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초청강연 Ⅲ

Applications of Cholesteric Liquid Crystal In a Nd:YAG Laser and a Cr:Nd:GSGG Active Mirror Amplifier

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Over the past 15 years, major advances in the field of liquid crystals have been achieved. The main motivation was the application of liquid crystals for displays. Low voltage requirements, low power consumption, compactness and flexible size were the unique features that made liquid crystal displays preferable. Many applications in different fields are also found in the literature. Applications of liquid crystals involving lasers such as spatial light modulators, optical A/D converters, power limiters and beam deflectors are described in the literature. Applications of liquids in large laser systems were explored, starting in 1979 by S. D. Jacobs[1]. He realized that large clear aperture requirements of some optical components could not be easily satisfied by solid crystal materials. Solid crystalline materials were either very expensive, not available in large clear apertures and large quantities, or could not be reused once damaged by intense laser beams. Liquid crystals were the solution for the problems described above. In this paper, we will focus how cholesteric liquid crystals (CLCs) can be used for reducing and improving the quality of solid state laser systems.

A CLC mirror consists of a CLC fluid confined between two flat glass substrates as shown in Fig. 1. The CLC fluid has a helical structure of molecules, and this helical structure leads to the important optical properties of selective reflection in wavelength and circular polarization. One full 360° rotation of the molecule layers is defined as one pitch length, P_0. The field reflected by the CLC preserves its sense of polarization, whereas a conventional dielectric mirror changes the sense of circular polarization for a reflected field.

Active-mirror amplifiers (AMAs) have been demonstrated for use in laser fusion systems. Unlike rod and disk amplifiers, AMAs are inherently double-pass devices, exhibiting larger energy extraction and compensation for thermally induced birefringence. A Cr:Nd:GSGG AMA is shown schematically in Fig. 2. It consists of a circular plate of the gain medium pumped from one side by a shape tailored array of flashlamps. The keys to the operation of the active mirror are the dielectric thin film coatings applied to the plate. The coating on the rear (pumped) side of the plate is highly reflecting at the gain wavelength and highly transmitting at the pump wavelengths. The front coating is the converse of the rear. In operation, both the beam to be amplified and the pump light double-pass the gain medium for efficient extraction and absorption. Cooling is done through a major face only, to ensure that with uniform pumping, thermal gradients are parallel to the direction of propagation of the amplified beam. The circumference of the plate is angled and fine-ground to defeat parasitic oscillations. A combination of blastshield and UV filter protects the active medium from ultraviolet light emitted by the flashlamp array. In 1981, D. C. Brown et al.[2], implemented a passively switched double/double-pass active-mirror amplifier (D^{2}AMA) system (four passes of the active medium) which employed a polarizer, three quarter wave plates, a series of AMAs and a dielectric mirror for sending the beam backward to make the second double pass. However, this system was quite complicated and several difficulties were encountered. Leakage ocurred at the polarizer due to its imperfections and depolarization introduced by the active mirrors. This leakage caused a back reflection to the driver line and laser oscillator. A much simpler alternative for multiple passing of AMAs is suggested, wherein a CLC mirror is used to passively transmit and reflect laser irradiation in front of an AMA. The setup for a D^{2}AMA using a CLC[3] is shown in Fig. 3. The right-handed CLC mirror is placed in front of the GSGG active mirror. The presence of the

CLC causes the crystalline disc to be traversed four times , instead of the usual double pass. In this figure, the input probe beam from the GSGG oscillator, which is left-handed circularly polarized (LH), is incident on the CLC mirror. No interaction occurs between the right-handed helical structure of the CLC and the LH incident beam. It is transmitted to the rear, dielectric-coated side of the active mirror, where it reflects back with a change in polarization from LH to RH. Upon returning to the CLC, the beam is now reflected by the CLC because its handedness matches that of the CLC. There is no polarization change upon reflection from the CLC, however, and the beam proceeds as shown in the figure. One more reflection from the dielectric HR permits the beam to exit the CLC. As it is shown here, the beam makes a quadruple pass through the active-mirror gain medium due to the inherent nature of the active mirror being double passed. Therefore, one can get the square of the small- signal gain for the D^2AMA configuration. The small-signal gain of the active mirror was measured with and without the CLC mirror as a function of the bank energy. The probe beam from a Q-switched GSGG oscillator with a pulse width of 0.5 μs was attenuated to ensure that the small-signal gain was being measured. The small-signal gain at the maximum bank energy of 460 J, was 1.46 without the CLC and 2.05 with the CLC. This demonstrates that the small-signal gain can be approximately squared by placing a passive CLC mirror element in front of the active mirror.

The literature contains few references to the use of CLCs as laser end mirrors. In 1978, Il'chishin et al.[4] reported the tuning and narrowing of the emission spectrum of a dye laser with a CLC mirror. The frequency tuning from 567 to 585 nm was achieved in the temperature range of 22-28 °C. In1980, Denison et al. [5]also reported the operation of a CuI vapor laser with a CLC end mirror. Temperature tuning for operation at 510.6 or 578.2 nm was demonstrated.

In our previous work[6-7] , we showed that under exposure to a plane wave with Gaussian intensity distribution, a retro-self-focusing effect in a CLC mirror occurs in which the reflected field comes to focus, as a result of intensity-dependent pitch dilation. When this CLC element acts like a well-aligned concave mirror/pinhole combination and TEM_{00} mode operation is obtained as a result of the pinholing effect. The mechanism of this pinholing effect is as follows: the TEM_{00} mode has the lowest loss per round trip compared to higher-order spatial modes. After sufficient round trips, the TEM_{00} mode becomes dominant and effectively creates a concave mirror over finite lateral dimensions across the CLC, preventing higher-order modes from oscillating.

In a solid state laser cavity, where two waves with the same frequency travel in opposite directions, interference between these two waves produces a standing-wave pattern in the optical field intensity . This interference effect in the gain medium produces a spatial modulation of the population inversion, which leads to multi-longitudinal-mode operation even in spectrally homogeneous lasers. This is called spatial hole burning. There are several ways to eliminate spatial hole burning. One way is to put the laser rod between two quarter wave plates and place one linear polarizer between one wave plate and a laser end mirror. In this configuration, counter-propagating circularly polarized beams with the same handedness, with respect to a fixed coordinate system, are generated, and no standing wave can be formed inside the cavity. As discussed earlier, a single CLC mirror inherently provides an orthognal polarization states between incident and reflected beam. This leads to single-longitudinal-mode operation (SLM) in a solid state laser.

A commercial cw Nd:YAG laser(Control laser Model 256) was used to demonstrate SLM operation as well as TEM_{00} mode operation. Both SLM and TEM_{00} mode operation were achieved for cw powers in excess of 1 W. No pinhole is required to obtain TEM_{00} mode operation[8]. Long-term single-mode stability can be maintained without complicated thermo-mechanical isolation aids.

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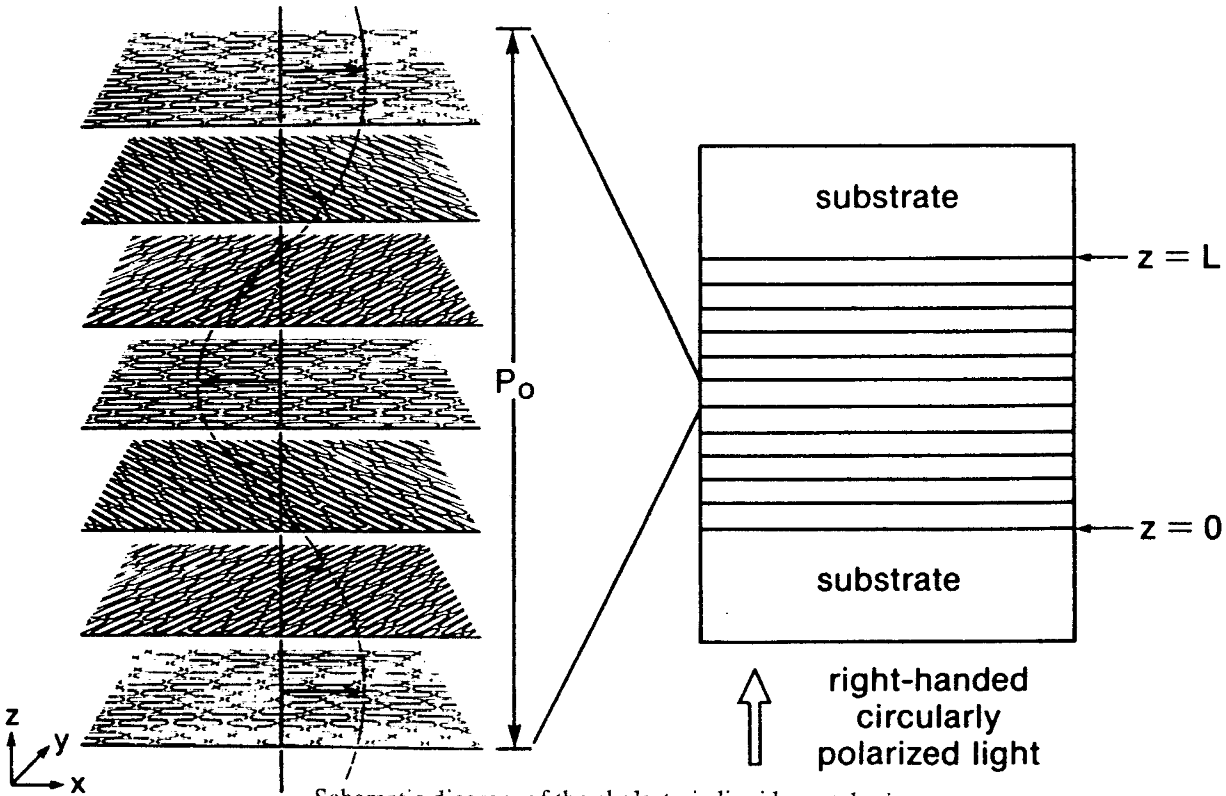
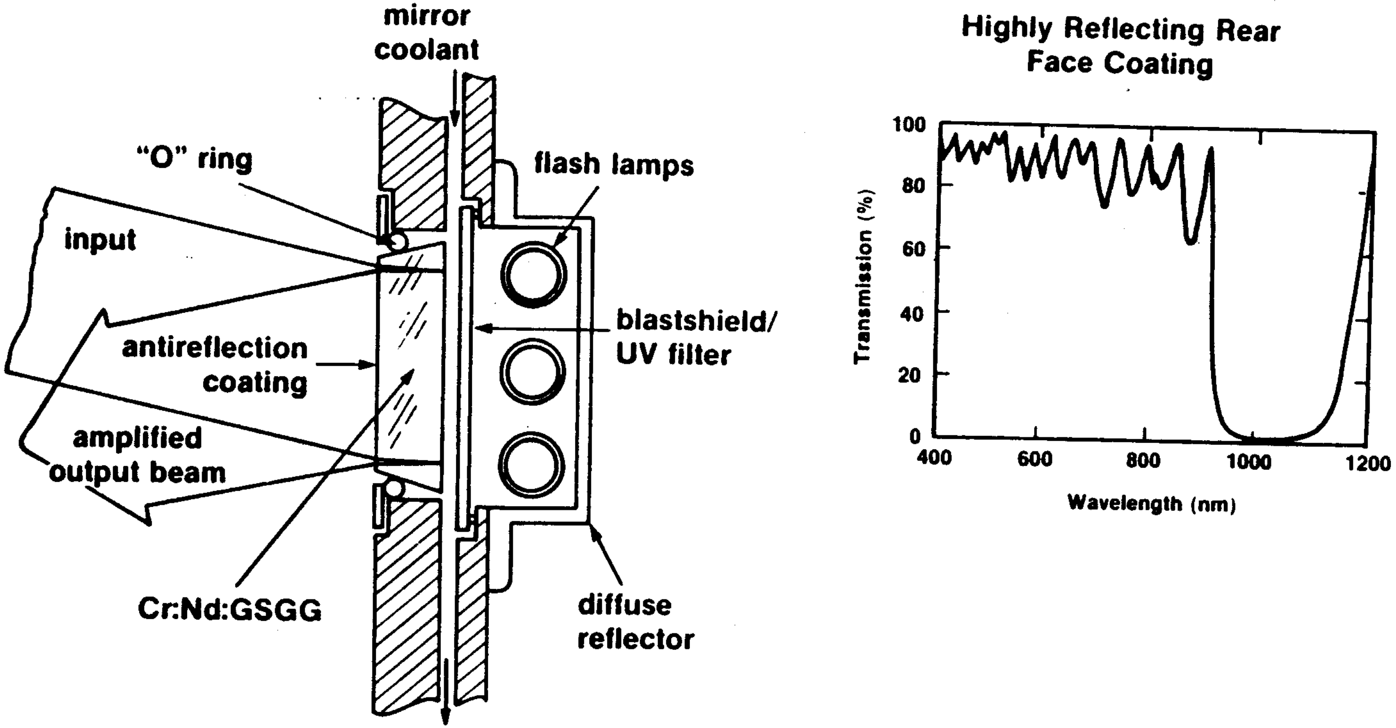
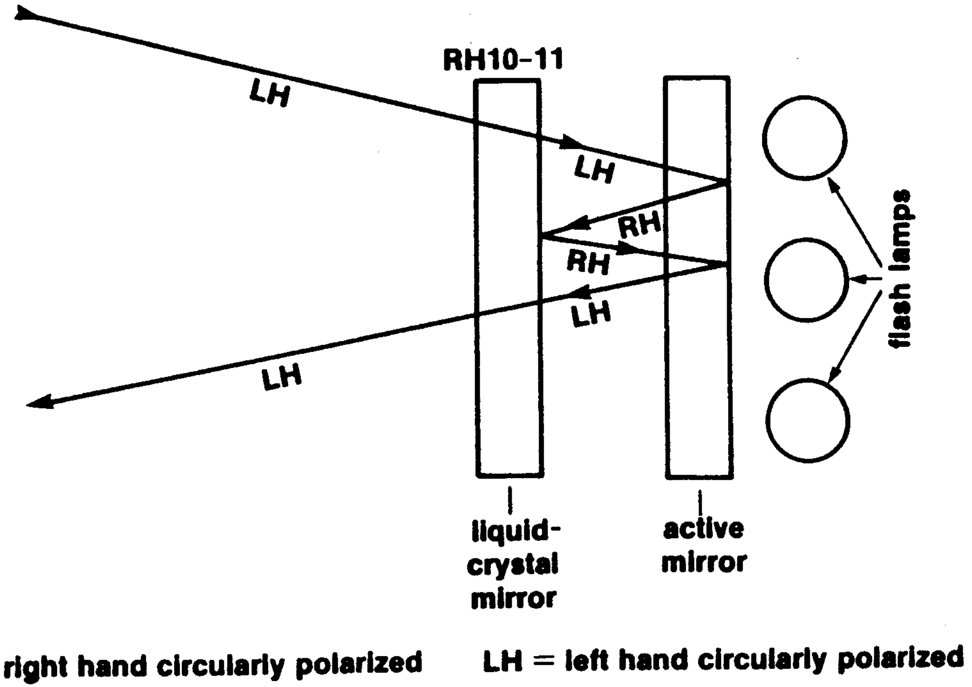
Schematic Diagram of the Cholesteric Liquid-Crystal Mirror



Schematic diagram of the cholesteric liquid crystal mirror.



Active mirror amplifier geometry.



Experimental setup for doubling the number of passes in an active-mirror amplifier by insertion of a CLC element.