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SPECTROSCOPY CHARACTERISTICS OF QUASI THREE LEVEL LASER TRANSITION INDUCED BY FLASHLAMP PUMPED ND:YAG LASER

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Abstract. Laser transition at 946 nm from flashlamp pumped Nd:YAG crystal is investigated. The fluorescence radiation induced after pumping is observed via spectrometer. The spectra comprised of absorption and emission lines. The optimum absorption fluorescence is found to be at thermal boosted line of 882 nm. This is an indicator of less heat generation involve in the laser transition. This is confirmed by the generation quasi three level transition at 946 nm. The stimulated emission cross section of 946 nm is estimated to be three times greater than that reported by previous researcher.

Keywords: Quasi three level laser; thermal boosted line; four level laser transition; Nd:YAG; flashlamp; cross section

Abstrak. Transisi laser pada 946 nm daripada lampukilat pum Kristal Nd:YAG telah dikaji. Sinaran pendaflour yang diaruh selepas pengepaman diperhatikan melalui spektrometer. Spektrumnya terdiri daripada garis penyerapan dan pancaran. Pendaflour penyerapan optimum didapati pada garis penggalak terma 882 nm. Ini adalah petanda kurangnya penglibatan janaan haba dalam transisi laser. Ini disahkan melalui penjanaan transis aras tiga pada 946 nm. Kawasan rentasan pancaran rangsangan pada 946 nm dianggarkan tiga kali lebih besar berbanding daripada kebiasaan yang dilaporkan oleh penyelidik terdahulu.

Kata kunci: Kuasi laser aras tiga; garis penggalak terma; transisi laser aras empat; Nd: YAG; Lampukilat; kawasan rentasan

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1.0 INTRODUCTION

Since the discovery of the first solid-state laser by Maiman in 1960, a variety of laser materials has been developed among which the most practical and widely accepted host is the yttrium aluminum garnet (YAG). The trivalent neodymium activated YAG system Nd:YAG has been exploited most fully in commercial optical technology and is the basis of a major solid-state laser industry now. Garnet structure oxide crystals doped with a rare-earth ion possess a unique combination of spectral and laser properties, as well as high mechanical strength, thermal conductivity, optical transparency over a wide spectral region and high stimulated emission cross section. These remarkable properties place these compounds among the most attractive candidates in quantum electronics and its applications [1].

In recent years, much attention is made to produce Nd:YAG laser at 946 nm wavelength due to the possibility of frequency conversion of 946 nm laser line into blue light. However, the generation of 946 nm line is difficult to achieve because of the smaller emission cross section of this transition and significant thermal population of the lower laser level as compared to 1064 nm emission [1].

The room temperature spectrum properties and stimulated emission cross section of Nd:YAG crystals have been studied [2, 3]. Recently, Rapaport [4] studied the temperature dependence of the 1064 nm emission cross section and lifetime of the Nd doped YAG crystal over the range of temperatures from -70°C to +70°C. Furthermore, the stimulated emission cross-section of the laser transitions of Nd^{3+}:YAG crystals is dependent on temperature [4, 5] and input energy, and the variation of cross-section will affect the lasing performance characteristics, such as threshold, output power, pulse width, etc.

An alternative way needs to be identified in order to enhance the generation of 946 line. One initiative has been taken by pumping Nd:YAG rod using a novel flashlamp driver. In this paper, the spectroscopic properties of Nd:YAG laser pumped by the new flashlamp is investigated. The cross section as well as the saturation intensity of the light is also discussed in detail.

2.0 THEORY

2.1 Stimulated Emission Cross Section

Stimulated emission cross section is a fundamental quantity to characterize an active medium and play an important role in modeling laser performance. However, the stimulated emission cross section for a specific transition between two states of an active ion can be determined from the spectral properties of the intensity of the emission line. The neodymium emission from YAG is not polarization dependent, so the emission spectra could be used to calculate the effective stimulated emission cross section of a Nd^{3+} ion by applying the F–L formula [4, 6]:

$$\sigma = \frac{\lambda^4 \eta \beta}{4\pi^2 n^2 c \tau_f \Delta\lambda} \tag{1}$$

where λ is the wavelength, η is the quantum efficiency (assumed to be close to 1), β is the branching ratio for the corresponding inter-Stark transitions, n=1.82 is the refraction index, c is the velocity of light, and τ_f= 230 μs is the fluorescent lifetime of the upper level from which the transition occurs.

2.2 Saturation Intensity

Reducing the threshold energy is a very important parameter for laser action especially for quasi three level lasers. A major contribution to this phenomenon could come from the reduction in re-absorption process. The emission threshold for laser operation is directly proportional to the saturation intensity which is given by [7]

$$I_s = \frac{hc}{\sigma \tau_f \lambda} \tag{2}$$

where h is Planck's constant. Material with a large stimulated emission cross-section and long fluorescence lifetime tends to induce low I_s and hence low threshold laser.

3.0 EXPERIMENTAL SETUP

A Nd:YAG laser rod with doping level 1 % is employed as an active medium. The diameter of the rod is 4 mm with cylindrical length of 70 mm. Both ends of the laser rod are cut at Brewster angle in order to polarize the beam besides minimizing the reflection.

A linear flashlamp filled xenon gas at pressure of 450 Torr is placed parallel to the laser rod in an alumina ceramic reflector for side pumping technique. The flashlamp is powered by a new driver [8]. The free running flashlamp is operated in a single and repetitive mode.

The active medium together with the flashlamp are flooded with water coolant to stabilize the output as well as to self filtering the infrared beam. The flashlamp is enclosed with a samarium flow tube to absorb UV light radiation and to keep a steady state of water coolant flow rate. The coolant temperature is set at 18°C.

The fluorescence radiation emitted after excitation is recorded via an Ophir Wavestar spectrometer. The couple charge device CCD camera is located at a distance of 20 cm from the oscillator. The absorption and emission spectra are analyzed via Wavestar version 1.05 software. The whole experimental set-up is shown in Figure 1.

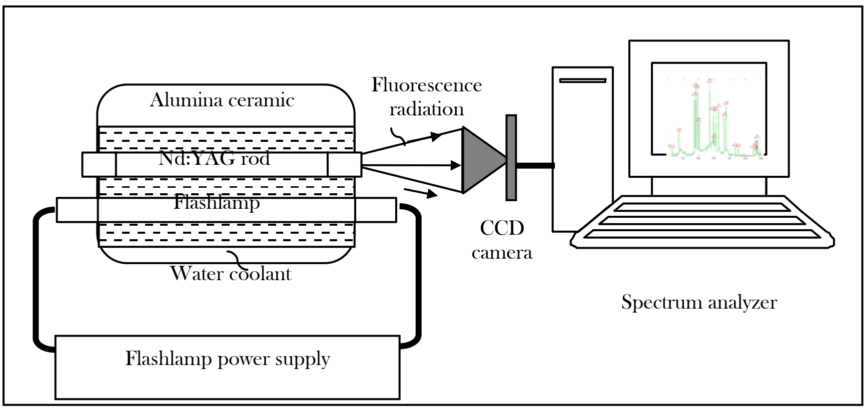

Figure 1 Schematic diagram of experimental set-up

4.0 RESULT AND DISCUSSION

The selection of flashlamp as a pumping source is important to ensure the production of the radiation spectrum matched with the absorption band of Nd:YAG laser crystal [9].

Typical spectrum of xenon flashlamp pumped by a novel driver is shown in Figure 2. The fluorescence radiation covered in the range of 540 – 1080 nm. The spectrum comprises atomic lines and continuum components. The atomic lines correspond to the discrete transition between the bound energy states of the gas atoms and ions which also known as bound-bound transitions. While the continuum part is primarily due to recombination radiation from gas ions capturing electrons into bound state and bremsstrahlung radiation from electrons accelerated during collisions with ions.

The intensity of longer wavelengths at low current density is prominent than shorter wavelength such as shown in spectra *a* in Figure 2 when the capacitor of the flashlamp is charged by 300 V. As the current density increases by charging the capacitor at higher voltage of 700 V as shown in spectra *b*, the continuum part almost dominant implying that shorter wavelengths are greater intensity than longer wavelengths.

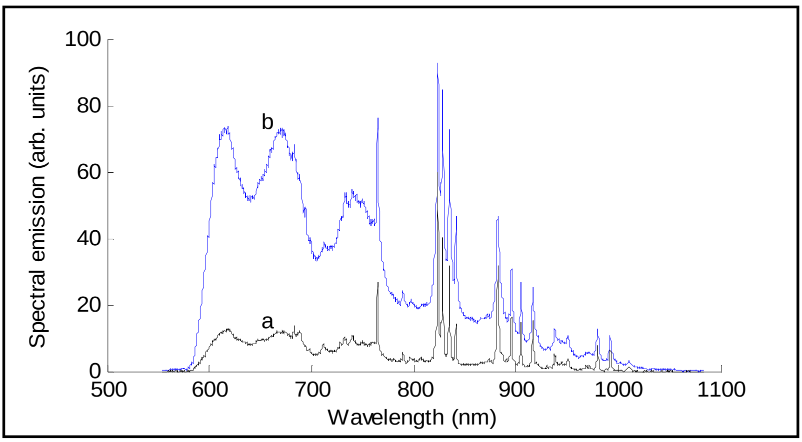

Figure 2 Spectral emissions from Xenon flashlamp at pressure of 450 torr (150-μF capacitor charged to (a) 300 V and (b) 700 V)

The main absorption band of Nd:YAG are reported to be at 0.525 - 0.585 μm, 0.73 - 0.75 μm and 0.79 - 0.9 μm as illustrated in Figure 3 [7]. The spectrum of xenon flashlamp pumped by this new driver is shown in Figure 4. The major absorption lines includes of 764.59 nm, 823.79 nm, 834.92 nm, and 841.29 nm, 882 nm which are responsible to excite Nd^{3+} from ground state ($^4F_{9/2}$) to upper level state ($^4F_{3/2}$). Clearly seen that the 882 nm, which known as direct pumping line is the optimum absorption line.

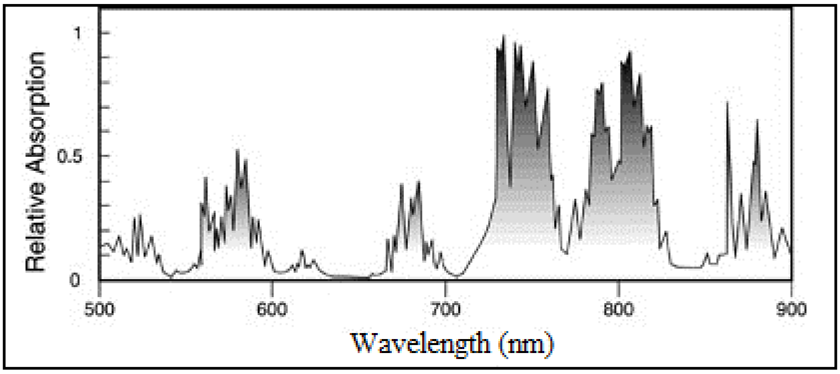

Figure 3 Absorption spectrum of Nd:YAG [7]

The emission lines comprise of quasi three level at 938.5 and 946.0 nm and four level that are 1064, 1061 and 1051 nm respectively. The branching ratio for the inter-Stark transitions is calculated by comparing the area embraced by the inter-Stark transitions to the total area of the inter-manifold transition [6]. The calculated branching ratio of inter-Stark transitions are summarized in Table 1.

The measurement of linewidth from each of the transition lines is important for computing the emission cross section using Eq. (1). The calculated results are also presented in the same Table 1. The average emission cross section of 946 and 1064 nm are 1.51×10^{-19} cm^2 and 3.67×10^{-19} cm^2 respectively. The result of 1064 nm is in good agreement with other researchers [10]. Entirely different result is obtained with line 946 nm. It is found that three times greater than usual [10].

Furthermore, the transition lines of the fluorescence emission spectra are also investigated at various input energies by manipulating the capacitor voltage of the flashlamp driver in the range of 300 - 700 V. The peak stimulated emission cross sections calculated with Eq. (1) are depicted in Figure 5. The Nd:YAG stimulated emission cross section at 1064 nm is constant whereas the stimulate emission cross section at 946 nm varies linearly with a negative slope of 4.3 × 10^{-21} cm^2/J. This indicates that the line 946 nm is decreasing with pumped voltage.

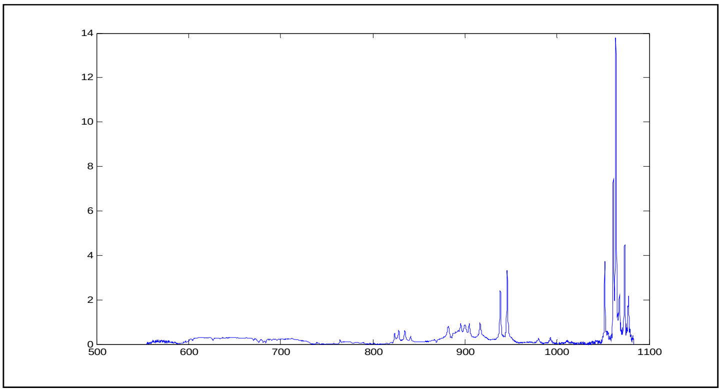

Figure 4 Fluorescence spectrum of a new flashlamp pumped Nd:YAG at 300 K

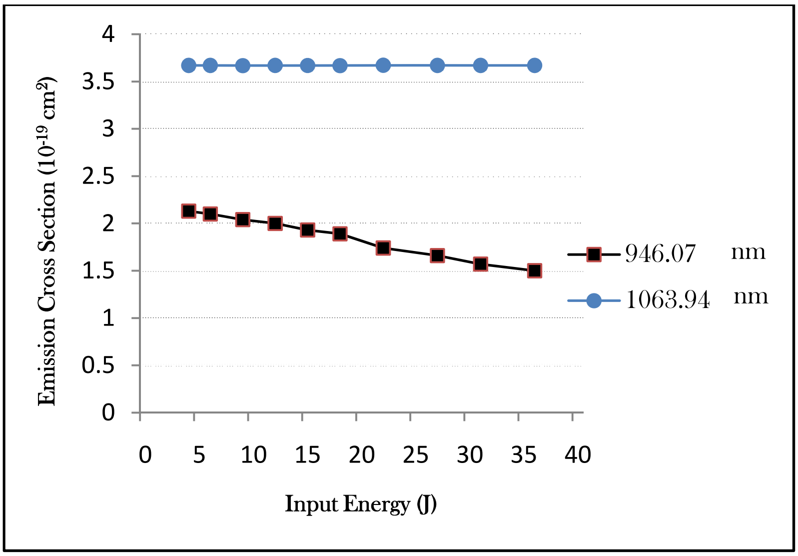

Figure 5 Stimulated emission cross section of 1% Nd:YAG for different laser transition

Table 1 Spectroscopic properties for some inter-stark transitions

Wavelength (nm)	**Branching Ratio**	**Average Linewidth (nm)**	**$\sigma_E \times 10^{-19}$ (cm^2)**	**$I_s \times 10^3$ (Wcm^{-2})**
938.44	0.265	1.98	1.26	8.04
946.07	0.342	1.92	1.85	6.02
1051.86	0.144	1.09	1.83	4.47
1061.46	0.219	0.99	3.17	2.56
1063.94	0.328	1.33	3.67	2.20
1073.76	0.113	1.14	1.49	5.37

5.0 CONCLUSION

The optical properties of Nd:YAG laser rod pumped by a new flashlamp is studied by spectroscopic technique. The spectrum of fluorescence radiation indicates that, the absorption line is peak at 882 nm, implies that the neodymium ions are directly pumped by thermal boosted line. Consequently the stimulated emission cross section of 946 nm is found to be three times greater than usual at room temperature.

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