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Green laser photocoagulator for the treatment of diabetic retinopathy developed at Raja Ramanna Centre for Advanced Technology

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Abstract. An all-solid-state green laser photocoagulator at 532 nm with output power varying from 100 mW to 1 W in a step of 10 mW and exposure time varying from 50 ms to 1000 ms in a step of 10 ms is developed for the treatment of diabetic retinopathy. The output power stability is better than ±1.5% with a nearly diffraction-limited beam quality. The system includes various safety and operational features like internal power monitoring system, safety interlock, emergency switch-off, graphical LCD display with table-top touch mode portable control panel, smart delivery device selection, aiming laser beam with controllable intensity, foot switch, patient records, service mode etc. The system has successfully passed the clinical trials and is being used on patients.

Keywords. Green laser photocoagulator; diabetic retinopathy.

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1. Introduction

Green laser photocoagulator is a laser-based medical equipment extensively used for the treatment of diabetic retinopathy. Diabetic retinopathy is a disease which causes the growth of excess fragile blood vessels in the retina of the patient suffering from prolonged diabetes. The rupture of these blood vessels causes bleeding and subsequently leads to blindness. The green light from the photocoagulator can reach the retina without much absorption at the intermediate ocular media and gets absorbed at the retina, enabling controlled cutting and blocking of the excess blood vessels leading to simple and less painful treatment of the disease with faster healing than the conventional surgical methods.

In India the diagnosis of diabetes ranges from 10% in urban to 4% in rural areas and hence diabetic retinopathy is becoming a major health concern [1]. Unfortunately, the high cost of imported laser photocoagulators not only puts the treatment beyond the reach of many patients, but also restricts its availability to only a few hospitals who can afford it. Hence there is an urgent need to develop this technology indigenously so that this equipment can be made available at an affordable price in every corner of the country. This will help to reduce the cost of treatment benefiting hundreds of thousands poor patients.

During the last decade, the diode-pumped intracavity frequency doubled solid-state green (DPSS-green) lasers operating at 532 nm wavelength has attracted a great deal of interest because of its several advantages like high efficiency, compact size, small weight, excellent beam quality, cost-effectiveness and all-solid-state features. In this paper we report the performance of indigenously built photocoagulator based on DPSS-green laser for the treatment of diabetic retinopathy. The system has successfully passed clinical trials and is being used on patients with diabetic retinopathy at Aravind Eye Care Hospital, Madurai, India.

2. Description of the system

The DPSS-green laser set-up, based on neodymium-doped yttrium vanadate crystal ($Nd:YVO_4$), is shown schematically in figure 1. It consists of a pump source, a lens assembly for transferring the pump beam to the gain medium, a $Nd:YVO_4$ crystal as the gain medium, a type-II phase-matched KTP crystal for intracavity frequency doubling and a linear resonator. The pump source is a conductively cooled fibre-coupled diode laser array with 400 μm core diameter with numerical aperture of 0.22 with a maximum output power of 30 W. The fibre tip is reimaged on the gain medium to a spot radius of 290 μm using a couple of lenses. The gain medium is an a-axis cut $Nd:YVO_4$ crystal with 0.3 at.% doping and 12.0 mm thickness and is placed at the focussed pump spot location. For intracavity frequency doubling 10 mm long KTP crystal cut for type-II phase matching is used. The KTP crystal is chosen because it has the highest nonlinearity among the most commonly used nonlinear crystals like LBO, BBO or KDP [2]. To maximize the conversion efficiency, z-axis of the KTP crystal is oriented at 45° to the c-axis of the $Nd:YVO_4$ crystal. The resonator is a concave-plane type linear cavity designed to obtain a large ratio of the spot size at the gain medium to that at the nonlinear crystal [3] for efficient intracavity frequency conversion. The input mirror, M1, is a curved mirror with 125 mm radius of curvature and the other end-mirror M2 is a

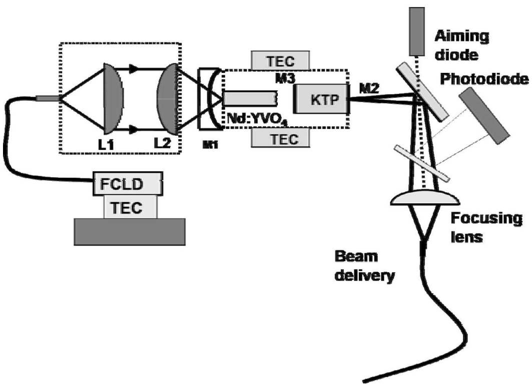

Figure 1. Schematic of the laser set-up.

plane mirror. M1 is highly reflective ($R > 99.8\%$) at the fundamental wavelength (1064 nm) and is highly transmitting at the pump wavelength (808 nm) for efficient pumping. The end-plane mirror, M2, is highly reflecting at the fundamental wavelength ($R > 99.5\%$) and is highly transmitting at the second harmonic wavelength in order to couple out the green beam from the cavity. M2 is coated directly on the surface of the KTP crystal. Other surface of the KTP crystal (M3) is highly reflecting for 532 nm and is highly transmitting at the fundamental wavelength to retroreflect the backward generated green beam.

Both the gain medium and the KTP crystal are press fitted in single copper block with the help of indium foils and is actively cooled by TEC cooler for removing the dissipated heat. The temperature of KTP crystal is required to maintain at a value at which it acts like a QWP for stable operation [4,5]. The optimum temperature was experimentally found to be 24°C. The temperature was maintained within ±1°C. To protect the laser head from dust and moisture formation it is placed inside a hermetically sealed cavity which is first evacuated and filled with nitrogen. The output from the sealed chamber is then deflected by a mirror with high reflection coating at 532 nm but with high transmission coating at the fundamental wavelength and at 808 nm to completely remove these wavelengths. A small fraction of the green beam is sampled for internal power monitoring. A low power laser diode at 630 nm is employed for aiming purpose. The green beam and the aiming beam are precisely aligned and focussed on the fibre tip of the beam delivery system for efficient coupling.

3. Result and discussion

The laser was essentially a continuous wave (CW) type but for the purpose of treatment, the system was operated in long pulsed mode. For this purpose, stable current pulses varying from 50 ms to 1 s with incremental step of 10 ms are applied [6,7]. Figure 2 shows the slope efficiency curve for the laser operated at various exposure time or pulse duration. There is a slight difference of slopes for different exposure times as can be seen from the graph, which can be attributed to the variation of thermal effects in the gain medium for different exposure times. A look-up table is prepared from the measured slope efficiency curves for different pulse durations, such that as the user sets the output power the laser diode current will be adjusted automatically. At an applied current of ∼24 A, stable green power of ∼2.6 W is obtained. The power level is sufficient to meet the power specification of the green laser photocoagulator considering the 90% and 43% coupling efficiency to the beam delivery fibre probes namely the Endoprobe and SLA, respectively. It can be seen that the input–output curve is not linear with the diode current due to the dynamics of intracavity frequency doubling process but the variation of power with the current is highly repeatable and a reliable look-up table can be made. This is possible because of the precise and highly stable temperature control of the temperatures of the crystals and the diode.

Figure 3 shows the recorded green beam pulse shape from the laser. It can be seen that the pulse has a sharp rise and fall with a flat top with less than 1% variation of the power which is highly desirable for a photocoagulator system. To obtain highly flat pulse, the current pulse applied must be free of any ripples or drift. The

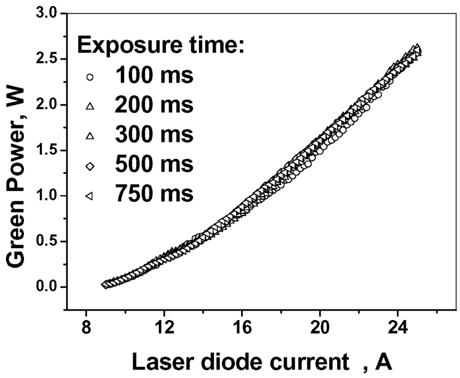

Figure 2. Green power vs. diode current with various exposure time.

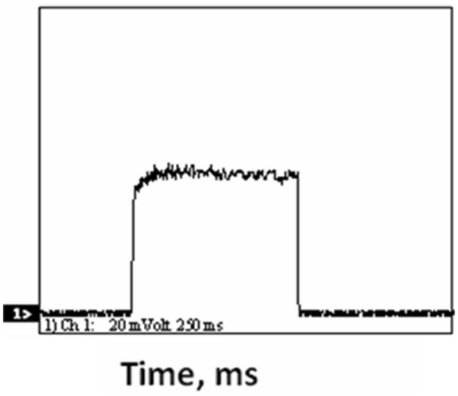

Figure 3. Green pulse shape from the laser.

electronics design can take care of this. But, any fluctuation of temperature of the laser and the nonlinear crystal can lead to green power fluctuation within the pulse. We experimentally found the optimum temperature for efficient and stable frequency conversion and maintained the temperature precisely to avoid any power fluctuation within the pulse.

We have characterized the reliability of the system by measuring the shot-to-shot power stability of the green beam at different durations of diode current. Figure 4 shows the results of the studies of the pulse energy recorded at different power levels varying from 100 mW to 1 W for a given pulse duration of 100 ms for more than 100 number of shots. It can be seen that the system operates reliably with less than ±1.5% fluctuation in shot-to-shot power.

The laser beam is nearly TEM_{00} Gaussian with a measured M^2 parameter of ∼1.2. This extremely good beam quality helps in efficient coupling to the beam delivery fibre with 60 micron core diameter. The output from the beam delivery is nearly flat-top in shape as shown in figure 5 which is desirable to avoid the damage of the surrounding tissues of the treated area.

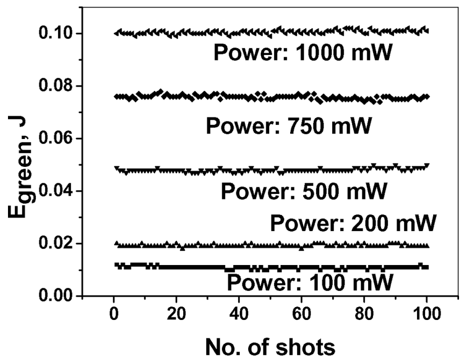

Figure 4. Shot-to-shot energy stability at different power levels.

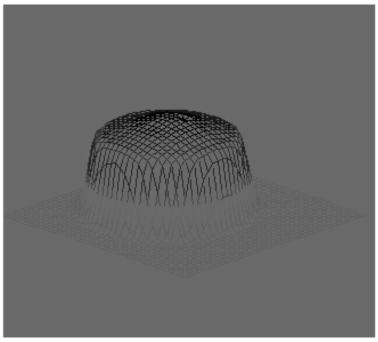

Figure 5. Recorded beam profile at the output of the beam delivery fibre.

Safety and reliability are the biggest concerns for medical equipments and we put special efforts to avoid any hazards while using the system while meeting the safety norms for a medical system. Power, current and temperature interlocks are provided to avoid any unusual performance. Apart from these, an internal power monitoring system is incorporated to check whether the power is of desired level for every shot. Any unusual performance will be detected and the system will be shut-off immediately. A manual emergency shutdown of the system is also included as per the norms of a medical equipment.

Apart from the reliable operation of the system, efforts have been made to make the system user-friendly by incorporating several features. These include graphical LCD display with table-top touch mode portable control panel, smart delivery device selection, aiming laser beam with controllable intensity, foot switch, patient records, service mode and so on. The system is portable, stands alone with turnkey operation and is compatible with diverse ambient conditions. A photograph of the complete system is shown in figure 6. The system was delivered to Aravind Eye Care Hospital, Madurai for clinical trials. After successfully passing the clinical trials it was extensively used on patients with diabetic retinopathy and the performance of the system is very satisfactory. A photograph of part of the laser-treated retina using our laser is shown in figure 7.

Figure 6. Photograph of the complete system.

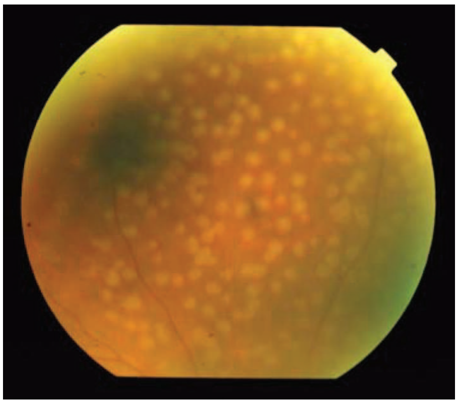

Figure 7. A magnified part of the treated retina.

In conclusion, we have successfully developed and characterized DPSS green laser-based photocoagulator for the treatment of diabetic retinopathy incorporating all the necessary safety and user-friendly operating features. The system has undergone successful clinical trials and was extensively used for treatment of patients with diabetic retinopathy.

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