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Investigation of Indian Costus Plasma Parameters Using Q-Switched Laser Nd:YAG

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Abstract

The Indian costus plasma properties are investigated, including electron temperature (T_e), electron density (n_e), plasma frequency (f_p), Debye sphere length λ_D, and amount of Debye (N_D), using laser-induced breakdown spectroscopy (LIBS). The study is done for different laser energies ranging from 300 to 600 mJ. The Boltzmann plot is used to calculate the temperature. The Indian costus is spectroscopically examined in the air with the laser 10 cm away from the target and the optical fiber 0.5 cm away. The X-ray fluorescence (XRF) analysis reveals that the Indian costus contains various minerals, each with a different percentage, which explains why the optical emission spectrum has so many peaks. Optical emission spectroscopy (OES) is used to analyze the plasma spectrum of the Indian costus in the air. The results show that as the laser energy grows, the amount of Debye will be greater, i.e (N_D) >>>1, at a laser energy of 300 mJ, N_D is 2.506775, as it increases to 600 mJ, N_D becomes 3.006884, the electron temperature T_e for 300 mJ is 1.86209223 eV as the energy increases, the T_e becomes 2.205687353 eV.

Article Info.

Keywords:
Indian Costus, Optical emission technique, Boltzmann Plot, Stark's Line Broadening, Laser deposition (PLD).

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1. Introduction

Indian costus, sometimes referred to as kuth root or costus, is a member of the flowering Asteraceae family. It is a well-known herb whose roots have been researched for therapeutic purposes in many traditional Indian medical systems. It grows in numerous places all over the world. It is used in many medical procedures to treat stomach disorders, ulcers, asthma, cough, cold, stomachache, toothache, typhoid, and fever. Indian medicinal systems employ a variety of formulations made from their roots for medical purposes. One of the largest angiosperm families, Asteraceae has around 23,600 species of plants, including trees, shrubs, and herbs in 1,620 genera. There are roughly 300 species in the Saussure genus [1]. Indian costus roots' chemical constituents have been studied since the 1950s. Many chemicals have been isolated, namely anthraquinones, alkaloids, and favonoids, but terpenes are the most active constituent [2].

Laser-induced breakdown spectroscopy (LIBS) has become a widespread technique in atomic spectroscopy due to its many benefits. Studying solids, liquids, and gases is possible using LIBS sampling initiated by optical absorption processes [3]. The plasma is created when the energy from the laser pulse warms, ablates, atomizes, and ionizes the sample material. A spectrograph and a detector are used to resolve and detect the plasma's light. The resulting plasma spectrum can be utilized to derive quantitative and qualitative information from the plasma, including its elemental composition. Information about plasma temperature and electron density can be gleaned from the widths, forms, and fluctuations of emission lines [4].

This work aims to study the plasma parameters of the Indian costus, which are electron temperature (T_e), electron density (n_e), plasma frequency (f_p), Debye sphere length, and amount of Debye (N_D), using the spectrum of optical emission technique for different energies between (300-600) mJ.

2. Material and Methods

The temperature of plasma is an important parameter. Boltzmann plot approach which assumes that local thermodynamic equilibrium (LTE) has been attained within the plasma, was used to calculate T_e. It offers a more precise way of measuring plasma temperatures in LIBS studies. The temperature (T_e) was obtained using the following equation [5]:

$$T_e = \frac{(E_2 - E_1)}{k \ln(\frac{I_1 \lambda_1 A_2 g_2}{I_2 \lambda_2 A_1 g_1})} \quad (1)$$

where, I is the intensity, g is the statistical weight, A is the probability of transformation, λ is the wavelength, E is the energy (in eV) of the excited state and k is Boltzmann constant.

The density (n_e) can be calculated using the following equation [6]:

$$n_e = \frac{I_1}{I_2^*} 6.04 \times 10^{21} (T)^{3/2} e^{\frac{(E_1 - E_2 - X_Z)}{kT}} cm^{-3} \quad (2)$$

where;

$$I_2^* = \frac{I_2 \lambda_2}{g_2 A_2} \quad (3)$$

X_z denotes the ionizing potential at ionizing level 2 Z (in eV), I_2 denotes the line intensity for a transfer from top-level 2 to level 1, g_2 denotes the statistical move weight from level 2, A_2 denotes the transition eventuality from level 2 to level 1, and the subscript z denotes the species ionization stage for the referred species [7].

One of the most fundamental plasma features is plasma frequency, which is purely reliant on plasma density [4]. It was computed using the following equation [8]:

$$f_p = 8.98 \sqrt{n_e} \text{ (Hz)} \quad (4)$$

Debye sphere length is the reaction of charged particles to limit the effect of local electrical fields, and it is this shielding that gives the plasma its quasi-neutrality property. The Debye sphere length is defined by [9, 10]:

$$\lambda_D = \sqrt{\frac{\varepsilon_0 k_B T_e}{n_e e^2}} = 7.43 \times 10^{2\sqrt{T_e/n_e}} \quad (5)$$

Compared with the machine dimension used to detect the spectra, Debye's length should be short. This first need is defined as follows for plasma life [11, 12]:

$$\lambda_D <<< L \quad (6)$$

L is the dimension (cm) of the device used to detect the spectra, while its width (in centimeters) is N_D. Describing the density of particles on Debye's surface, in which N_D>>>1 for the plasma condition, Debye length can be calculated from the following relation [13]:

$$N_D = \left(\frac{4\pi}{3}\right) n_e \lambda_D^3 \quad (7)$$

2.1. Indian Costus Plant Powder

The tablets (pellets) were made from a 1.5 g of Indian costus plant, crushed by a piston with a pressure of (6 Pa) for ten minutes: the resulting granules were with a diameter and thickness of 20 mm, according to the amount of material used, which were used to measure the emission spectra of Indian costus. Fig. 1 shows the hydraulic piston used. The powdered Indian costus plant and the pressed Indian costus plant powder are shown in Fig. 2.

Figure 1: The Hydraulic piston.

Figure 2: The Indian Costus plant powder and its pellets.

2.2. The Experimental Setup

A 1064 nm Nd:YAG laser with a 6 Hz pulse repetition rate and various energies ranging from 300 to 600 mJ was used to study the emission spectra of the Indian costus specimen. The laser was positioned 10 cm away from the sample. A lens with a short focal length, and shallow focus depth can produce a small beam waist, as seen in Fig. 3. As for the LIBS, the light emitted from the sample after being hit by the pulse laser was used to operate the spectrometer. The light emitted was examined in the setting using short response time spectrometer optics. An optical fiber was positioned at a roughly 45-degree angle, as shown in Fig. 3. The spectrum analyzer detects the spectrum emitted from Indian Costus plasma within a spectral range of (300-600) nm [12, 14].

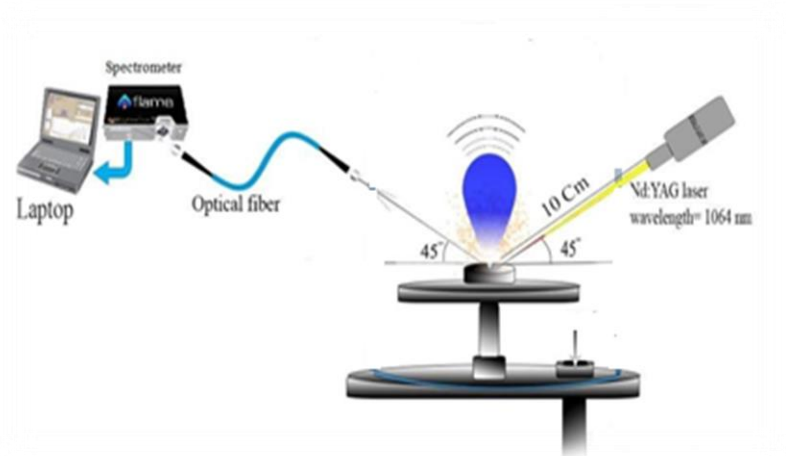

Figure 3: The experimental setup of laser induces plasma spectroscopy.

3. Results and Discussion

X-ray fluorescence (XRF) technique has been used to study the properties of the Indian costus. The chemical elements with their maximum concentrations of Indian costus specimens acquired using the XRF examination technique are listed in Table 1; elements with low concentrations are not listed because they have no effect on the result.

Table 1: The elements Concentration for Indian Costus Powder.

Symbol	Elements	Concentration
MgO	Magnesium	0.3336%
Al_2O_3	Aluminum	2.644%
SiO_2	Silicon	4.119%
K_2O	Potassium	2.211%
CaO	Calcium	1.242%
Fe_2O_3	Iron	0.261%

3.1. Optical Emission Spectroscopy Analysis (OES)

Optical Emission Spectroscopy Analysis (OES) was used to measure the emission spectra of Indian costus plasma created in the air at different laser energies (300-600 mJ). The spectral region (300 to 600 nm) was used to record the emission spectra. It is used to determine the temperature of electrons as well as the density of electrons. As a result, the produced plasma's properties (such as plasma frequency) were calculated. The spectra of the Indian costus plasma in the air were created at various laser strengths (300-600 mJ) using an optical emission spectroscopy technique. Emission spectra were recorded in the format spectral range of (250 to 850 nm).

Fig. 4 depicts the Indian costus emission spectra for different energies of the atoms and ions of the elements that make up the Indian costus; the intensity of the peaks grew as the laser energy increased, as seen in Fig.4 (one peak is used in the air at 380.93 nm). The fitted lines of the plots have a slope of -1/T and R^2, which is the statistical coefficient that represents the linear suitability efficacy that spans from 0 to 1. A corresponding fitted equation and R^2 value were provided for each composition line. An R^2 number that is closest to 1 is the best. Table 2 shows the laser energy and statistical coefficient (R). The best energy value that gave a linear suitability closest to 1 (an R^2 value of 0.8542) was 600mJ. As the laser energy increased, the linear suitability increased.

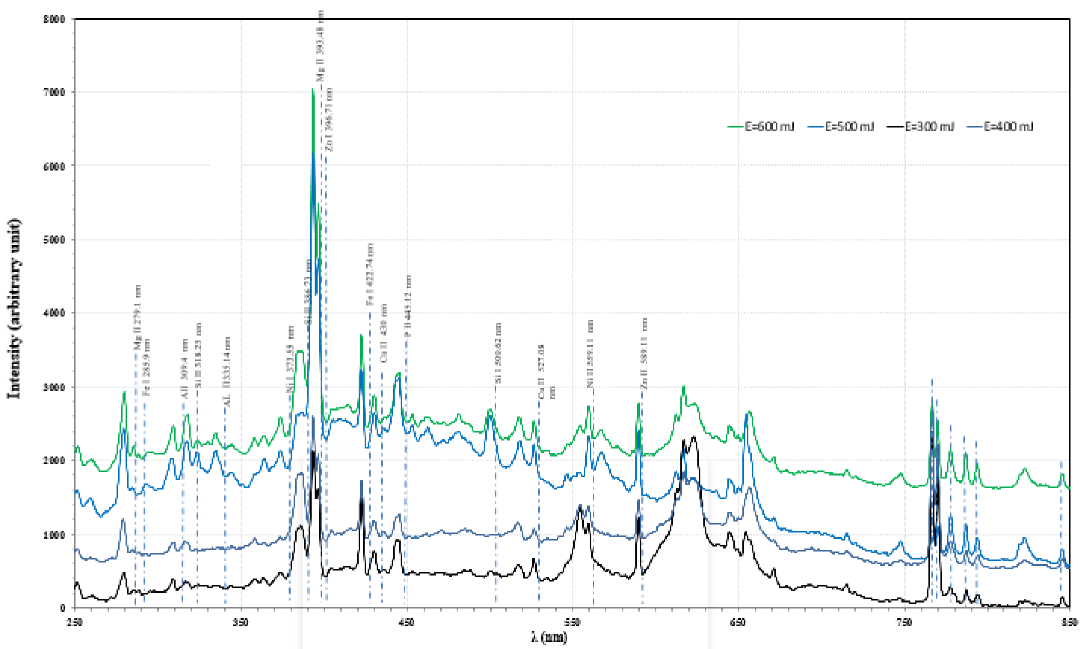

Figure 4: The Optical Emission Spectra for Indian Costus Plasma Produced in the Air with Different Laser Energies.

The distribution of the Indian costus target is shown in Fig.5 which describes the stark distribution of the Indian costus target with various laser energies. Table 2 shows the Laser energy and statistical coefficient (R), the best energy value that gives linear suitability is 600mJ; it gives value of 0.8542 which is the value of statistical coefficient closer to one, as the energy increase the suitability increase.

The distribution of the Indian costus is shown in Fig. 6, which describes the Stark distribution of the Indian costus for different wavelengths at various laser energies. The intensity increased as the energy increased. Fig. 7 shows the measured electron temperature (T_e) values deduced using Boltzmann plots as a function of the laser energy. It was noted that as the laser pulse energy increases, the temperature of the electron (T_e) and the density of the electron (n_e) increase in the air. At high laser powers, the duration of Debye (D) grows with rising laser energy.

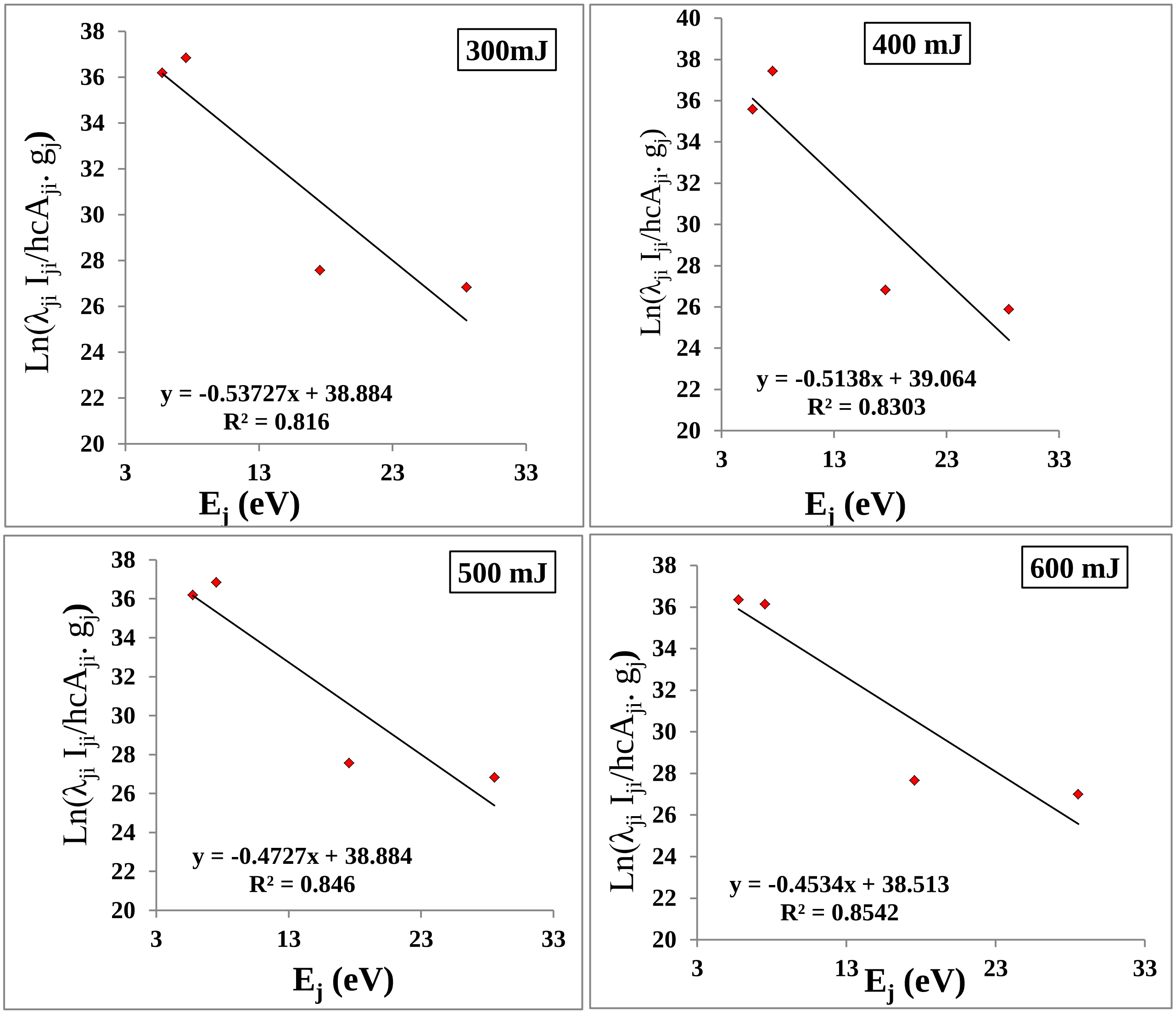

Figure 5: Boltzmann plots of Indian costus targets with different laser energies in the air.

Table 2: Laser Energy and Statistical Coefficient (R^2).

Energy(mJ)	Statistical coefficient (R^2)
300	0.816
400	0.8303
500	0.846
600	0.8542

As shown in Fig. 8 and Fig. 9, the plasma frequency (f_p) is directly proportional to the laser energy. The Boltzmann plot equation indicates that as the laser pulse energy grew, the electron temperature (T_e) and density (n_e) increased in the air, as seen in Fig. 7.

Fig. 9 illustrates the length of Debye (λ_D) with laser energy; it increases with increasing laser energy; and the plasma frequency (f_p) which increases as the laser energy increases because it is proportional to density (n_e).The plasma parameters for different values of laser energy (300-600 mJ) are shown in Table 3. (f_p) and (n_e) of Indian costus increased with the increase of the laser energy. The results showed that all plasma properties increased as the laser energy increased.

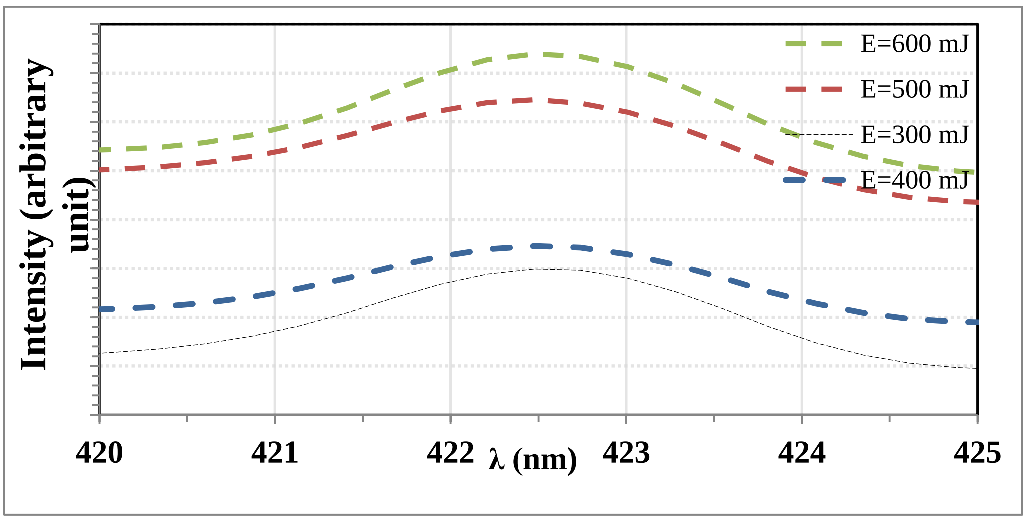

Figure 6: The Stark distribution of the Indian costus target for different wavelengths at different Laser Energies.

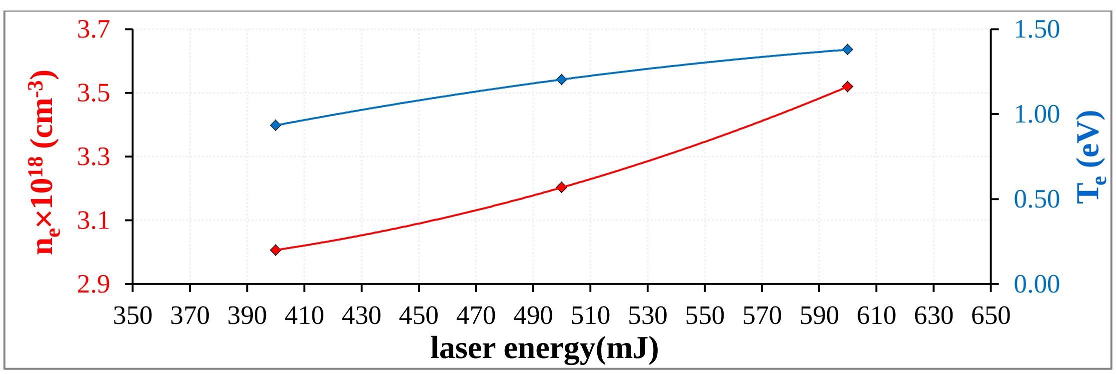

Figure 7: (Te) and (ne) against Laser Energy of the Indian costus target.

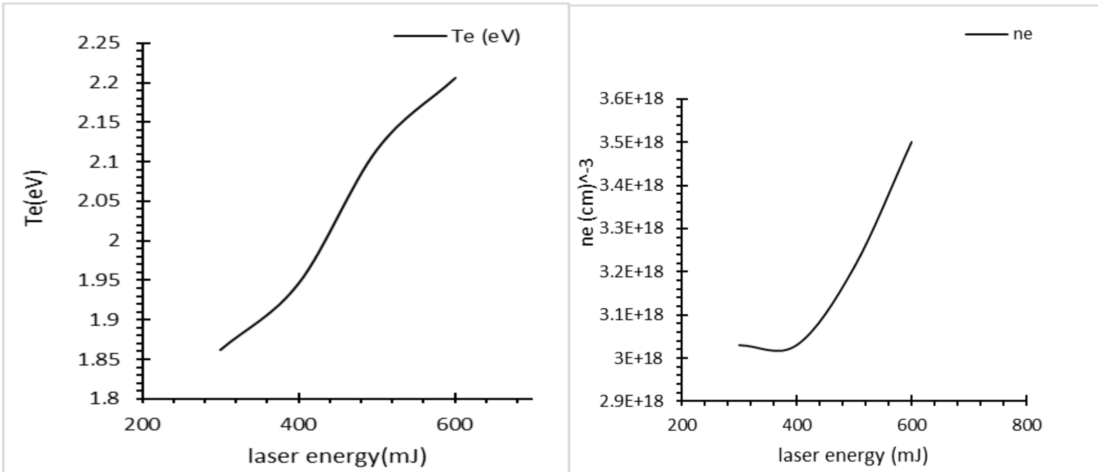

Figure 8: (T_e) and (n_e) against Laser Energy of the Indian costus Target.

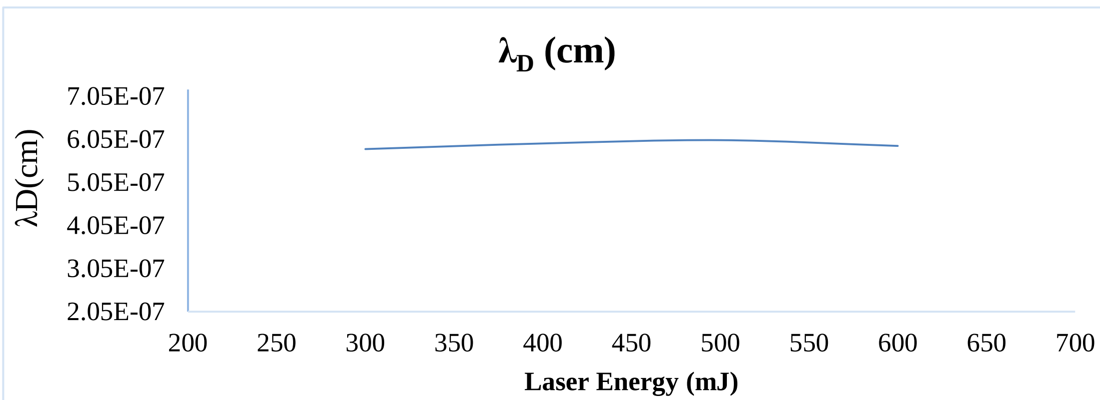

Figure 9: The determination of Debye length (λ_D) and the plasma (f_p).

Table 3: Plasma parameters for Indian costus with different laser energies in the air.

Laser energy (mJ)	FWHM (nm)	T_e (eV)	$n_e \times 10^{18}$ (cm^{-3})	fp $\times 10^{13}$ (Hz)	$\lambda_D \times 10^{-7}$ (cm)	N_D
300	2.83	1.86209223	3.03	1.56314	5.82463	2.506775
400	3.03	1.946256048	3.03	1.56314	5.9548	2.678635
500	3.21	2.115392211	3.21	1.6089	6.03159	2.948959
600	3.5	2.205687353	3.5	1.68	5.8983	3.006884

4. Conclusions

The Indian costus plasma parameters were studied using the LIBS technique. Increasing the laser's power causes an increase in the electron condensation in various laser atom forces, as well as an increase in Debye length, plasma frequency, and the number of Debye particles; it also results in a slight increase in the electron's temperature. Indian costus plasma parameters grew as the laser energy increased. The energies employed were between (300 and 600 mJ), higher energies will destroy the bonds that make up the substance; for this reason, and high energies have not been used. A plasma spectrum can be produced from the Indian costus; this was investigated from the value of N_D where $N_D >>> 1$.

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Conflict of interest

Author declares that they have no conflict of interest.

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التحقق من معلمات بلازما القسط الهندي باستخدام Q-Switched Laser Nd: YAG

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الخلاصة

تم فحص خصائص بلازما القسط الهندي بما في ذلك درجة حرارة الإلكترون (T_e) ، "كثافة الإلكترون (n_e)" ، "تردد البلازما (f_p)" ، "طول كرة ديباي λ_D" ، وكمية ديباي (N_D) ، باستخدام تقنية الانبعاث البصري . هناك العديد من الطاقات المستخدمة ، تتراوح من 300 إلى 600 ميغا جول. يتم استخدام مخطط Boltzmann لحساب درجة الحرارة. تم فحص القسط الهندي طيفيًا في الهواء باستخدام الليزر على بعد 10 سم من الهدف والألياف الضوئية على بعد 0.5 سم. يكشف تحليل XRF أن القسط الهندي يحتوي على مجموعة متنوعة من المعادن ، لكل منها نسبة مئوية مختلفة ، وهو ما يفسر سبب احتواء طيف الانبعاث البصري على العديد من القمم. عندما تكون طاقة الليزر (بين 300 و 600 ميغا جول) ، يتم استخدام "التحليل الطيفي للانبعاثات الضوئية (OES)" لتحليل طيف البلازما في القسط الهندية في الهواء. تظهر النتائج أنه مع ازدياد طاقة الليزر ، ستكون كمية ديباي أكبر من 1 <<< (N_D) ، عندما تكون طاقة الليزر 300 مللي جول ، فان N_D تكون 2.506775 وعندما تزداد إلى 600 مللي جول ، يصبح N_D مساوي 3.006884، درجة الحرارة الإلكترون T_e لـ 300 مللي جول هي(eV 1.86209223) عندما زادت الطاقة لل 600 مللي جول أصبحت درجة حرارة الالكترون eV 2.2.205687353 T_e.