INVESTIGATION THE HOLMIUM EMISSION SPECTRA IN THE (200-400) NM REGION

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Abstract

In this work plasma emission spectra and atomic structure of the holmium target by Q-switched Nd:YAG laser (1064 nm) has been studied. This work was done theoretically and experimentally. Cowan code was used to get the emission spectra for different transition of the holmium target. In the experimental work, the influences of the laser pulse energy and pulse repetition rate on the emission lines intensity of the laser induced plasma spectrum by spectroscopic technique in air has been investigated. Three laser pulse energies (600, 700 and 800) mJ with repetition rate (5Hz, and 20Hz) are used. The result indicate that, the emission line intensities increase with increasing of the laser pulse energy and repetition rate. The holmium target can give a good emission spectra in the UV region (200-400) nm. The best emission spectra appeared when the laser pulse energy is 800mJ and 20 Hz repetition rate at λ= 341.54nm, 342.76nm, and 345.53nm with the maximum intensity of 80000 counts.

Key words : Emission spectra, pulse energy, Nd-YAG laser, holmium.

I. Introduction

The plasma produced by intense laser pulse can give information about qualitative and quantitative analyses of the sample [XII]. Plasma emissions provide spectral signatures of many different type of materials in solid, liquid, or gas state [XIV]. The plasma emitted light consists of discrete lines, bands, and an overlying continuum [IX]. The continuum emission of plasma is emitted as a result of free-free and free-bound transitions. It is very important to determine plasma parameters, such as electron temperature, pressure, and electron density, which are very important to characterize plasma [II,X]. Transitions between bound states in an atom give rise to discrete lines. Such lines observed in both absorption and emission spectra, these discrete lines, are very important to characterize the material, and have three main features. Wave length, intensity, and shape [IV]. These parameters depend on both the structure of the emitting atoms, and their environment.
In this work, pure holmium ($Z = 67$) was used, Holmium (Ho) is the eleventh element of the so-called lanthanides, or the rare Earth element group that has only one stable isotope (165Ho). This isotope has a nuclear spin of $I = 7/2$. [III]. Spectra of rare earth elements, are of astrophysical interest, for example, experimental data are needed for the quantitative evaluation of element abundances due to the unfilled 4f electron shell [XI]. The spectra of all rare earth elements are very dense and complex [VIII]. All these spectra are far from being fully identified. In general, more than half of the lines that occur in a rare earth spectrum are neither currently classified nor classifiable on the basis of known energy levels [V].

The main focus of this paper is to classify the spectral lines intensity of holmium target in the 200 - 400nm spectral range at different laser pulse energy with different repetition rate. The results obtained show that the emission intensity changes considerably with the laser energy used. Cowan code is the most widely available numerical computer code for calculating atomic structure.

This fortran code was comprised by Robert D. Cowan in 1968 [XV]. Based on Hartree-Fock equations, Cowan code is also employs several other approximations such as Hartree-Fock [XIII], with exchange in which different methods are used for self-interaction correction and another method to approximate the remainder of the Hartree-Fock exchange term [XVI].

II. The Experimental Set-up:

The experimental setup for obtaining the emission spectra for the plasma in the uv region can be shown in Fig (1).

![Fig 1.1: Schematic diagram of the experimental setup for laser induced plasma](image)

The setup consists of Nd:YAG laser source for plasma generation and vaporization of the target. The 1064nm beam from a Q-switched Nd:YAG laser, with (10 ns) pulse width and (1-20)Hz pulse repetition rate(PRR) , emitting a laser pulse with maximum energy (920) mJ. The laser beam was focused horizontally onto the target surface by Bi-convex lens with (100 mm) focal length. The distance from the lens to the target was set to about (100 mm) in order to gain a nearly spherical plasma plume and a
reproducible breakdown. The plasma was generated in air at atmospheric pressure on (1.75 mm²) surface area of the metal target. The content purity of the target was almost 99.9%. The emission was collected by the optical fiber which was set at angle of about 45 degree of the target and diverted into a spectrometer connected to the laptop. The spectrometer has a high resolution to analyze the emission lines spectra. Different laser parameters have been used in this work. Different laser pulse energies of (600 mJ, 700 mJ, and 800 mJ) are focused each time with different repetition rate of (5Hz, and 20Hz).

III Results

i. Holmium Emission at 5Hz Repetition Rate

The maximum intensity of holmium line emission was appeared at (λ = 345.75 nm), when the laser pulse energy was (600 mJ) with a maximum intensity (58000), as shown in figure (1.2).

If the laser pulse energy is increased to (700 mJ), the intensity of the emission line is also increased, and the maximum intensity of emission spectra was (70000 at λ = 345.75 nm), as shown in the figure (1.3).

![Fig. 1.2: laser energy 600 mJ with (5Hz) repetition rate.](image-url)
Fig. 1.3: laser energy 700 mJ with (5Hz) repetition rate.

The results of figure (1.4) indicate that, when the laser pulse energy is increased to (800 mJ), the maximum intensity of the emission spectra was (80000 at $\lambda = 345.75$ nm).

Fig. 1.4: laser energy 800 mJ with (5Hz) repetition rate.

Fig. 1.5: the emission spectra of laser induced holmium plasma with different laser energies and (5 Hz) repetition rate.
In figure (1.5). It is observed that the maximum intensity of holmium line emission appeared at (345.75 nm), when the laser pulse energy increased of (600 mJ, 700 mJ, and 800 mJ) respectively, and the maximum intensity was also increased from (58000 to 70000, and then to 80000) respectively.

ii. Holmium Emission at 20 Hz Repetition Rate

Using of (600mJ) laser pulse energy with repetition rate (20 Hz) a maximum holmium line emission intensity at (λ = 345.53 nm), with maximum intensity of 55000. Fig. (1.6).

Increasing the laser pulse energy to (700 mJ) lead to increase the intensity of the emission line. Many line emission spectra have been observed. The maximum intensity was (70000 at λ = 341.54 nm and 345.53 nm) respectively, as shown in the figure (1.7).

![Fig.1.6: laser energy 600 mJ with (20Hz) repetition rate](image1)

![Fig.1.7: laser energy 700 mJ with (20Hz) repetition rate](image2)
The results of figure (1.8) explain that, when the laser pulse energy increased to (800 mJ), the maximum intensity of the holmium line emission spectra was 80000 for the three emission lines at (λ = 341.54nm, 342.76nm, and 345.53nm) respectively.

![Figure 1.8: laser energy 800 mJ with (20Hz) repetition rate.](image)

![Fig.1.9: the emission spectra of laser induced holmium plasma with different laser energies and (20 Hz) repetition rate](image)

Figures (1.9) shows many maximum line emission intensity appeared at (λ= 341.54nm, 342.76nm and 345.53nm) with the maximum intensity at (80000), when the laser pulse energy (800 mJ) and (20 Hz) repetition rate. The intensities of the emission lines increase with increasing of the laser pulse energy and repetition rate [VI]. The increasing of the pulse energy means the increase of its absorption by the plasma leading to more ablation from the target and finally increasing of the emission line intensity [I], [VII]
Figure (1.10) represents the emission spectra for Ho II (Dy like) ion. The first ionization stage (Ho II) ion theoretically computed using Cowan code covering wavelength region between (340 to 360) nm has been presented. From computational method it has been illustrated that the emission spectra when $\lambda= 345.75$nm is from transition (4f) 5d, while the emission spectra at $\lambda= 341.54$nm is from transition (4d) 6b, and at $\lambda= 342.76$nm is come from transition (4f) 6p, and $\lambda=345.53$nm it has been assigned transition from (4d) 6p.

**IV. Conclusion**

The emission spectroscopy of the laser-induced plasma in air was investigated. The spectral line intensities of the laser induced plasma emission exhibited a strong dependence on pulsed laser energy and repetition rate. Many maximum line emission intensity appeared at ($\lambda= 341.54$nm, 342.76nm and 345.53nm) with the maximum intensity at (80000), when the repetition rate (20 Hz) and (800 mJ) laser pulse energy, Theoretically using Cowan code have been assigned as transition from (4d) 6b, (4f) 6p, and (4f) 6p respectively. The increasing of the laser pulse energy and repetition rate means many maximum emission intensity appeared at the same maximum intensity. From these results, it can be concluded that the emission intensity shows a marked dependence on the laser energy and repetition rate.

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