient pressure, which are temporary in nature [4,5]. The plasma generated by the laser has become confined by use of the magnetic field. To control the energetic plasmas ineffectual ways and dynamical properties of the transient by using the magnetic field. The high intensity of the magnetic field pulse has been found to be useful in improving the radiation emitted from laser-induced breakdown plasma [2]. Many physical phenomena like plume confinement, plasma instabilities, the transformation of plasma thermal energy into kinetic energy and Joule heating, effect emission improving may initiate in the expansion of laser-induced plasma in the

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existence of the magnetic field [6]. In laser generated plasma the used dynamic, play a basic role in deciding the characteristics of the plasma [7]. The plasma confinement degree was in good consent with simple magnetohydrodynamic (MHD) modeling. [8]. Plasma diagnostics method can be done through an account of the plasma electron temperature (T_e) and density (n_e). The strength of the different distribution functions describing the plasma state determines by the temperature, while the state of thermo- dynamical equilibrium of the plasma specifies by the electron density [9]. For the calculation of electron temperature the Boltzmann plot method it is one of the methods that are used [10,11].

$$\ln\left(\lambda_{mn} I_{mn} / g_m A_{mn}\right) = -\frac{1}{KT}\left(E_j\right) + \ln\left|\frac{N}{U(T)}\right| \quad (1)$$

where λ_{mn} is wavelength, I_{mn} intensity.
A_{mn} is transition probability of upper (m) and lower (n) energy states.
E_m and g_m are the upper states (m) energy and statistical weight

Te is the electron temperature, K is the Boltzmann constant, N (T) and U (T) are the total number density and partition function.

The Stark broadening effect using to calculate the electron density requires a line which is free from self-absorption[12]:

$$n_e = \left[\frac{\Delta\lambda}{2\omega_s}\right] N_r \quad (2)$$

ω_s is the theoretical line full width Stark broadening parameter, N_r is the reference electron density , equal to 10^{16} (cm^{-3}) for neutral atoms and 10^{17} (cm^{-3}) for singly charged ions. plasma parameter β it is a measure of the effect of the external magnetic field on the plasma generated ,which is the ration of plasma pressure to the magnetic field pressure [13].

$$\beta = \frac{\sum nkT}{\frac{B^2}{2\mu^\circ}} \quad (3)$$

where B is the magnetic field, T_e is the electron temperature ,K is the Boltzmann constant and n_e is the electron density.

Experimental part

LIBS system used for the detection spectral lines of laser-generated Cu plasma in the existence and without of magnetic field. Illustrated in Figure-1 the experimental setup of The target were bombarded by Nd: YAG pulse laser (9 ns duration, 6 Hz frequency, and fundamental wavelength of 1064 nm) and laser pulse energy ranging from 100 mJ to 400 mJ on target surface for the generation of Cu plasma, at an angle of 45^0. To focus the laser on the target surface we used the convex lens with a focal length equal to 10 cm.The circularly shaped pellet of the copper target with diameter 3 cm is placed inside a vacuum chamber. The chamber was filled up with Argon gas at a pressure (0.2 and 0.4 Torr).The vacuum chamber made of a cylindrical stainless steel tube. The two ends closed by Pyrex windows, by two stainless steel flanges, and with small quartz window fixed in it is center, that allows for a laser pulse to shoot the Cu target. Two small pipes connected to pumping systems, while the other was used to deliver the argon gas with purity (99.9%).for applying a magnetic field ,two types of the permanent magnetic field were used -(located under the target); the first is the outer and the second is the inner which is located inside the outer circular permanent. Figure -2 shows the radial profile of the magnetic field distribution along the Cu target. One can observe from this figure, the magnetic field intensity has nonuniform distribution along the target. The maximum value of the magnetic field is approximately 41 mT in the central region of the Cu target.

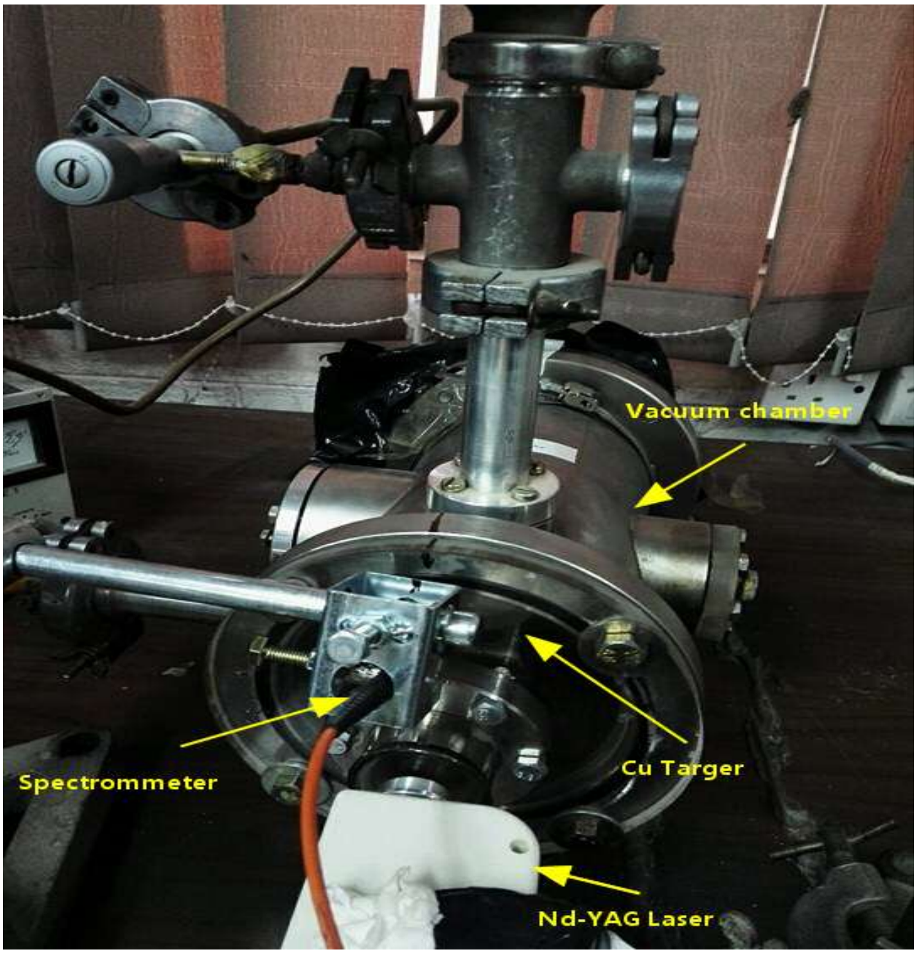

Figure1- the experimental set up of LIBS system

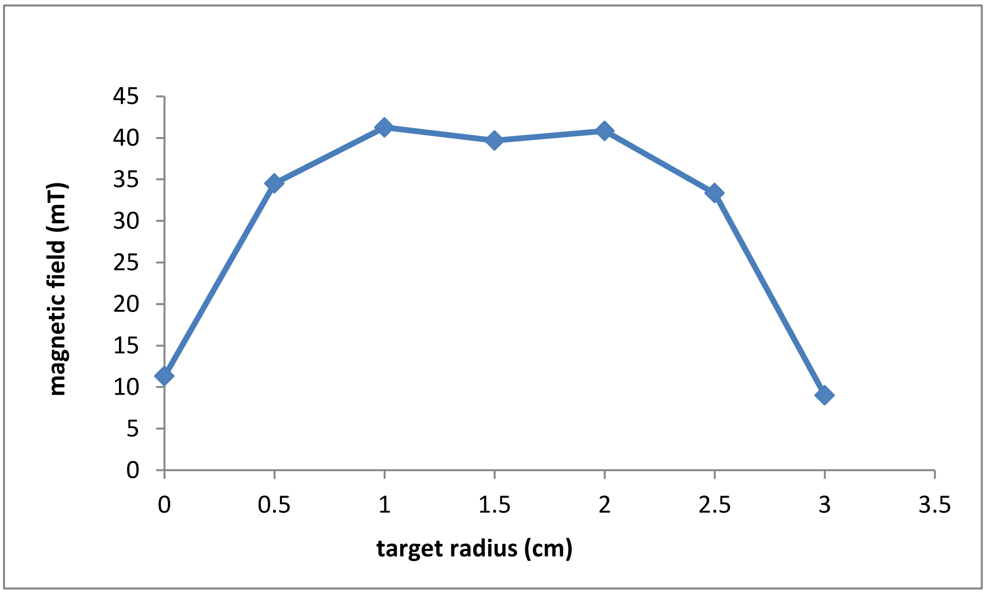

Figure 2- The magnetic field distribution on the radial profile of light emission of Cu target.

Results and discussions

The Cu plasma was generated by the laser interaction with Cu target using Q-switched Nd: YAG in a vacuum. A spectrum consists of a number of characteristic spectral lines of particular atoms and ions . We notice increasing of laser peak energy caused increase the intensities of the spectral lines because the mass ablation rate of the target also increases. The value of $T_e$is obtained using the

Boltzmann plot method (Equation (1)), this requires peaks that originated from the same atomic species and the same ionization step with data site, where the electron temperature equal to the invert of the slope of fitting line (the slope of fitted line equals to ($-1/k_B$ T). Figures- 3 and 4 show a Boltzmann plot by plotting a diagram between logarithmic as a function of E_k with existence and without magnetic field, respectively . The electron temperature of Cu plasma increase with increasing laser energy from (100 to 400 mJ), one notice the electron temperature existence magnetic field is higher than in case without magnetic field.

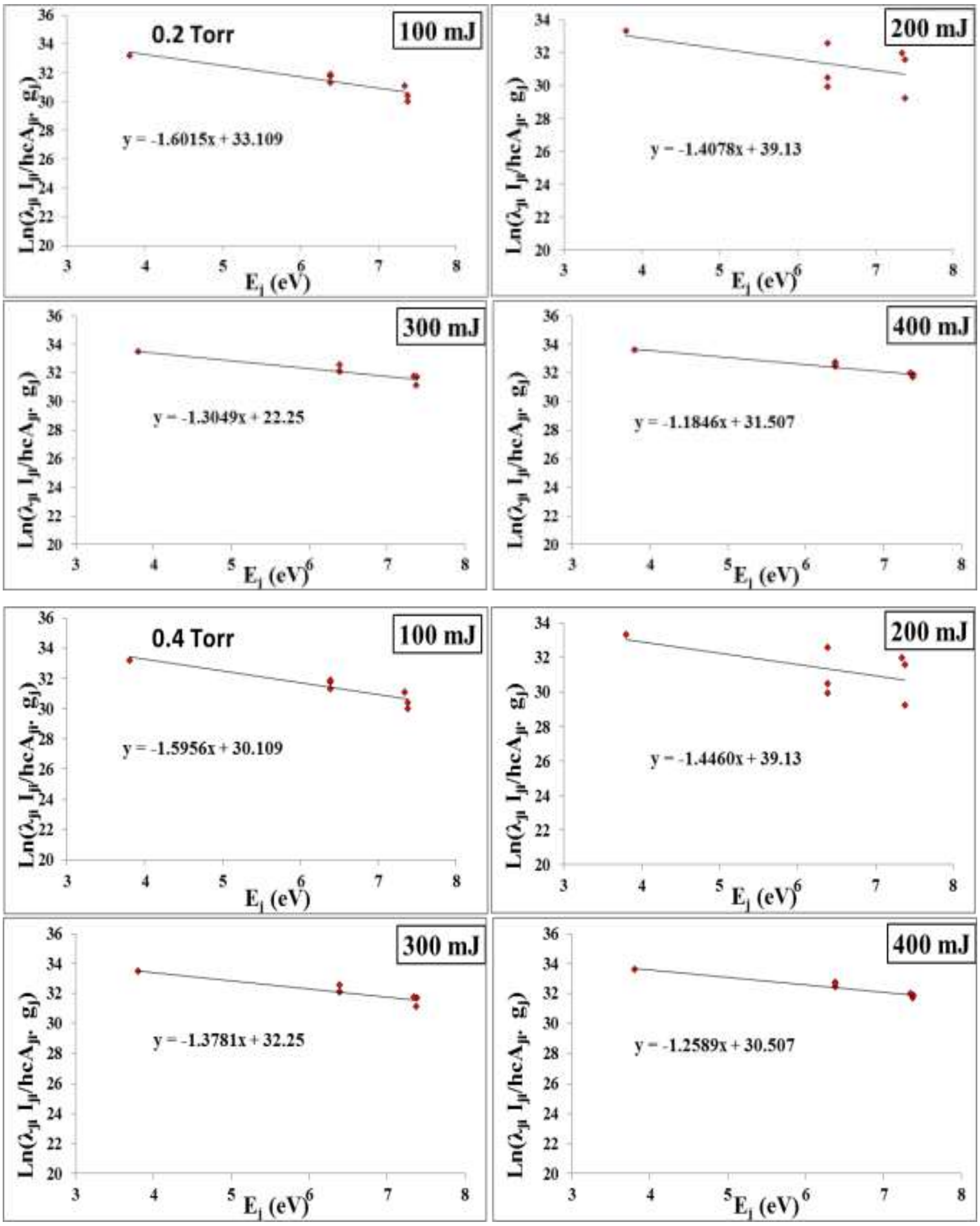

Figure 3- Boltzmann plot for a copper target with existence magnetic field.

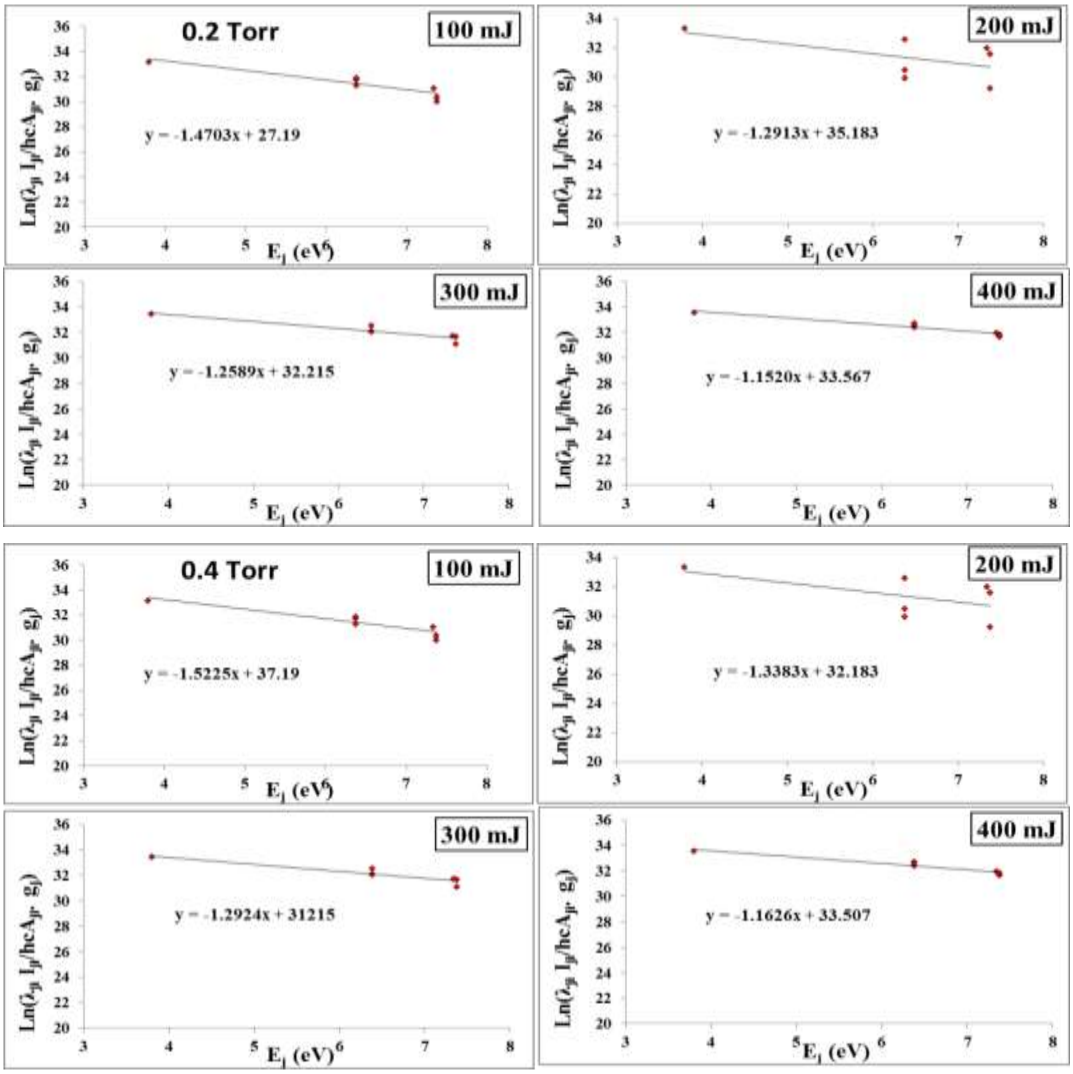

Figure 4- Boltzmann plot for the copper target in without magnetic field

Figures-5 and 6 show the difference in value of Te and n_e against the pulse laser energies for Copper plasma in with existence magnetic field and without of magnetic field respectively. Electron density of Cu plasma increases with increasing laser pulse energy from (100 to 400m J) , one notice the magnetic field confinement is accountable for improvement of electron number density in the existence of magnetic fields compared with without it.

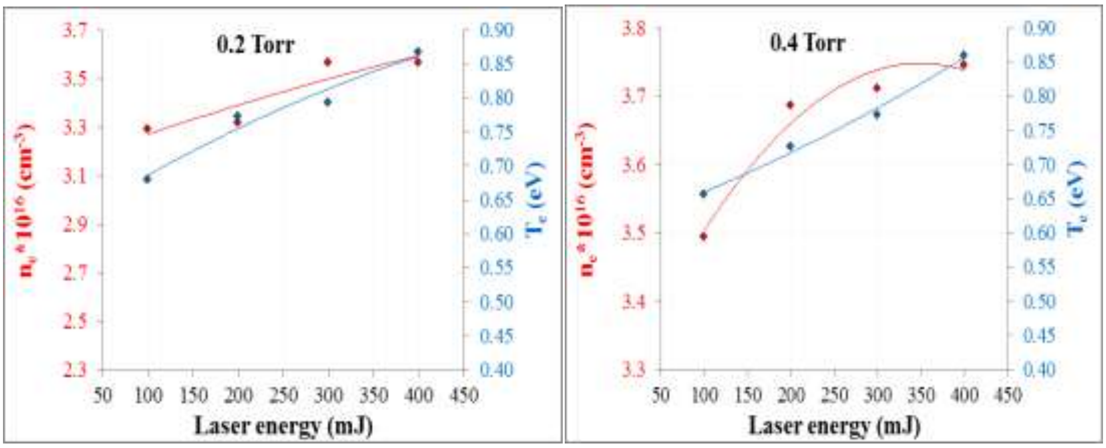

Figure 5- The difference of (Te) and (ne) against the laser energies for a Copper target with existence magnetic field

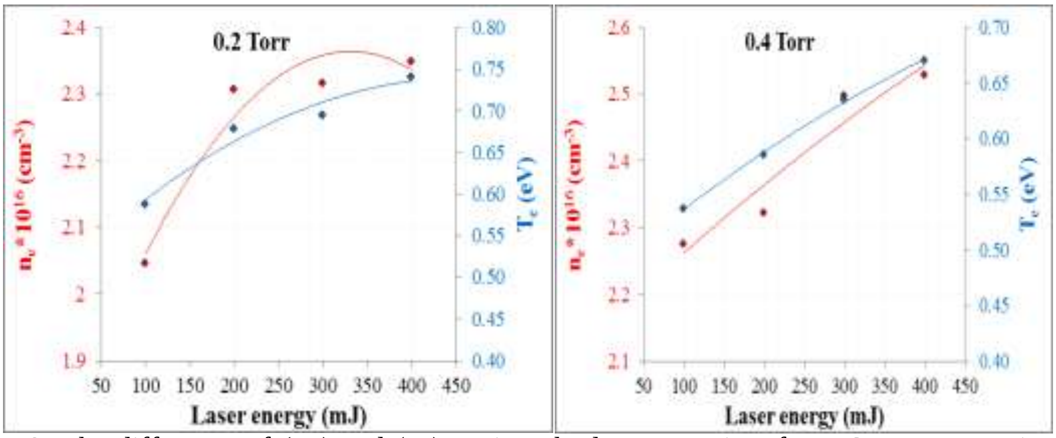

Figure 6- The difference of (Te) and (ne) against the laser energies for a Copper target in without magnetic field

Figures-7 and 8 remarked the radial profile of β–value along Cu target. One notice the values of beta are less than 1.This shows that the magnetic field confinement has been achieved ,values of beta in 0.4 Torr are less than in 0.2 Torr because the electron temperatures in 0.4 Torr are less than in 0.2 Torr .Plasma parameter in presence and absence magnetic field in all energy listed in Tables-1 and 2 show the evaluation electron density and electron temperature T_e n_e for Cu target at wavelength 1064 nm at different laser energies and different working pressure in presence and absence magnetic field. The values of electron temperature and electron density increase with increasing laser energy. Electron temperature decreases with increasing in working pressure because the increasing in collision causes to decrease in electron temperature, where the electron temperatures lose by inelastic collisions. In general the values of T_e and n_e with presence magnetic field are higher than their values absence magnetic field due to plasma confinement

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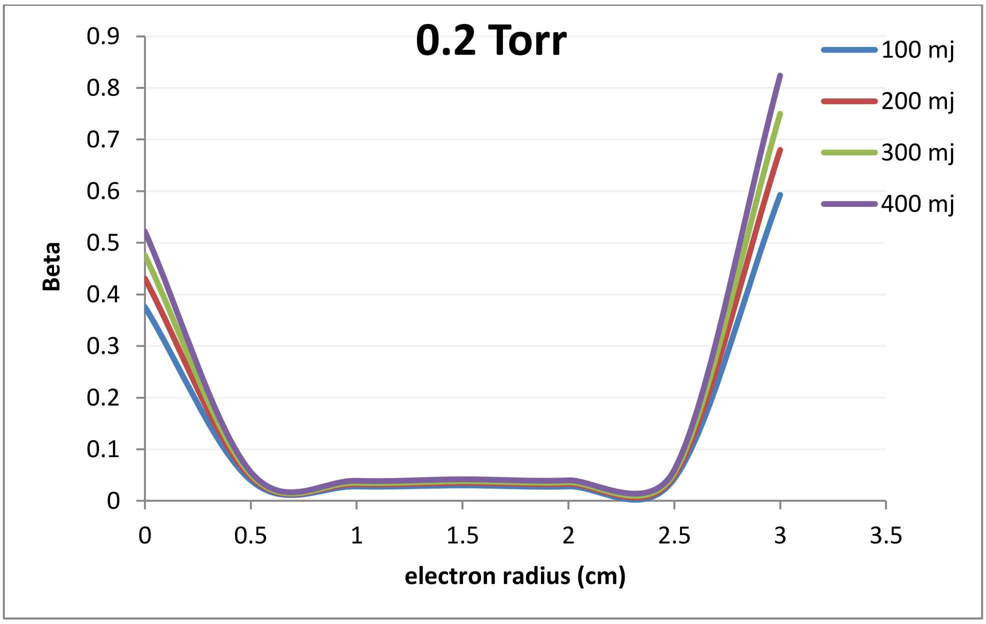

Figure 7 - The different of beta with the target radiul for a Copper target in 0.2 Torr

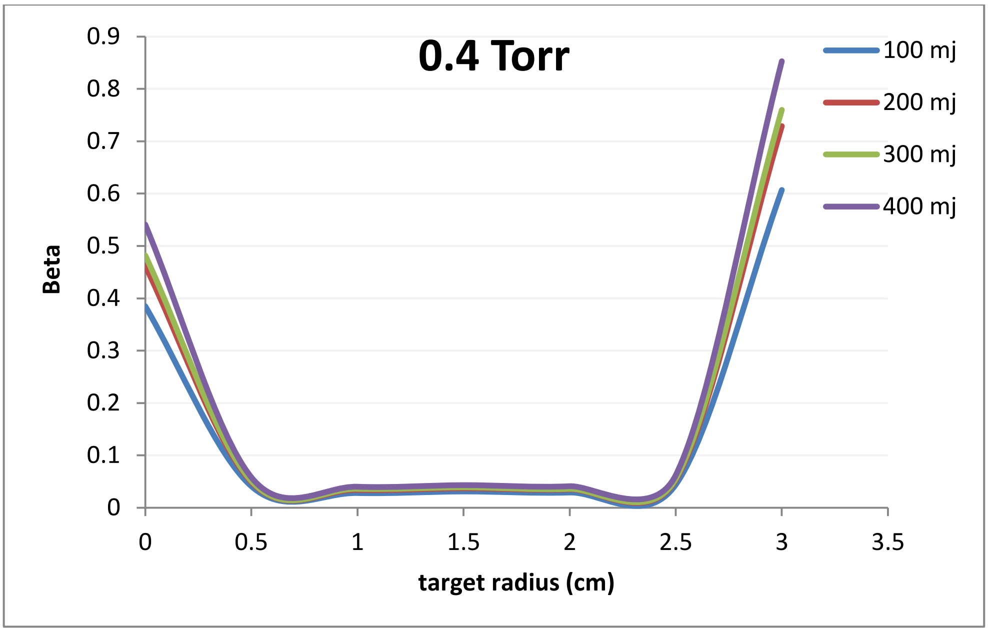

Figure 8- The different beta with the target radius for a Copper target in 0.4 Torr

Table 1- Plasma parameters for Cu target with different laser energies and different working pressure in presence magnetic field .

	E (mJ)	Te (eV)	$n_{e}*10^{16}$ (cm^{-3})
0.2 Torr	100	0.6801	3.2948
	200	0.7744	3.3186
	300	0.7943	3.5700
	400	0.8678	3.5862
0.4Torr	**E (mJ)**	**Te (eV)**	**$n_{e}*10^{16}$ (cm^{-3})**
	100	0.6568	3.4946
	200	0.7472	3.6878
	300	0.7737	3.7117
	400	0.8601	3.7473

Table 2- Plasma parameters for Cu target with different laser energies and different working pressure without magnetic field .

	E (mJ)	Te (eV)	$n_{e}*10^{16}$ (cm^{-3})
0.2 Torr	100	0.6244	3.1509
	200	0.7103	3.2307
	300	0.7663	3.3515
	400	0.8441	3.4801
0.4Torr	**E (mJ)**	**Te (eV)**	**$n_{e}*10^{16}$ (cm^{-3})**
	100	0.6267	3.2026
	200	0.6915	3.2419
	300	0.7256	3.4570
	400	0.7943	3.6372

Conclusions

By using the laser produce copper plasma, technique and the effect of the magnetic field were observed in the confirm the confinement of plasma through the measurement of plasma beta parameter , its value is less than 1.Plasma characteristic like electron density and its temperature increases with increase the laser energy from 100 to 400 mJ. Also, it found that the electron temperature and its density with the existence of the field are higher than in the absence it. The measured value of beta decreases with increasing working pressure.

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