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Two-wavelength dye laser pumped by excimer laser

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A photodynamic cancer diagnosis and treatment system has been developed, using an excimer-dye laser as a light source. The diagnosis and treatment laser beams were alternately generated by one dye laser having two-cell dye cuvette. In initial laboratory testing being presently performed, the system is yielding encouraging results.

1. Introduction

One of the more interesting applications of dye lasers is their use in medicine – in the photodynamic method of tumor treatment (PDT). In the initial phase of research, simple light bulbs, xenon lamps and others with high illumination intensity were used. Only the introduction of lasers, producing narrow beams of light which could be led through a flexible optical cable and introduced via the arm of an endoscope into internal organs had created the possibility of using the photodynamic method for treatment of almost all internal organs.

The laser set appropriate for both the PDT method and hematoporphyrin type preparations is the one which generates radiation of about 405 nm wavelength for suitable diagnostic purposes and 630 nm for tumor therapy. The 405 nm radiation is optimal for the first absorption peak of porphyrines. As a result of light absorption at this wavelength the region becomes strongly fluorescent in the red light band. The laser light wavelength of 630 nm fits into the weaker peak of absorption, but assures greater penetration of the light into human tissue.

Up till now, the PDT method is most commonly used with the Argon dye laser [1]. In this set-up diagnostics of tumor is effected by continuing action of 488 nm beam of light. The treatment is effected with 630 nm continuous beam of dye laser pumped with an Ar laser. In this case, the duration of treatment extends to many minutes.

It has recently been discovered that the application of a pulsed beam may improve efficiency of treatment and shorten the treatment duration by some 170-fold. One of the lasers emitting such radiation of 628 nm wavelength [2] is a golden vapour laser.

However, most hope for the future is associated with the pulsed tunable dye laser which enables generation of both the diagnostic and the therapeutic wavelengths. Presently, the excimer laser is considered to be the best pumping system for a dye laser coupled with the PDT method [3].

In 1985, an excimer-dye laser system was applied to the PDT method by Y. Hayata (Tokyo). The laser presented in [4] consists of a 50 mJ excimer laser and two dye lasers pumped alternately. One of them is tuned to 405 nm and the other to generation of 630 nm wavelength. The diagnostic and therapeutic wavelengths are delivered through two different optical cables. Authors of that work presented also a modern imaging system used to investigate the tumor (fluorescence of porphyrines from the tumor region) and to destruct the tumor cells during pulsed illumination with 630 nm radiation.

The laser set-up presented below includes an excimer laser generating radiation with power up to 100 mJ and repetition frequency up to 10 Hz and one dye laser with original design solution to permit generation of radiation at two wavelengths.

2. General description of laser set-up construction

This laser set-up adopts a solution with one dye laser giving a possibility to generate radiation of two wavelengths, 405 and 630 nm. This is a novelty as compared to the solution with two dye lasers [5]. The solution applied is an original one, and offers the advantage of simple construction together with only one optical cable to guide the radiation of both wavelengths — so important when using an endoscope.

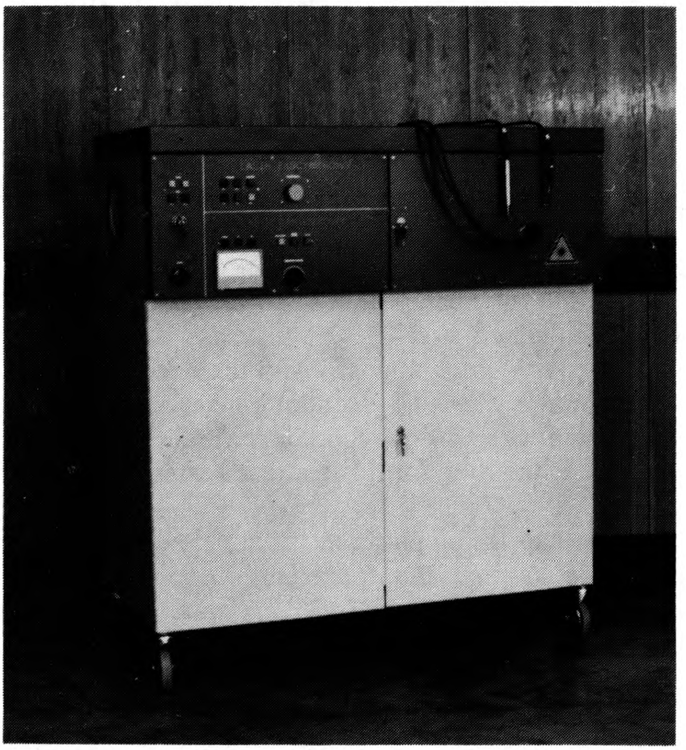

Fig. 1. View of two-wavelength excimer-dye laser

The laser set-up has modular structure and is placed upon a mobile unit to facilitate easy movement. The unit is fully integrated, the external connection to 220 V mains being only required. The modules are placed vertically as it is presented in Fig. 1. Laser heads (excimer and dye), energy meter, optical cable connection are located in the upper part of the unit. Below, there are cylinders for He, Xe, He:HCl (95:5%). These cylinders are connected via the pressure reducer valves and electric valves to the chambers using hoses. The lowest level module contains the high voltage supplier with capacity of up to 30 kV, excimer laser triggering unit with 0–10 Hz repeating rate. The same level contains also modules with the vacuum pump AW-2 with halogen filter on the inlet and oil filter on the outlet, and a Vega fan maintaining a slight underpressure within the unit. Air is disposed through a carbon filter. The upper part of the laser module contains a control desk from which lasers are operated, including such operations as filling of the laser chamber with the appropriate gas mixtures, setting of the required loading pressure, selection of desired wavelength, dye selection. The unit has been designed according to the due requirements for medical equipment.

The laser heads constitute the heart of the system and will be discussed in detail below.

3. Excimer laser

In designing the excimer laser head, use was made of the theoretical XeCl laser model [6]. The main characteristics of the due mode structure was given in [7]. The active gas mixture consists of He:Xe:HCl in the proportion 95:4.8:0.2%. The laser

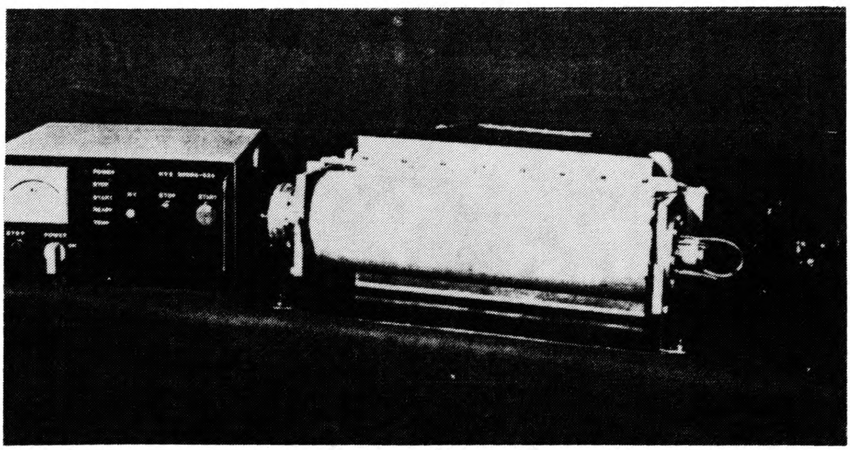

Fig. 2. Photography of excimer laser head with power supply

is excited by an electric discharge with automatic preionization. The main discharge takes place between two aluminium electrodes 50 cm long, with 2 cm gap between them. The initial ionization of gas appears under the effect of UV radiation generated during discharges in spark gaps placed symmetrically along the main electrodes. Capacitor batteries of respective capacities 64 nF and 32 nF were used for storage and discharges. They consisted of high voltage ceramic capacitors made in Poland, each of 2 nF capacity. Laser initiation takes place by sending the triggering pulse onto the TGI 1000/25 thyratron. The replacement of the active gas in the electric discharge region is realized by using a mixer connected with an external motor through a magnetic clutch. Components of the discharge chamber were made of aluminium and tarnamid. The optical resonator consists of two dielectric mirrors on quartz substrates of reflection coefficients nearly 100% and 8%, respectively. Thin layers for the 308 nm beam were made of ZrO_2/SiO_2. A photo of the excimer laser head is given in Fig. 2.

4. Dye laser

As already mentioned, the presented solution makes use of one dye laser generating radiation at two wavelengths, 405 and 630 nm. The dye laser is pumped by radiation from an excimer laser, the due laser beam being concentrated with a quartz cylindrical lens onto the cuvette with dyes. The focal length of the lens is 50 mm. A special double chamber cuvette has been prepared for the dyes, permitting us to obtain two wavelengths alternately in one system.

The resonator consists of two specially designed and made dielectric mirrors: the first one of reflectivity almost 100% for both wavelengths and the second of reflectivity 45% or 48% for 405 nm and 40% or 82% for 630 nm. The Lambda Physics dyes were used, *i.e.*, DPS (LC4090) and Rhodamine 101 (LC6400), the emission spectra of which have peaks at 405 nm and 630 nm, respectively. Both dyes circulated in closed and separated systems.

The active dye was changed by moving the cuvette transversely to the resonator axis and introducing the part of the cuvette with the other dye into the pumping

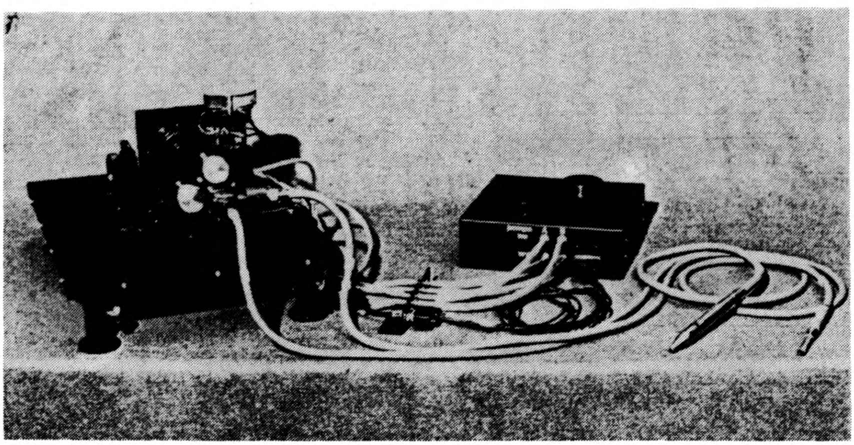

Fig. 3. Picture of two-wavelength dye laser head

region. Cuvette movement is effected by an electric stepper motor. The mechanism has a play balancing to assure correct positioning of the cuvette without any additional aligning.

The DPS solution was used at 0.25 g/l and Rhodamine 101 at 0.75 g/l. Figure 3 presents a photo of the dye laser head and of the dye pumping system.

5. Preliminary results

The results of preliminary tests made during start-up of the laser system are presented below. Measurements of the dye laser radiation were made using the PCME 14B meter from Celtron with a piezoelectric head of SRE 14-10A type. Figure 4 presents the radiation energy of the dye laser as a function of dye concentration for different transmissions of mirrors (TM1 and TM2). Figure 5 shows the dye laser beam energy as a function of pumping energy. The efficiency of dye laser radiation generation is 5% for 630 nm and 12% for 405 nm. This conforms to the ranges required for the method. Start-up testing included stability of operation, stability of radiation, damping of electromagnetic interference, no ex-

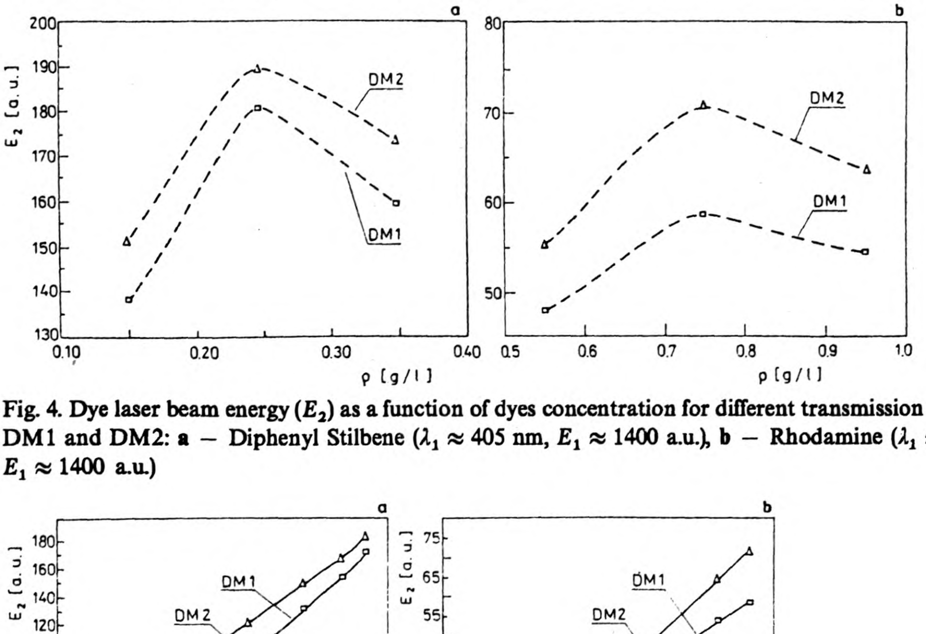

Fig. 4. Dye laser beam energy (E_2) as a function of dyes concentration for different transmission of mirrors DM1 and DM2: **a** – Diphenyl Stilbene ($\lambda_1 \approx 405$ nm, $E_1 \approx 1400$ a.u.), **b** – Rhodamine ($\lambda_1 \approx 630$ nm, $E_1 \approx 1400$ a.u.)

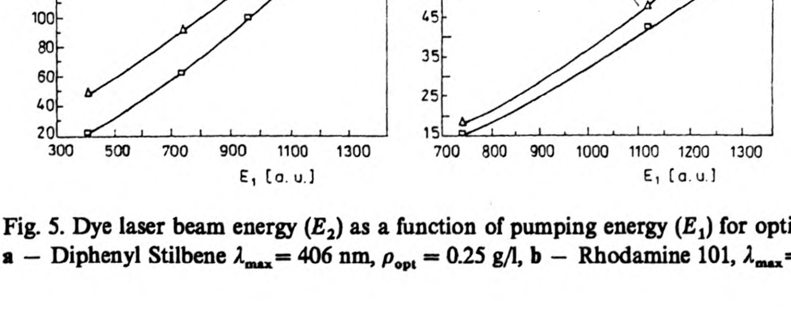

Fig. 5. Dye laser beam energy (E_2) as a function of pumping energy (E_1) for optimal dye concentrations: **a** – Diphenyl Stilbene $\lambda_{max} = 406$ nm, $\rho_{opt} = 0.25$ g/l, **b** – Rhodamine 101, $\lambda_{max} = 630$ nm, $\rho_{opt} = 0.75$ g/l

ternal pollution with aggressive compounds. Initial operating results enable us to conclude that the device can be successively tested under clinical conditions.

6. Conclusions

The construction of two-wavelength laser system for photodynamic cancer diagnosis and treatment was described. The above experimental results concerning this laser system were achieved at its first starting and are of preliminary character and their role was to confirm its general concept. Now, the works are continued with radiation guided through optical fiber which should, hopefully, lead to common clinic investigations with physicians.

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