

ATMOSPHERIC PRESSURE PULSED DISCHARGE FOR DYE LASER PUMPING

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Using a novel atmospheric pressure fast risetime flashlamp superradiant laser, emission from a number of organic dyes has been obtained. The experiments indicate high light efficiency of these flashlamps.

1. Introduction

The discovery and the applications of various types of pulsed lasers initiated rapid development of different types of pulsed light sources — flashlamps for optical pumping of laser active medium. All these flashlamps can be classified in various groups depending upon the physical shape of the lamp (linear, helicoidal, coaxial etc.), gas filling (argon, xenon, krypton, mixture of gases etc.) and light pulse duration (fast $\tau < 10 \mu\text{s}$ usually with submicrosecond risetime and slow $\tau \approx 1 \text{ ms}$). We shall further confine our discussion to the fast flashlamps which are mainly used for optical pumping of organic dyes.

At the present time three types of flashlamps are mostly used with pulsed dye lasers: coaxial^{1,2)}, and linear³⁾ flashlamps and various types of linear ablating wall lamps⁴⁾. Initial gas (usually xenon) filling pressure for the first two types is typically between 50 and 100 torrs while for ablating wall flashlamps pressure of residual gas (usually air) is below few torrs.

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Appart from these, most frequently used types of the flashlamps, few attempts have been made to use, for the same purpose, light efficient high pressure discharges.

Aussenegg and Schubert⁵⁾ used atmospheric pressure spark in air, 5 cm long confined in 3 mm quartz tube. The discharge is placed along the focal line of an elliptical pumping with the dye cuvette situated along the other focal line. Specially constructed low inductance capacitor (7 nF) has been used. With laser resonator formed from one totally reflecting and one 70% reflecting mirror they obtained lasing from rhodamine 6G at a threshold of electrical input energy of 3J.

Mack⁶⁾ and Ferrar⁷⁾ used short unconfined sparks in argon above atmospheric pressure as a light source for high repetition rate dye laser systems. Lasing has been achieved⁷⁾ for electrical inputs as small as 5 mJ and pulse repetition rates as high as 2000 pulses per second. An argon-jet guided spark (10 mm long) discharge lamp has been used by Weysenfeld⁸⁾ also for high repetition rate dye laser system.

From these examples⁵⁻⁸⁾ one may conclude that high pressure spark discharges are preferably used for optical pumping of high repetition rate systems with high average output power and relatively low single pulse power. For high peak power laser system longer powerful light source is needed and for this purpose standard linear and coaxial flashlamps are employed. High initial pressure pulse discharges are impractical for this applications since they require very high voltages for their operation.

We report here a novel fast risetime flashlamp with initial gas filling pressure at 1 atm. With two stage Marx bank generator charged up to 23 kV it is possible to obtain the discharge lengths as long as 40 cm. This flashlamp is successfully used for optical pumping of various dyes lasing from blue to red end of the visible spectrum. Lasing of these dyes is achieved without resonator in a superradiant mode.

2. Flashlamps and dye laser system

A schematic drawing of the flashlamp laser arrangement and circuitry with energy storage capacitors are shown in Fig. 1. In accordance with the drawing in Fig. 1 a number of flashlamps were constructed using standard Pyrex and quartz glass tubes with internal diameter ranging from 3-5 mm and various lengths from 10-40 cm.

Two types of the flashlamps are tested. One of them is schematically presented in Fig. 1 with continuous flow of gas. For this purpose holes of 2 mm diameter are located at the centre of both electrodes. These holes, at the same time are used to allow the expansion of the hot gas.

Second type of the investigated flashlamps is without gas flow as shown schematically in Fig. 2. Two glass containers with the total volume of $\approx 200 \text{ cm}^3$ are attached to the discharge tube in order to increase the volume of the gas and in this way lifetime of the lamp and to increase the explosion limit of the flashlamp by allowing expansion of the hot gas from the discharge tube. After few minutes of the flushing of the glass containers and the discharge tube with required gas, gas valves are closed (Fig. 2.) and the flashlamp prepared for operation.

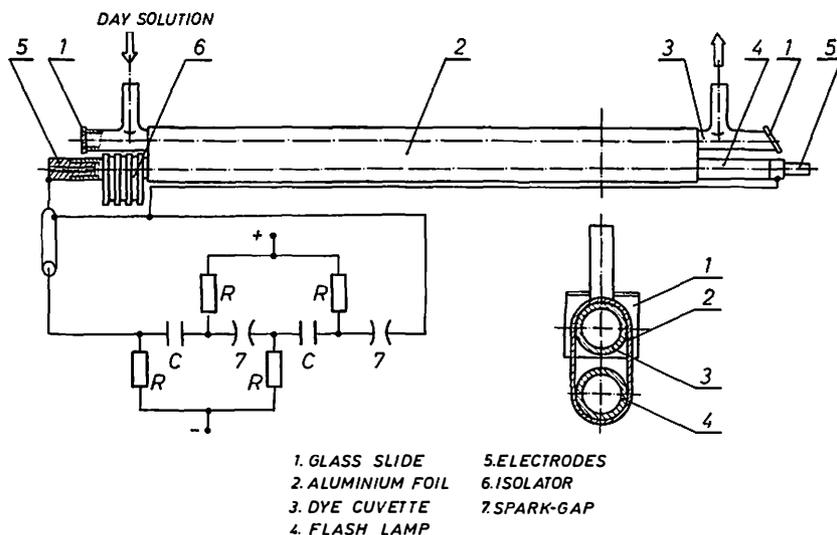


Fig. 1. Schematic diagram of the flashlamp with continuous gas flow, dye cuvette and capacitor bank with electrical circuitry.

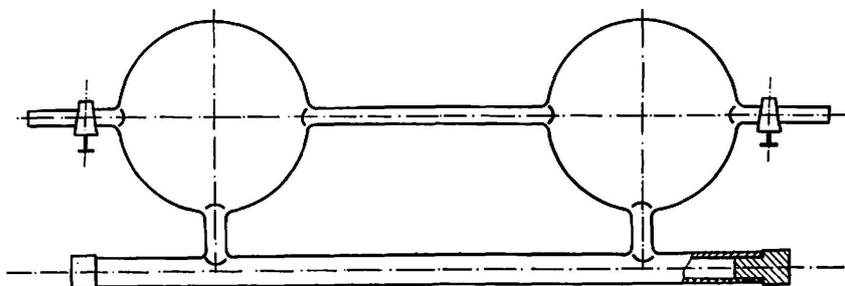


Fig. 2. Schematic diagram of the flashlamp without gas flow.

For the both types of the flashlamps, Figs. 1 and 2, brass electrodes are connected with glass discharge tube with the silicon rubber.

Laser cuvettes are also made of standard Pyrex and quartz tubes with internal diameter 4 mm. One of dye cuvette windows, Fig. 1, is tilted to prevent unwanted oscillations in laser active medium. It should be noted that cuvette windows are uncoated and made of 1 mm thick microscope glass slides.

Laser experiments are carried out with air equilibrated ethanolic dye solutions. All dyes were obtained from Eastman Kodak and used without further purification.

The discharge tube and the dye cuvette are wrapped together with aluminium foil to reflect part of the radiation back into the dye solution.

Energy storage capacitor bank consists of two low inductance 0,1 μF , 40 kV capacitors connected in a two stage Marx generator. The capacitors are charged in parallel (typically between 12 kV and 23 kV) via the charging resistor. By triggering

spark gaps, capacitors are connected in series and doubled charging voltage appears at the flashlamp electrodes. High frequency and high voltage field induced between one electrode and nearby lead, Fig. 1, produce preionisation which facilitates breakdown between the electrodes.

For comparison, commercial, quartz, linear flashlamps (distance between electrodes 15 cm, tube internal diameter 4 mm) with xenon gas filling of 200, 400 and 700 mbars has been used.

Laser action from the dye solution is confirmed when a pump threshold is reached so that a collimated laser beam is observed visually. A photo-diode observation of the radiation protruding axially from dye cuvette confirms the visual observation of laser action.

3. Experimental results

All laser experimental results reported here are obtained with both types of flashlamps, Figs. 1 and 2, filled up with argon to the atmospheric pressure. The discharge length is 15 cm, discharge tube i. d. 4 mm. Dye cuvette: 4 mm i. d., 15 cm long. In case of the flashlamp shown in Fig. 1 continuous flow of argon (≈ 50 – 100 cm^3/min) is sustained.

With energy storage capacitor bank voltages from 12 to 23 kV peak current through the flashlamp varied from 1.2 to 2.9 kA. Typical current waveform of the discharge measured with Rogowski coil and an oscilloscope is given in Fig. 3a. Corresponding light pulse shape from the flashlamp taken with planar vacuum photo-diode without spectrally selective filter is given in Fig. 3b. The light output waveform typically exhibits a risetime of 120–150 ns and the duration (FWHM) in the range of 600–700 ns. Laser pulse shape from ethanolic solution of rhodamine 6G recorded with a fast photo diode and an oscilloscope is given in Fig. 3c.

The experimental results for the threshold energy for the superradiant lasing action of investigated dyes pumped with the continuous flow flashlamp, Fig. 1, is given in Table 1. Only for rhodamine 6G and 7-diethylamino-4-methylcoumarin

TABLE 1.

Dye	Concentration [$10^{-3}Ml^{-1}$]	Threshold energy [J]
Rhodamine 6G	5	10.6
Rhodamine B	5	12.5
7-Diethylamino-4 methylcoumarin	7	16.0
Fluorescein disodium salt	1	16.4
2', 7' Dichlorofluorescein	10	17.4
Cresyl violet perchlorate	0.3	17.4

Threshold energy for superradiant lasing of the different dyes with flashlamp and cuvette made of pyrex glass.

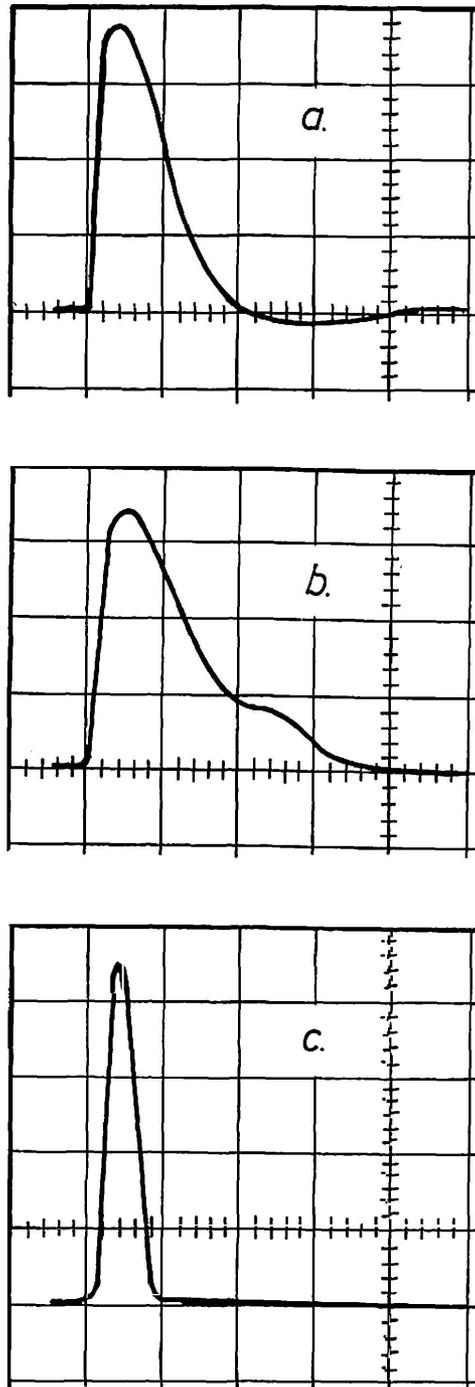


Fig. 3. Waveforms of (a) current through the flashlamp (b) corresponding light output from the flashlamp and (c) relative laser output intensity. Time base: 0.5 μs per division.

an attempt has been made to find an optimum dye concentration. For the rest of the dyes values for the threshold energy in Table 1, most probably, can be decreased by optimization of dye concentration.

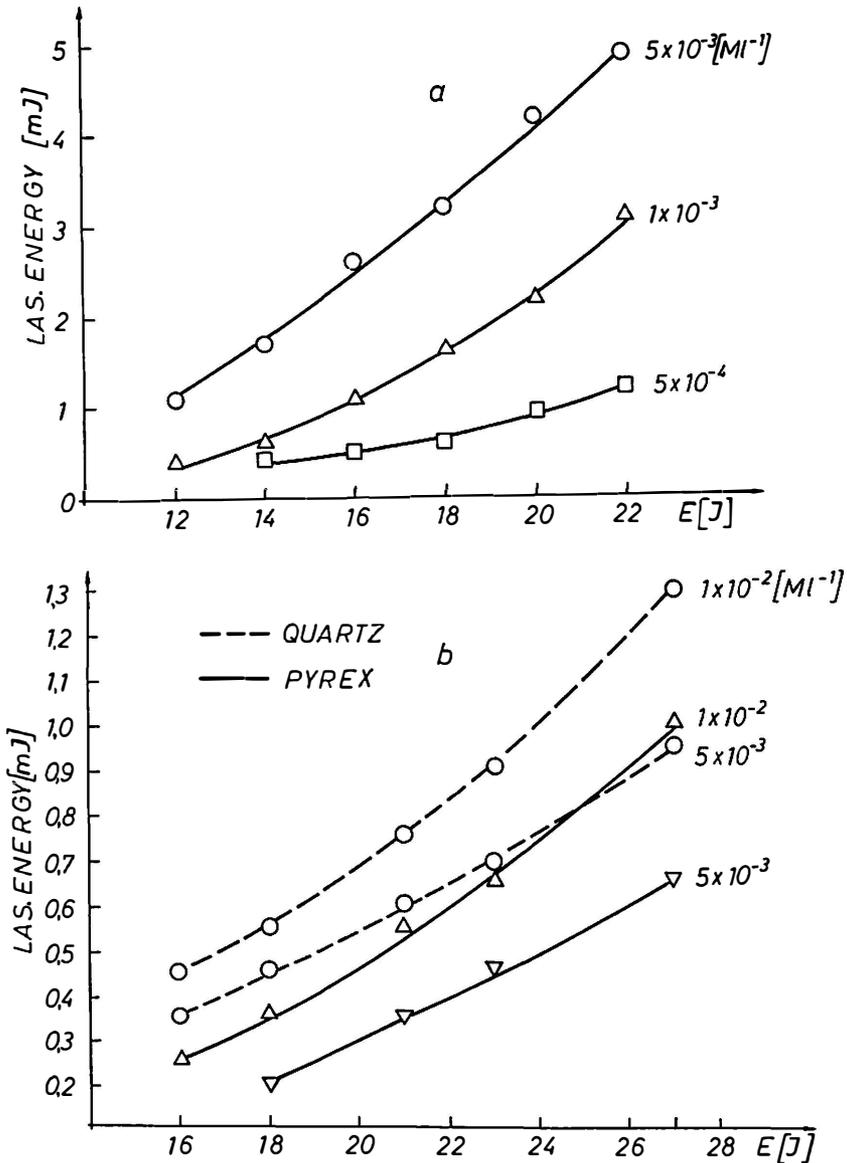


Fig. 4. Energy superradiant laser emission from ethanolic dye solutions of various concentrations (MI^{-1}) from one side of laser cuvette versus electrical input energy for (a) rhodamine 6 and (b) 7-diethylamino 4-methylcoumarin. Under (b) are given separately results obtained with pyrex and quartz flashlamp and cuvette. Rhodamine 6G is investigated only with pyrex flashlamp and cuvette.

Two typical examples of the dependence of the laser output energy (only from one side of dye cuvette) versus electrical input energy for various dye concentrations pumped with continuous flow flashlamp Fig. 1 are given in Fig. 4a and 4b. The results of the comparison with commercial xenon flash lamps is given in Fig. 5. Laser output energy is measured with Laser Instrumentation energy meter Model 14NO.

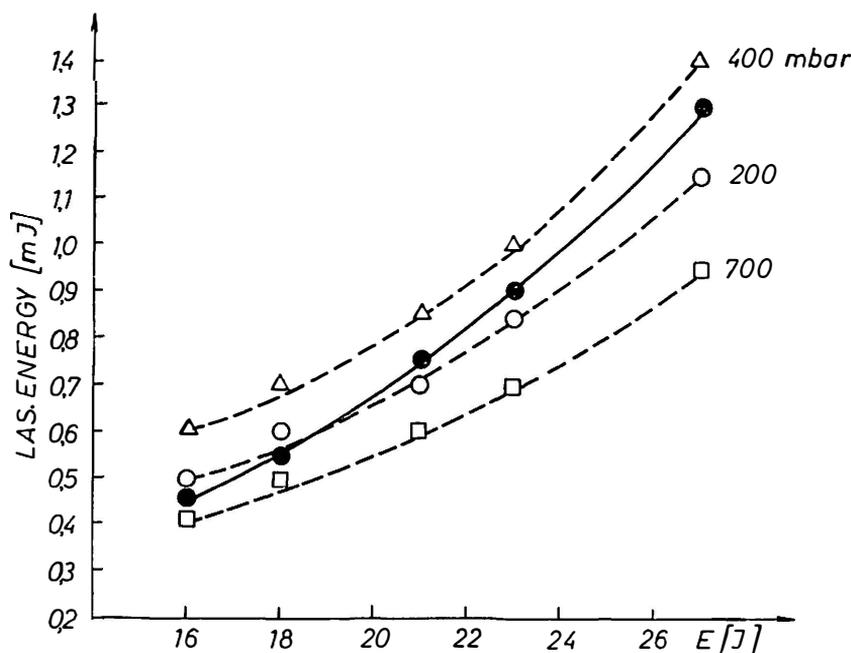


Fig. 5. Comparison of the output energy superradiant laser emission from ethanolic solution of 7-diethylamino-4-methylcoumarin ($1 \times 10^{-2} \text{ Ml}^{-1}$) pumped with xenon flashlamps and our quartz flashlamp with continuous flow of argon at atmospheric pressure. Xenon filling pressure (in millibars) of the flashlamps is indicated in the figure. Solid line is drawn through the results obtained with our flashlamp.

An attempt has been made to assess the importance of the gas for the efficiency output of the flashlamp. Air, nitrogen, argon and xenon are investigated. With the first two it is not possible to reach the threshold for superradiant lasing of rhodamine 6G even at highest allowed voltages of 23 kV which is at the vicinity of the lamp explosion limit. Within the error of experimental measurements threshold for lasing action does not differ if argon is replaced with xenon. Therefore technically pure argon has been used throughout.

With the flashlamp schematically shown in Fig. 2 tests have been performed in order to estimate, the possibility of sealed-off operation of this type of the flashlamp. For this purpose flashlamp is flushed with argon. After the closure of the gas valves an automatic system for triggering spark gaps has been initiated. With the repetition rate of one pulse per 3 seconds 4×10^4 laser pulses from rhodamine 6G has been obtained with an electrical input energy of 18 Joules per pulse.

4. Discussions and conclusions

Although it is very difficult to compare our measurements given in Table 1, with the results of the other authors^{9,10} obtained under different experimental conditions (type of the flashlamp, risetime of light pulse, dye concentration etc.) one may conclude that the threshold values for superradiant lasing action are rather low indicating high light output of our flashlamps. For example Mumola⁹ achieved with the coaxial flashlamp 13 cm long (light pulse risetime 250 ns) 46J threshold for superradiant lasing of rhodamine 6G at optimum concentration of 2.9×10^{-4} mole/liter. Same author⁹ obtained laser action from 7-diethylamino 4-methylacoumarin in ethanol only by using a single total reflector from one side of the dye cuvette and an input energy of approximately 90J.

Here, it should be noticed that on our laser arrangement care is not taken to insure best optical coupling between dye cuvette and the flashlamp.

Results obtained with the flashlamp without gas flow, Fig. 2, are very encouraging indicating that sealed off flashlamp of this type can be realized.

Finally it should be underlined great simplicity and high light output efficiency (see comparison with commercial xenon flashlamps, Fig. 5 of the flashlamp and the whole laser system which can be easily used to obtain superradiant laser action system such as flash photolysis chemical lasers.

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PRAŽNJENJE NA ATMOSFERSKOM PRITISKU ZA PUMPANJE TEČNIH
LASERA SA ORGANSKIM BOJAMA

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Pomoću novog tipa brzih bljeskalica na atmosferskom pritisku dobijena je laserska emisija iz većeg broja organskih boja. Eksperimenti su pokazali da ove bljeskalice imaju veliku svetlosnu efikasnost.