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ACTIVE MODE-LOCKING OF A DIODE-PUMPED Ce, Nd: YAG

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ABSTRACT : We have developed a mode-locked Ce,Nd:YAG laser end-pumped by a 500 mW laser diode. With a short cavity configuration the cw optical output power was 155 mW, which corresponds to an optical efficiency of 30.9 % and an electrical efficiency of 9.5 %. A cavity length extended to 1.4 m allows mode-locked operation at 106 MHz and pulses widths of 150 ps have been obtained with an average power of 23 mW.

We describe Ce,Nd:YAG and Nd:YAG lasers end-pumped by a 500 mW laser diode (SDL-2432-H1) mounted on a thermoelectric cooler used to adjust the diode array emission wavelength to the absorption peak of the crystal. The diode output is collimated by a 6.5 mm focal length lens (Melles Griot 06GLC001/D), made approximately circular by passing through an anamorphic beam expander (Melles Griot 06GPA002), and then focused on the laser rod by a 25.6 mm focal length lens (Melles Griot 06GLC004). With this coupling optics, a spot diameter smaller than 130 μm can be produced with about 10 % power loss. The Ce,Nd:YAG rod is 5 mm in length and 5 mm in diameter, and the Nd:YAG rod is 10 mm in length and 3 mm in diameter, both with planar ends. The pumped end of the rods is dielectrically coated to be of high transmission at the pump wavelength of 810 nm and high reflection at the lasing wavelength of 1.064 μm , so that this end acts as cavity input mirror. The other face is antireflection coated at 1.064 μm .

In a first attempt we developed a short cavity setup (fig.1a) in order to test the rods. In this configuration, an output mirror of 20 cm radius of curvature was placed about 10 cm from the rod. At 857 mA dc pump current applied to the diode array, the electrical input power was 1.6W and the diode output power was 500 mW. Under these conditions the TEM_{00} cw optical output power was 155 mW with the Ce,Nd:YAG rod but only 107 mW with the Nd:YAG rod, which corresponds respectively to 9.5 % and 6.6 % electrical efficiency. The slope efficiency together with the optical and electrical efficiencies obtained with the two rods are summarized in table 1. The results reported for the Ce,Nd:YAG rod are the highest obtained with a 500 mW laser diode [1,2]. This rod being more effective, we used this rod to achieve mode-locked operation.

Fig.1 - Schematic diagrams of the short cavity setup (a) and extended cavity setup (b)

Table 1 : Performances of the short cavity setup

ROD	Ce,Nd:YAG	Nd:YAG
SLOPE EFFICIENCY	34.7 %	24.4 %
ELECTRICAL EFFICIENCY*	9.5 %	6.6 %
OPTICAL EFFICIENCY*	30.9 %	21.3 %

*with 500 mW emitted from the diode

In the extended cavity setup (fig.1b), an intracavity folding mirror of 15 cm radius of curvature produces an intracavity focus. The resonant cavity is completed by a plane output coupler of 10 % transmission with a 10° wedged rear surface. Mode-locking was accomplished using an acousto-optic mode-locker (IntraAction ML-53C) with a 1° wedged rear surface placed close to the output coupler. It was either modified to operate at 95 MHz, either driven at the rated frequency of 53 MHz. The laser was frequency doubled using a crystal of potassium titanyl phosphate (KTP). The mode-locked system was optimized by use of a fast photodiode and sampling oscilloscope and the pulses at 532 nm were analysed with a streak camera used in synchroscan mode and calibrated by mean of a Prot-Fabry interferometer. Figure 2 shows the curves recorded for a cavity length of 79 cm (fig.2a) or 140 cm (fig.2b) with 500 mW emitted from the diode. The best pulse durations were 133 ps and 149 ps full width at half maximum (FWHM) respectively at 190 MHz and 106 MHz. The pulses should be compared with the predictions of the Kuizenga and Siegman theory of mode-locking of homogeneously broadened lasers [3]. In this theory the pulse FWHM is proportional to $f_m^{-1/2}$ where f_m is the drive frequency applied to the modulator. Thus, under the same experimental conditions but the modulation frequency being changed, the product $t_p f_m^{1/2}$, where t_p is the pulse FWHM, should be constant. The results obtained for the two repetition rates are $1.1\text{ps}^{1/2}$ and $1.3\text{ps}^{1/2}$ respectively at 106 MHz and 190 MHz, which indicates that the system has to be improved.

Fig.2 - Streak camera records at 190 MHz (a) and 106 MHz (b)

In conclusion, mode-locked operation of a diode-pumped Ce,Nd:YAG laser has been achieved with pulse durations near 150ps. Further work is under way to optimize this device and upscale it to higher power levels.

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