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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

LAMP SERIES REPORT

(Laser, Atomic and Molecular Physics)

DEVELOPMENT OF TUNABLE FLASHLAMP EXCITED DYE LASER SYSTEM

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1991 MIRAMARE - TRIESTE

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DEVELOPMENT OF TUNABLE FLASHLAMP EXCITED DYE LASER SYSTEM

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ABSTRACT

A tunable flashlamp excited dye laser (FEDL) was successfully developed for the first time in Thailand by Thai scientists at KMIT Thonburi (Bangmod). The Rhodamine 6G dissolved in ethyl alcohol was utilized as a laser medium and circulated by a pump through a laser head. The dye cuvette had an inner diameter of 4.0 mm and was 90 mm long. The cavity mirrors M_1 and M_2 were concave mirrors with reflectivities of 100% and 73% respectively. A power supply of 0-20 kV and current of 0-50 mA charged a capacitor of 0.3 μ f at 10-15 kV which was then discharged via a spark gap through the flashlamp. The output laser wavelengths was tunable from $\lambda = 550-640$ nm. It is the first FEDL system, locally developed, which has a tunable wavelength for the laser output. The laser pulse width is about 1.0 μs with energy of 20 mJ and peak power of 20 KW. The repetition rate of the laser is 1/15 Hz.

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I. Introduction

The Dye laser was invented independently by F.P. Schäfer, W. Schmidt, and J. Volze [1], and P.P. Sorokin, and J.R. Lankard [2] in 1966. Since then there has been development of various types of flashlamp excited dye laser (FEDL) [3, 4, 5]. In recent years, there have been many direct applications of dye lasers in medicine, industry and in pollution control. There have been attempts to develop flashlamp excited dye lasers at the Scientific Instrument Centre for Standard and Industry, King Mongkut's Institute of Technology (KMIT) Thonburi since 1986. Finally, the first flashlamp excited dye laser of Thailand was successfully developed there in January 1988 The dye Rhodamine 6G ($C_{28}H_{31}N_2O_3Cl$) dissolved in ethanol at concentration of 2×10^{-4} M/litre was utilized as a laser medium in which the laser output wavelength λ = 550-600 nm was produced. The laser was the first FEDL system developed locally with tunable wavelength. The laser system was developed by utilizing indigenous technology and local material as much as possible.

The FEDL system consisted of a dye cuvette of inner diameter 4.0 mm and 90 mm long. The flashlamp is a linear xenon flashlamp. Both the cuvette and the flashlamp were at the foci of an elliptical cavity. The dye solution of Rhodamine 6G was circulated by a pump. The laser cavity has end reflecting mirrors M_1 and M_2 of reflectivities of 100% and 73% respectively. The cavity length was about 300 mm. The power supply of 0-20 kV and 0-50 mA was utilized for charging the capacitor of 0.3 μf. The capacitor was properly discharged via a triggered spark gap through the xenon flashlamp. The laser output with the Rhodamine 6G as the laser medium was capable of producing tunable wavelngth λ = 550-640 nm. The tunable wavelength was achieved by using an Abbe's Prism putting in the laser cavity. Furthermore, the FEDL has potentiality of producing laser output of λ = 350-1000 nm, if proper dye solutions are chronologically used as media. The laser output had pulse width of 1μ sec with energy of 20 mJ and peak power of 20 KW. The development of the first FEDL system at KMIT Thonburi will serve as a ground work for further developmnt of FEDL for medical and industrial application in the future.

II. Theory

The basic principles for laser beam generation involved in 3 fundamental, factors [6] namely a) proper laser medium, b) population inversion between energy level state $|i>$ and $|j>$ between which laser acton will take placed by stimulated emission and c) optical resonator composed of two dielectric mirrors M_1 and M_2 which have proper reflectivities R_1 and R_2 at laser respectively. In the experiment the solution of dye Rhodamine 6G in ethyl at concentration of 2×10^{-4} M/litre was utilized as the laser medium. For the population inversion where $n_j > n_i$ ($E_i < E_j$) together with stimulated emission, it is necessary that the laser medium under optical pumping by a xenon flashlamp, must have a small signal gain coefficient $\beta > 0$ where

$$\beta = B_{ij}(n_j - n_i)\frac{h\nu_{ij}}{4\pi c} \tag{1}$$

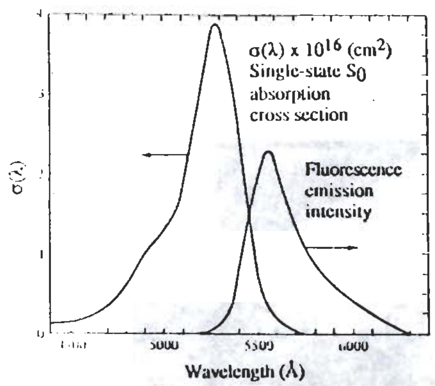
Fig.I Atomic energy levels for laser action

The coefficient B_{ij} [7] is the Einstein coefficient of stimulated emission. Since $B_{ij} > 0$, therefore, intensity of light in the laser medium will grow as

$$I = I_0 e^{\beta z} \tag{2}$$

Thus laser light amplification has taken place. Consequently laser light of high intensity and directionality will be generated which exists from the optical resonator to become a laser pulse.

The actual situation under the optical pumping by a xenon flashlamp to the active laser medium of Rhodamine 6G dissolved in enthanol for the population inversion, takes place as shown in Fig.II and Fig.III.



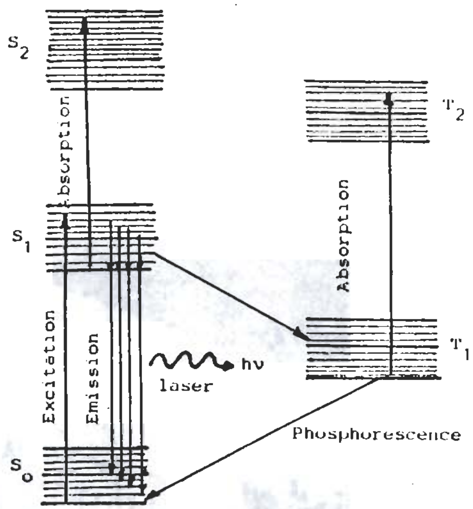


Fig.II Absorption and Emission (fluorescent) of Rhodamine 6G [8]

Fig.III Energy level diagram of for a dye system
S = Singlet State
T = Triplet State

From Fig.III, laser transition occurs between rotational-vibrational sublevels in the elecctronic level S_0 (singlet state). Since there are many rotational-vibrational sublevels within S_0 and S_1, the laser transition between them will result in a broadly tunable wavelength. The triple states T_1 and T_2 are not involved directly in laser action, but they have a pronounced effect. There is a small probability that the forbidden transition $S_1 \rightarrow T_1$ called intersystem crossing, will occur. Since the transiton $T_1 \rightarrow S_1$ (phosphorescence) is also forbidden, the dye molecules tend to pile up in the T_1 state. A significant fraction of the molecules having made the $S_1 \rightarrow T_1$ transition, the $T_1 \rightarrow T_2$ absorption quickly reduces the laser gain β, and consequently quenches the laser action. For this reason, it is preferable to operate the dye laser in the pulse regime and try to circulate the dye solution rapidly so that a new dye solution will be placed for laser action.

Stimulated emission will achieve higher gain when light in the optical resonator takes many roundtrips through the laser medium and is reflected back and forth between resonators cavity mirrors. In order to avoid optical loss due to diffracction and reflrection at both ends of the laser medium, a pair of Brewster's window at both ends of dye cuvette are required. The inclination of Brewster's angle ϕ_B [9, 10] can be calculated from the relationship.

$$\phi B = \tan^{-1}(n'/n) \tag{3}$$

where n' is the index of refraction of the Brewster window and n is the index of refraction of air. For our case, the Brewster are quartz glass with n' = 1.4585 and n_{air} = 1.0000. Therefore:

$$\phi B = \tan^{-1} \frac{1.4585}{1.0000} = 55.56^{\circ} \tag{4}$$

The stability condition of the resonator cavity plays an important role that makes the laser system produces stable laser pulses. The criteria for a stable cavity was given as follows [11, 12].

$$0 < g_1 g_2 < 1 \tag{5}$$

where $g_1 = 1 - \frac{L}{r_1}$; $g_2 = 1 - \frac{L}{r_2}$

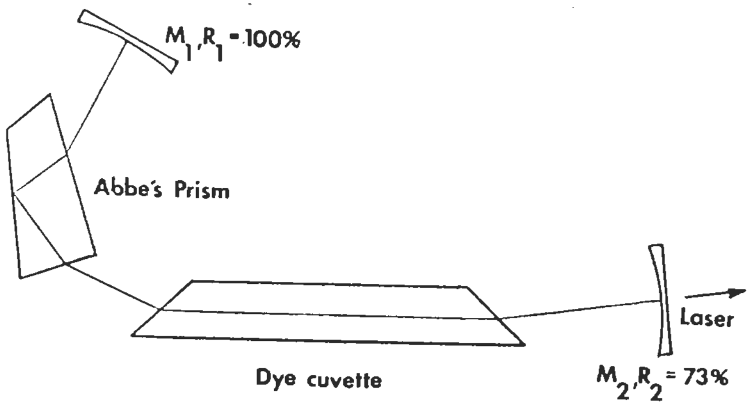
L is the cavity length

r_1, r_2 are the radii of curvature of the cavity mirrors.

For our case, the FEDL system has L = 300 mm, r_1 = r_2 = 400 mm. Therefore, the criteria of (5) is satisfied.

III. Experiment and Results

The FEDL system is set up with a resonator cavity of length about 300 mm. with Abbe's Prism situated inside the cavity. The end mirrors M_1, M_2 have reflectivities R_1 = 100% and R_2 = 73% respecctively. Both M_1 and M_2 are concave mirrors of radii of curvature of 4000 mm. (Fig.IV).



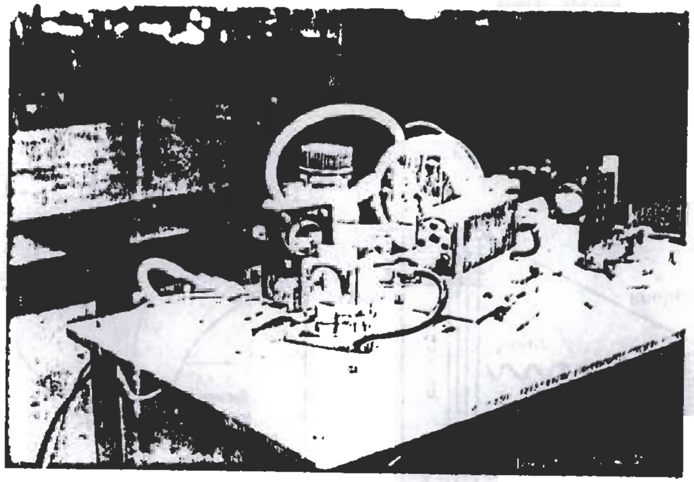


Fig.IV Experimental setup of the first tunable Flashlamp Excited Dye Laser (FEDL) of Thailand at the Scientific Instrument Centre for Standard and Industry, KMIT Thonburi (Bangmod).

The electrical system of the FEDL is composed of a power spply with a capability of 0-20 kV connected in series with resistor R_1 and then connected to a capacitor C of 0.3 μf, a xenon flashlamp L and a terminated resistance R_2 respective (Fig. V). The spark gap is made by an automobile spark plug connected between the caapacitor C and the xenon flashlamp L the spark gap is triggered by a generated pulse of 30-40 kV for breaking down the air gap. As a consequence, the capacitor C is able to discharge a dc current through the xenon flashlamp. The dc current passing through the xenon flashlamp was in form of a pulse with a maximum currect of 2000-2500 amperes for a duration about 1.5-2.0 sec, as shown in Fig VI.

The laser pulse width was measured to be about 1.0 μs as indicated in Fig. VII. The laser output was tunable by an Abbe prism [13] in order to observe the change of wavelength (colour), which corresponds with the characteristic of fluorescent of Rhodamine 6G' (λ = 550-640 nm.) The energy of the laser output was calculated to be about 20 mJ with a corresponding peak power of 20 KW [14]. Since the first FEDL system has an air cooled laser head, the repetition rate of laser firing is about 1/15 Hz. However, a more sophisticated FEDL is now being designed.

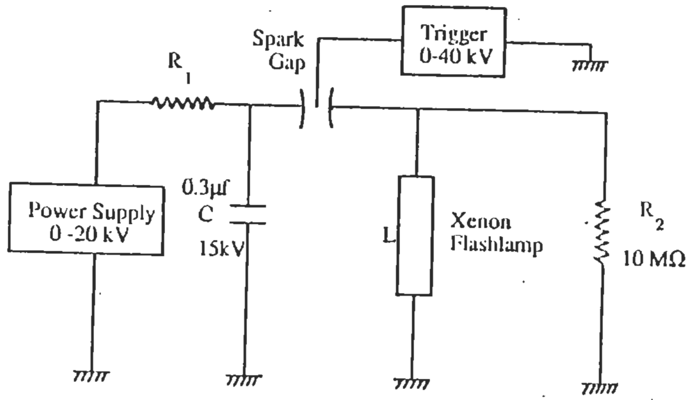


Fig.V Electronic block diagram for xenon flashlamp

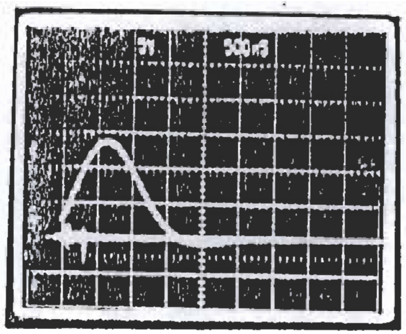


Fig.VI Current through the xenon flashlamp. The vertical scale is 1000 amp/div. The horizontal scale is 500 ns/div.

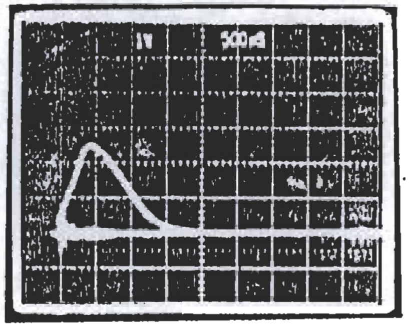


Fig.VII The laser temporal pulse shape. The horizontal scale is 500 ns/div.

IV. Conclusion

The first tunable excited dye laser system of Thailand, developed at the Scientific Instrument Centre for Standard and Industry at KMIT Thonburi (Bangmod), performs very well with good stability for a long time. The experiment demonstrates the use of local materials and indigenous technology as well as capability of construction and handling high voltage (H.V.) electronics device by Thai Scientists. The results of the experiment agree well with theory and with the previous experimental results obtained abroad. This tunable flashlamp excited dye laser (FEDL) provides various know-how and know-why of knowledge deemed necessary for future development of FEDL in Thailnd.

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