Design and construction of a narrowband dye (Rd6G) laser pumped with a KrF (248nm) laser (Littman setup) for determining the saturation intensity (I_s) and small-signal gain (γ_0) of the amplifying medium

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An oscillator-amplifier KrF pumped Rd6G dye laser has been successfully assembled in order to measure the small signal gain and saturation intensity of the amplifying medium. We have determined γ_0 and I_s to be 2.6 cm^{-1} and 350 kW/cm^2, respectively.

Introduction

The applications of tunable dye lasers are extremely important in medicine and laser spectroscopy. Dye concentration, resonator length, and pumping source are among the key parameters in the oscillator design of a dye laser. Red shift and broad line of a dye laser emission have been observed with the increase of the concentration,[1] mainly because of the collisional broadening.[2]

The linewidth is also dependent on the length of the oscillator due to higher divergence.[3] The choice of the optimum pumping source influences the oscillator efficiency. The efficiencies of the Rd6G lasers pumped with KrF and XeCl have been reported of 27 and 50% respectively.[4] It is well understood that Rhodamine and Coumarin lasers pumped with XeCl and Cu-vapor lasers exhibit higher efficiencies.[5]

On the other hand, the synchronization and the concentration of dye amplifier are recognized the keys to design and fabrication of an oscillator-amplifier assembly. Even though, the effect of the cavity length on the synchronization is critical in excimer lasers with photon lifetime of the order of 5–6 ns corresponding to 30–70 cm gain length. Nevertheless, it would be less significant for a dye laser corresponding to several centimeter resonator length, and few ps photon lifetime.

In this work, we have demonstrated a handmade Rd6G dye laser pumped with ArF (193 nm) and KrF (248 nm) excimer lasers. However, the laser pumped with a KrF laser has been mostly used during experiments, since the molecules experience photodissociation under irradiation of intensive UV beam at shorter wavelength.

Theory

The basic relation for the amplification of dye laser is given below[6,7]:

$$(I_{out} - I_{in})/I_s - \gamma_0 l = -\ln(I_{out}/I_{in}), \quad (1)$$

where I_s and γ_0 are the saturation intensity and the small signal gain, l is the amplifier length, I_{in} and I_{out} denote the intensities at the output and input of the amplifying medium. The relation (1), in some limiting cases, can be simplified as follows:

$$I_{out} = I_{in}\exp(\gamma_0 l),\ I_{in} \ll I_s, \quad (2)$$

$$I_{out} = I_{in} + I_s\gamma_0 l,\ I_{in} \gg I_s. \quad (3)$$

These relations indicate that for low input intensities, the gain increases and becomes equal to a small signal gain and for high intensities the gain reduces to the saturation value.[8,9]

In contrast, the amplification relation for the case with KrF excimer laser obeys the Hopf's model and can be written as follows[10]:

$$I_{out} = I_s \ln\left\{1 + \exp(\gamma_0 l)\left[\exp\left(I_{in}/I_s\right) - 1\right]\right\}, \quad (4)$$

so that I_{out} may be directly calculated from I_{in}, whereas Eq. (1) has to be solved numerically.

Moreover, Eq. (4) is valid for a medium with uniformly broadened gain provided that $(\Delta\nu)_c/(\Delta\nu)_D \gg \gg 1$, where $(\Delta\nu)_c$ and $(\Delta\nu)_D$ designate collisional and Doppler linewidths, respectively, though it is not applied to dye amplifier due to its inhomogeneous broadening. Besides, Eq. (4) has been derived using several approximations, like the neglect of spontaneous emission rate, which does not usually satisfy dye laser gain medium with high ASE.[10] The power gain is also given by

$$\gamma(\nu) = \gamma_0(\nu)\Big/\left\{1 + \frac{I_\nu}{I_s}\bar{g}(\nu)\right\}, \quad (5)$$

which is valid for both excimer and narrowband dye amplifiers, where $\bar{g}(\nu)$ can be defined as normalized line shape such that $\bar{g}(\nu) = 1$.

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Experimental setup

Various arrangements, such as Hanch array, Double–Quartet prism method and Littman setup are available to perform tuning and narrowing the emission of a dye laser. Each of the methods possesses its advantages and drawbacks. We have chosen Littman setup, mainly because of easy alignment to achieve single mode with spectral width as narrow as 0.001 Å, particularly without a Fabry–Perot etalon. The diffraction grating used in Littman arrangement operates as a beam expander and a dispersion element simultaneously, so that the dispersion power becomes two times higher than that of the Littrow mount. The Littman setup is shown in Fig. 1.[11]

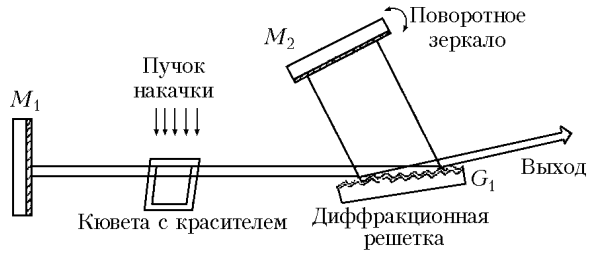

Fig. 1. Littman setup.

In this work, we have assembled a mirror-grating configuration as an output coupler with a 1200 grooves/mm grating blazed at 10° angle at incidence angle 86°. A 1-cm long cell with 1.32 g/l dye solution has been placed within a 7-cm long resonator with a 1-m radius high reflectance mirror.

The output pulses were detected with a semiconductor detector (*EG&G* FND 100 PIN diode), a 400-MHz oscilloscope (*Tektronix* 7844), and a calibrated power meter (*Fieldmaster* with an LM P10 head).

Results and discussion

We have succeeded to narrow the emission of a handmade dye laser oscillator, having 40-nm wide emission spectrum very intense in yellow, moderately intense in red, and weak in the green region of the visible spectrum. The beam cross section before narrowing is shown in Fig. 2. In accomplishing the narrowing process, each spectrum has been separated subsequently. We have selected the peak value at 573 nm for amplification.

The diagram of the oscillator-amplifier arrangement is shown in Fig. 3. A solution of 1.2 g/l concentration of Rd6G in methanol was circulated through a 1 cm long dye cell that has been used as an oscillator, and a 2 cm long cell with a dye solution of 1.8 g/l concentration was used in the amplifier.

The optics of the setup consists of two cylindrical quartz lenses with 10 cm focal length and a UV beam splitter. Various neutral density filters are used to regulate the intensity of radiation at the amplifier input in order to provide different output intensities.

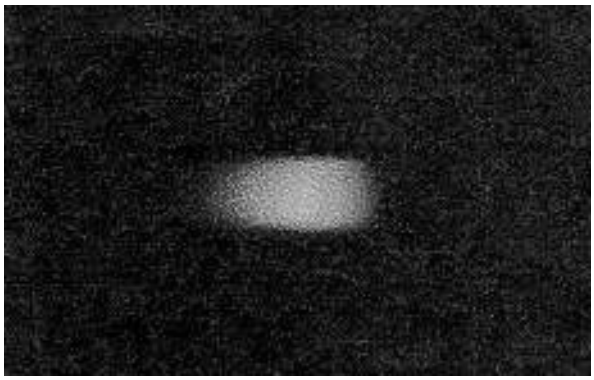

Fig. 2. Beam cross section before narrowing.

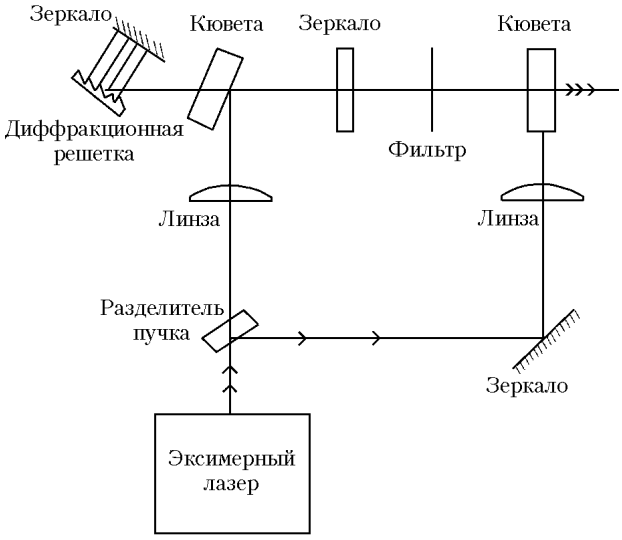

Fig. 3. The diagram of the oscillator-amplifier arrangement.

The energy and FWHM of typical excimer laser pulses measured were ~ 100 mJ and ~ 8 ns respectively. These of dye laser were found to be ~ 0.8 mJ and 3 ns correspondingly.

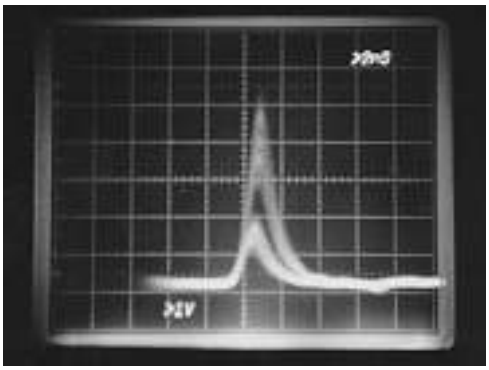

Fig. 4. The oscillogram of the oscillator and amplifier pulses.

An optimum optical path was chosen to achieve a suitable synchronization condition. The typical oscillator and amplifier pulses are shown in Fig. 4. The logarithmic display of the amplified intensity for various input pulses is shown in Fig. 5. The gain in

dB is defined as 10 log (I_{out}/I_{in}). A plateau region has been observed with ~ 33 dB which begins to decrease at an input intensity ~ 220 kW/cm^2 as shown in Fig. 6.

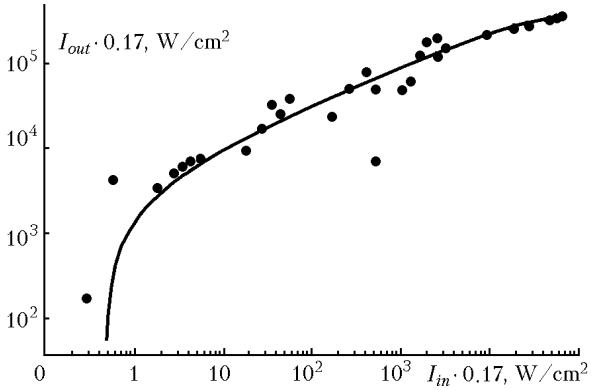

Fig. 5. Logarithmic display of the output amplified pulses for various input pulses.

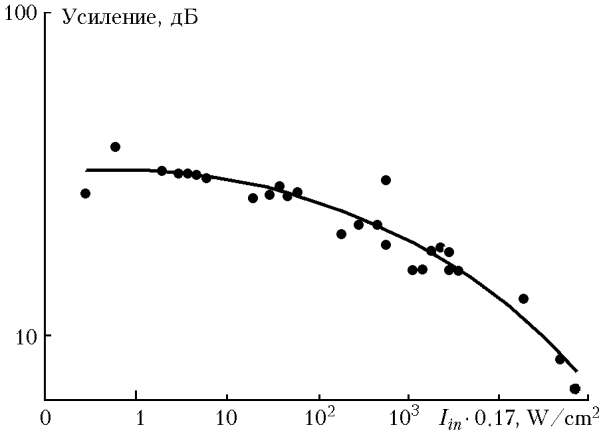

Fig. 6. Gain (dB) versus input intensities.

By examining the Eqs. (2) and (3), we can conclude that though the γ_0 can be determined by relative measurement with a PIN detector, the value of I_s should be calculated by means of the absolute measurement based on calibrated power meter readouts.

The values of γ_0 and I_s at 573 nm calculated from the best fit of the experimental data to the pulse amplification relation given by Eq. (1) are 2.6 cm^{-1} and 350 kW/cm^2 respectively.

Acknowledgements

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