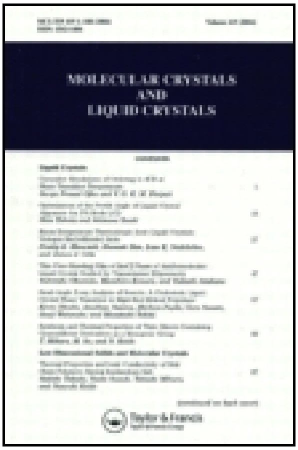

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Cholesteric Liquid Crystal Mirrors for Pulsed Solid-State Lasers

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Cholesteric Liquid Crystal Mirrors for Pulsed Solid-State Lasers

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Abstract. Cholesteric liquid crystals have been investigated as mirrors in an optical resonator for pulsed solid-state lasers. The outcoupling efficiency has been optimized by tuning the reflectivity of the cholesteric mirror with temperature. Furthermore, the polarizing properties of the helical Bragg-reflection have been used in an electro-optical Q-switched laser instead of the conventionally used combination of dielectric mirror plus polarizer. Pulses of 10 ns duration with peak intensities up to 1 GW/cm^2 have been obtained. It is further shown that light-induced changes in reflectivity lead to a passive cavity-dumping and improved transverse beam profile, which may be also of interest for other photonics applications.

Keywords: Cholesteric Liquid Crystals, Optical Nonlinearities

1. Introduction

Cholesteric Liquid Crystals (CLCs) are well suited for narrow band, polarizing optical filters and mirrors, due to their helically distributed birefringence, which makes them of interest for various laser applications. The spectral selective reflection, depending on temperature, was e.g. used to tune a broad band dye laser [1]. Furthermore, optical nonlinearities like retro-self-focusing and the so-called pinholing-effect [2,3] were observed in cw-operated neodymium doped ytrium aluminum garnet (Nd:YAG) lasers with medium peak intensities. Photonic switching and optical bistability has been reported with dye-doped cholesterics [4,5]. In the present paper CLC-mirrors were investigated as polarizing, high reflectivity optical components for high power solid-state laser resonators.

2. Sample preparation and CLC reflectivity in pulsed solid-state lasers

Cholesteric liquid crystals were sandwiched between two glass substrates, coated with an anti-reflection layer for the laser wavelength of 1.06 µm at the outside and an SiO_2 orientation layer for uniaxial planar alignment at the inner surface. The glass plates were separated by Mylar spacers between 5 and 10 µm thickness, filled with the nematic mixture ZLI-2359 from Merck doped with the chiral component CB-15. The samples were sealed and glued using an epoxy adhesive. The Grandjean-texture was obtained by slightly shearing the glass plates. The maximum CLC Bragg reflectivities were up to 95% with a bandwidth of 60nm (FWHM). The reflectivity for a fixed wavelength could be reduced down to 20% by shifting the Bragg condition with a temperature change of ±15 K.

First, temperature tuning of the CLC reflectivity has been investigated with free-running solid-state lasers to optimize output coupling. The laser oscillator (fig. 1) is build up by a highly reflecting dielectric mirror and the temperature controlled cholesteric outcoupling mirror. The flashlamp pumped Nd:YAG laser rod 3“ x 1/4“ is positioned in an elliptical reflecting cavity. Due to the polarizing property of the CLC-mirror and the change of handedness of circular light by the dielectric mirror, an additional quarter-wave-plate is required in order to conserve polarization and to keep output losses low.

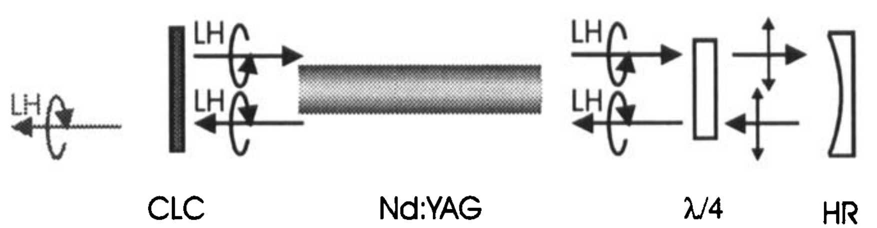

Fig. 1: Experimental solid state laser setup with cholesteric resonator mirror

The temperature dependence of the cholesteric mirror reflectivity for a fixed wavelength as shown in the lower plot of fig. 2 was measured with a 50 mW cw-Nd:YAG laser. The slope efficiencies of a free running, pulsed Nd:YAG laser were then measured for different temperatures resulting in a variation of the CLC reflectivity. The temperature dependence of the slope efficiency shown in Fig. 2 can be explained as follows: For too high reflectivities accumulated losses are rather high due to many roundtrips of the lightwave inside the resonator. If, on the other hand, the reflectivity is too low, the losses

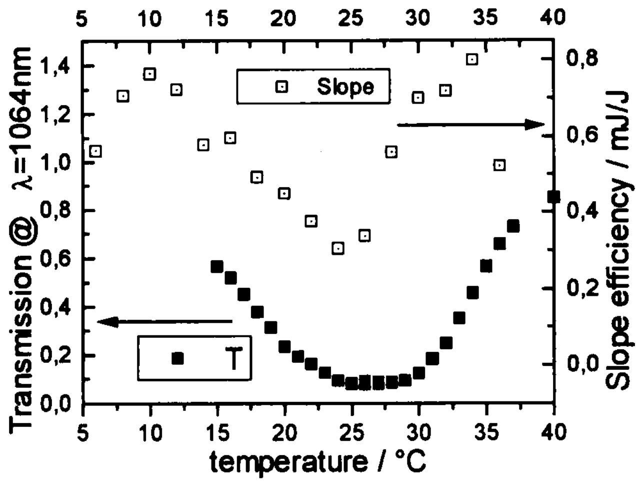

Fig. 2: Slope efficiencies for different reflectivities of the CLC mirror

per round-trip are high and laser efficiency is reduced as well. The maximum slope efficiency was obtained for a reflectivity of about 50 %, which is in agreement with results obtained with conventional mirrors in the same laser.

4. CLCs as polarizing end mirror for electro-optic Q-switch lasers

The polarization dependence of the reflectivity of a cholesteric liquid crystal is well suited to replace the combination of a separate polarizer and dielectric mirror required in electro-optic Q-switched lasers. Fig. 3 shows the setup of a conventional laser with a dielectric mirror in comparison with a laser with CLC polarizing mirror. In order to demonstrate the different modes of operation for these two setups, the upper arrangement of fig. 3 is explained first: starting with horizontally polarized light, the active Pockels cell (quarter-wave-voltage applied) produces left handed circular polarization, which is reversed by reflection at the HR dielectric mirror. The second pass through the Pockels cell results in orthogonally linearly polarized light, which is blocked by the polarizer. In that state, the inversion in the laser material is build up during pumping, since stimulated laser emission is suppressed due to the low Q-factor of the blocked resonator. After switching off the quarter wave voltage, the polarization in the resonator remains linear, resulting in low losses or a high Q-factor and the laser process starts, building up a short, intense laser pulse.

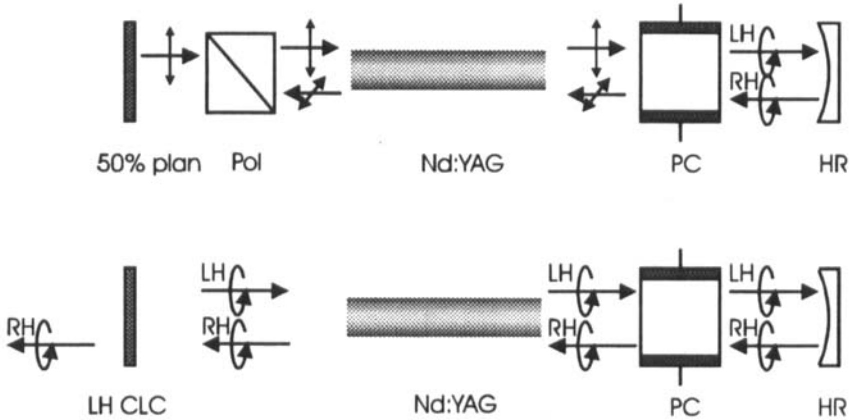

Fig. 3: Experimental setup with conventional mirror and polarizer (upper sketch) and with a cholesteric mirror (lower sketch)

Considering now a laser with a left handed (LH) cholesteric end mirror, the stable polarization is now left circularly polarized. In that configuration the voltage at the Pockels cell has to be shut down first, in order to conserve the polarization state of the passing light. The handedness of polarization is reversed by the dielectric mirror, but is almost completely coupled out by the polarizing CLC mirror. Consequently the polarization state is not reproduced after one resonator round trip and the resulting losses avoid to overcome laser threshold. If now the quarter wave-voltage is applied to the Pockels cell, losses are reduced rapidly and an intense laser pulse is emitted as well. The temporal structure of the emitted pulses is shown in fig. 4 for both configurations. The left plot

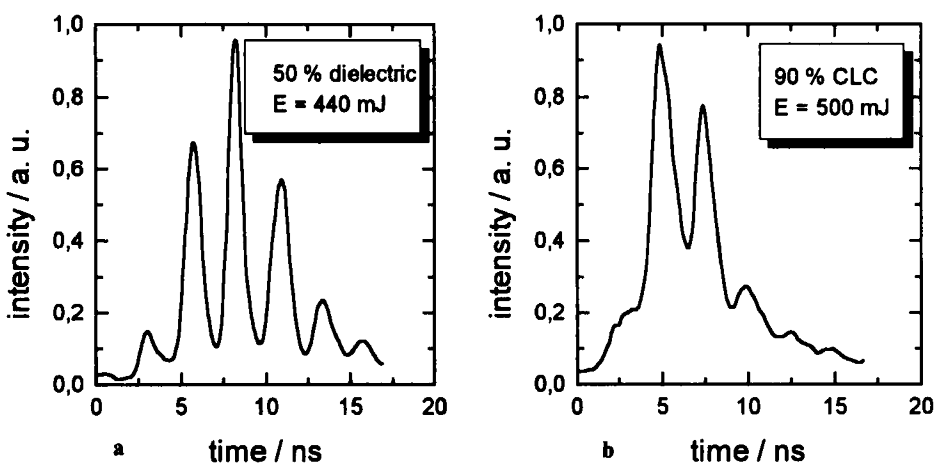

Fig. 4: Q-switch pulses of a laser with conventional (a-left) and cholesteric (b-right) mirror

displays a pulse of the laser with dielectric mirror exhibiting a symmetrical envelope and strong oscillations due to multimode operation in a conventional resonator. The pulses from the laser with CLC mirror show a somewhat weaker modulation and clearly an asymmetry, which can be explained by a decrease in reflection for strong optical fields during the pulse. This can be explained assuming a relative high reflectivity of the cholesteric mirror at the beginning. If now a high intensity is build up inside the resonator, the reflectivity may decrease due to nonlinear interaction. This behavior can explain the fast increase of the pulse in fig. 4b. Additional experiments show that the reflectivity of the cholesteric mirrors for circularly polarized light decreases from 90% at low intensities down to 25% for intensities about 100 MW/cm^2. These observations agree well with theoretical considerations of Winful [6] and Lee [7], who proposed that high intense optical fields may lead to an unwinding of the CLC pitch, which results in a change of reflection. Thermal effects can be almost neglected since the absorption at 1.06 μm is too weak, which is supported by high damage thresholds of more than 1GW/cm^2 achieved with the investigated materials.

Furthermore, light-induced changes in the reflectivity of CLCs may lead to the so-called pinholing effect, which yields a soft-edged aperture within the laser resonator. As a result a smooth transverse beam profile is emitted by the Q-switched CLC-laser without inserting any further aperture in contrast to the strongly modulated intensity profile obtained with conventional mirrors (see fig. 5). Observation of the pinholing effect also supports the assumption of photonic switching of CLCs in pulsed solid-state lasers.

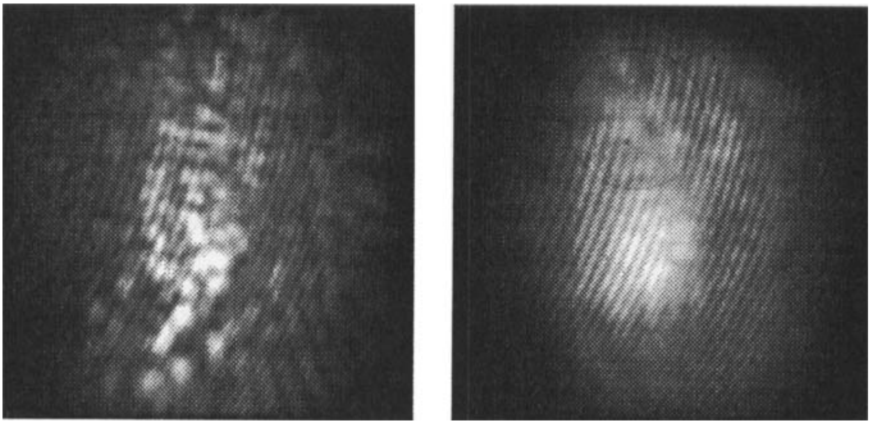

Fig. 5: Spatial mode structure of laser pulse with dielectric mirror (left) and CLC mirror (right)

5. Summary

Cholesteric liquid crystals have been investigated in flashlamp pumped Nd:YAG lasers as resonator end mirrors. The reflectivity of a cholesteric mirror for a free running Nd:YAG laser was changed between 95 and 20% by a temperature induced shift of the selective reflection band, in order to optimize outcoupling. In combination with an active Q-switch laser pulses of 10 ns duration with energies of 500 mJ corresponding to peak powers of 100 MW and intensities of about 1 GW/cm^2 have been realized. Furthermore, passive cavity-dumping and a pinholing effect has been achieved. The latter observations were explained to result from nonlinear reflectivity and all-optical switching of the CLC mirror at high light intensities. These all-optical switching effects of CLCs may be also of interest for other photonics applications.

Acknowledgments

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