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DFB Laser based on Liquid Crystal Waveguide by holographic lithography

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Introduction

Liquid crystal is one of the most famous anisotropic substance, and has large anisotropy on refraction index. The alignment direction of the liquid crystal molecules can be controlled by means of imposing voltage.

Recently, holographic lithography technique has attracted much attention for the easy fabrication technique of nanometer periodic structures. Not only the ease of fabrication, this technique possesses many advantages to the other techniques as follows. Various structures can be realized by changing the parameters of interfering laser lights, such as the number of laser beams, intensity, wave vector (direction), polarization, phase, and so on. More over, filling factor can also be controlled. The nanometer structures fabricated in this method can be applied to the cavity for distributed feedback (DFB) laser. [1]

In this paper, by means of one-shot holographic exposure of pulsed laser beams, nanometer-sized waveguide structures were fabricated. We inserted the mixture of liquid crystal and dye into the waveguide structure and excited it to laser emission. The lasing wavelength was tuned as a function of applied voltage.

Experiment

For the fabrication of one-dimensional periodic structures, surface relief grating (SRG), we used SU-8 2005 (Micro Chem), an epoxy based negative type photoresist, which has been widely used in the field of micro electrical mechanical system (MEMS) so far. SU-8 has very high optical transparency above the wavelength of 360 nm. We diluted the photoresist by adding its solvent, cyclopentanone in order to reduce the film thickness.

The fabrication processes go as follow.

(1) Spin-coating the SU-8 on Indium-Tin-Oxide (ITO)-coated glass (2) Soft bake (3) Exposure (4) Post exposure bake (5) Develop (6) Rinse and dry

SU-8 is very sensitive to variations of process especially baking and exposure processes. The experiments for the SU-8 were carried out in order to improve the lithography quality and optimize the parameters. [2, 3]

A third harmonic light of Q-switched Nd:YAG laser (Spectra Physics, Quanta-Ray INDI) was used as a light source of one-shot holographic exposure. The wavelength, the pulse width and the pulse repetition frequency were 355 nm, 8 ns and 10Hz, respectively. Only one pulse was exposed to the sample. The Lloyd's mirror, which was used for the interferential exposure, is shown in Fig. 1. When the angle of incidence is θ and the excitation wavelength is λ, the SRG period Λ is represented by the expression: $\Lambda=\lambda/2\sin\theta$, where θ was set as 22.7°. The polarization of both two excitation laser beams was set to be s-polarization. Fig.2 shows the SEM image of formed SRG structure by holographic lithography. The SRG period was 460 nm. This value corresponded to the calculation result of $\Lambda=\lambda/2\sin\theta$ when λ is 355 nm and θ is 22.7°.

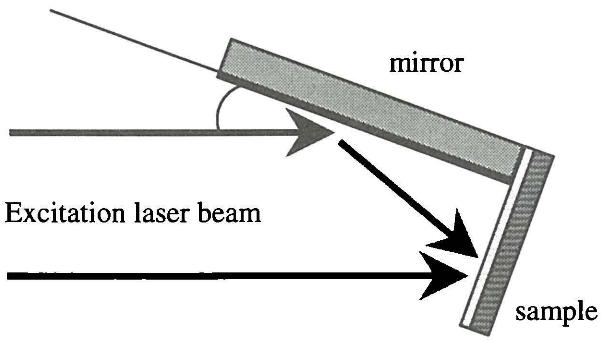

Fig. 1. Lloyd's mirror setup for interferential exposure

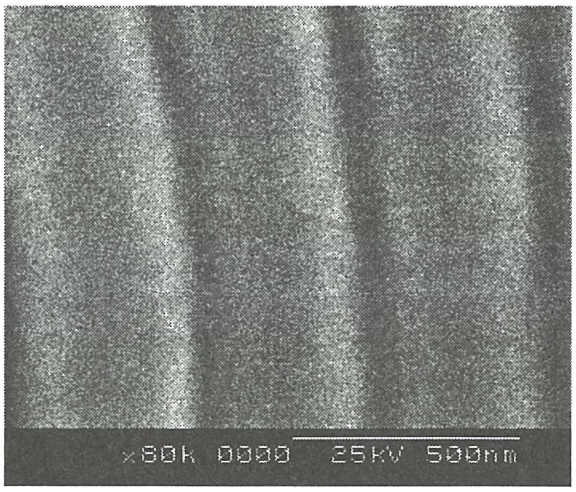

Fig. 2. SEM image of formed SRG structure.

We fabricated the sandwiched cell composed of one ITO-coated glass and the SRG structure on ITO-coated glass. Using 4 μm spacer to compose the NLC waveguide, the nematic liquid crystal (NLC) mixture E-47 (Merck), which shows a nematic phase in room temperature, was used as a host material. The dielectric anisotropy of this NLC is positive so that if an electric field is applied to liquid crystal layer, liquid crystal molecules align their molecular long axis along the applied electric field. A molecular structure of a laser dye dopant, [2-[2-4-(Dimethylamino)phenyl]ethenyl]-6-methyl-4H-pyran-4-ylidene] propanedinitrile, DCM (Exciton) is shown in Fig. 3. The concentration of the dye was 0.5 wt.-%. The ordinary and extraordinary refractive indices n_o and n_e of this mixture are 1.5 and 1.7, respectively. The mixture was introduced into the sandwiched cell. A rectangular AC voltage of 1 kHz was applied to the sandwiched cell to change the molecular alignment of the liquid crystal.

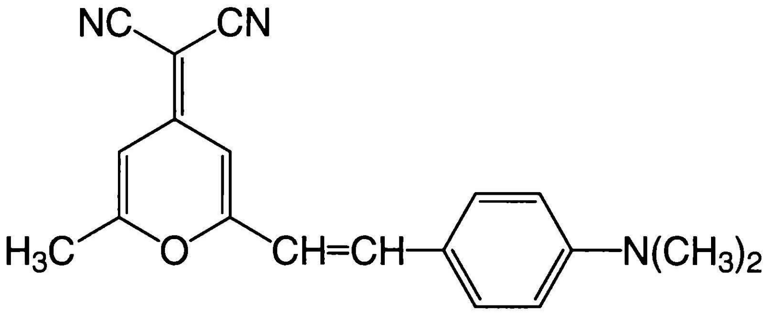

Fig. 3. Molecular structure of laser dye DCM used in this study

Figure 4 shows polarizing microphotographs of the sandwiched cell as a function of applied voltage. When the grating direction was parallel to the polarizer at 0 V, light didn't transmit through the sandwiched cell (Fig. 4 (d)). In contrast, when the angle between the grating direction and the polarizer was 45°, light transmitted through the cell (Fig. 4 (a)). Consequently, it is found that the director of the NLC is parallel to the grating direction.

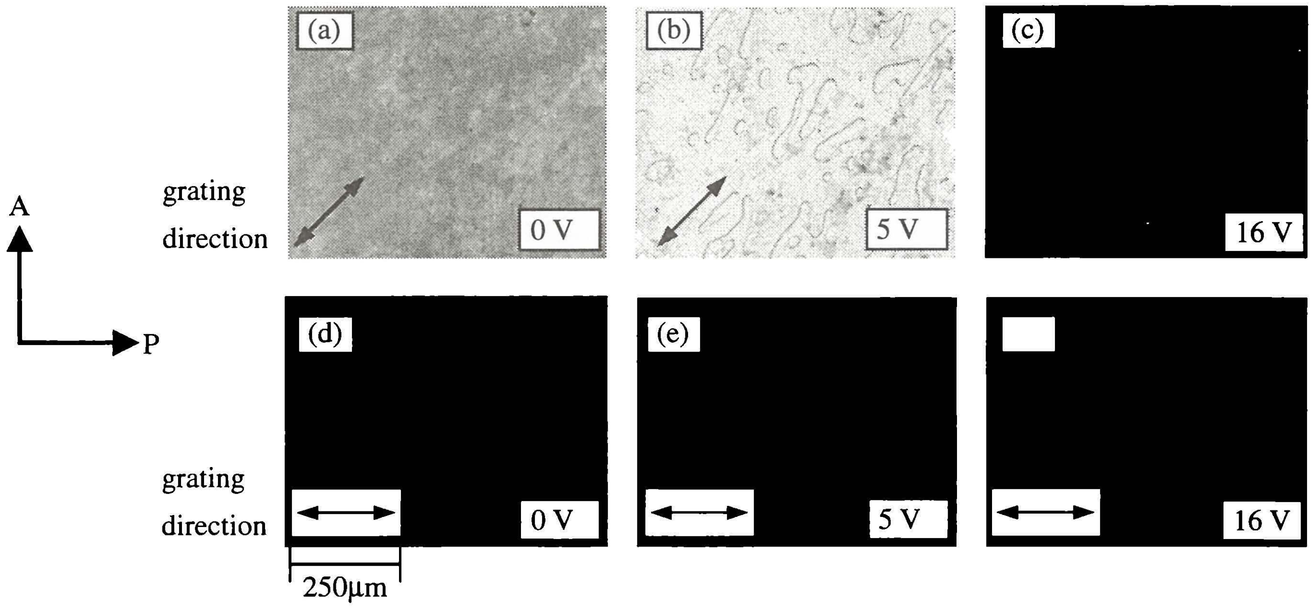

Fig. 4.Polarizing microphotographs of nematic liquid crystal on SRG

With increasing the voltage, we observed the change of the light transmittance under the polarizing microscope. When the angle between the grating direction and the polarizer was 45° (Fig. 4 (a)), the emission intensity once increased (Fig. 4 (b)) and gradually decreased (Fig.4 (c)) as the voltage increased. On the contrary when the angle between the grating direction and the polarizer was 0° (Fig. 4 (d)), light didn't transmit through the cell (Fig. (e) (f)). From the result, the director of NLC molecules in the sandwiched cell with SRG could be changed as a function of applied voltage.

Figure 5 shows the experimental setup used to measure the emission spectra. A second harmonic light of Q-switched Nd:YAG laser was used for an excitation of the DCM in the sandwiched cell. The excitation laser beam was focused into a stripe using a cylindrical lens. The O-56 color filter was put in front of the detector to prevent the excitation laser from entering the detector. Rectangular AC voltage of 1kHz was applied with a function generator.

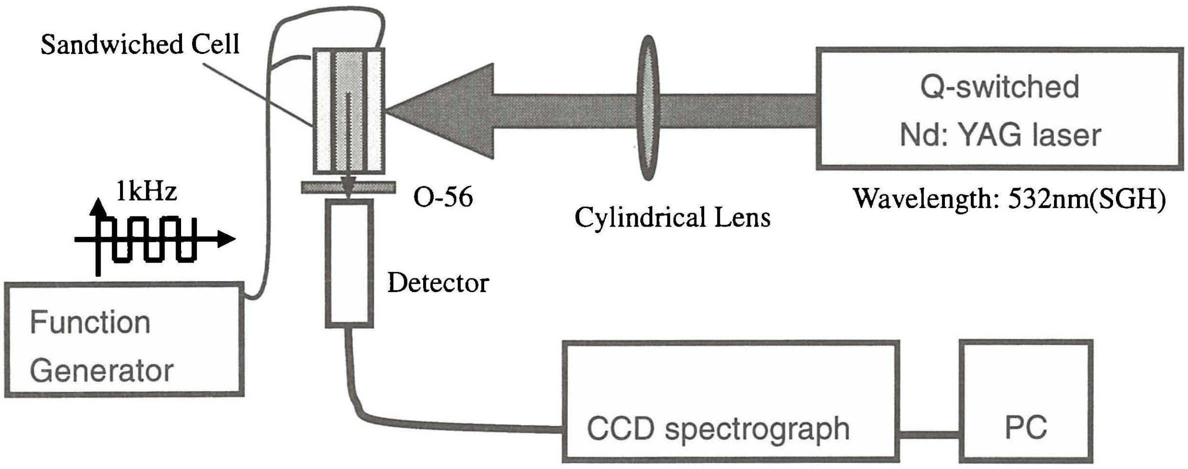

Fig.5. Schematic representation of the setup for laser emission measurement

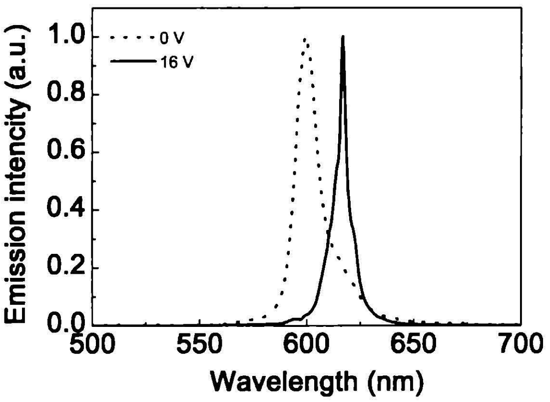

Fig. 6. Emission spectra of the dye-doped NLC wavelength as a function of applied voltage

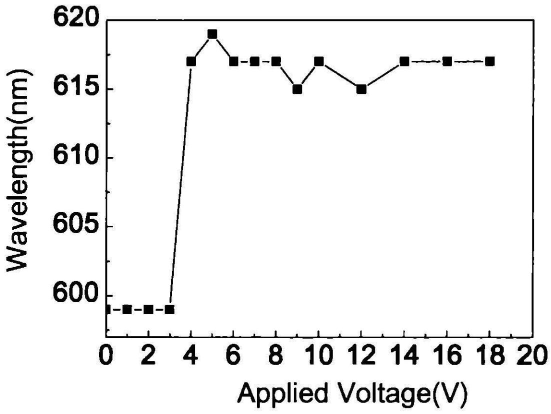

Fig. 7. Voltage dependence of the lasing wavelength

Figure 6 shows emission spectra of the dye-doped NLC as a function of applied voltage. The laser action was observed. The lasing wavelength changed from 599 nm to 611 nm as increasing of the applied voltage from 0 V to 16 V. Therefore about 20 nm change of the lasing wavelength was realized. Voltage dependence of the lasing wavelength was shown in Fig.7. At the threshold voltage of between 3 V and 4 V, the lasing wavelength shifted discontinuously (Fig. 7). Below the applied voltage of 3 V, the lasing wavelength was observed at 599 nm. However above the applied voltage of 4 V, the lasing wavelength was observed at 617 nm. This change was caused by the reorientation of the liquid crystal. When the applying voltage exceeded the Frederiks threshold, the alignment of the liquid crystal molecules changed and the refractive index which light feels changed. In the result, the laser wavelength switched.

Conclusions

By means of one-shot holographic exposure of pulsed laser beams, nanometer periodic structures, SRG, were fabricated using negative type photoresist, SU-8. To apply the structure to the cavity for DFB laser, the mixture of liquid crystal and dye was inserted into the sandwiched cell with SRG. The liquid crystal molecules aligned parallel to the grating direction of SRG. The lasing wavelength was changed about 20 nm as a function of applied voltage.

References

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