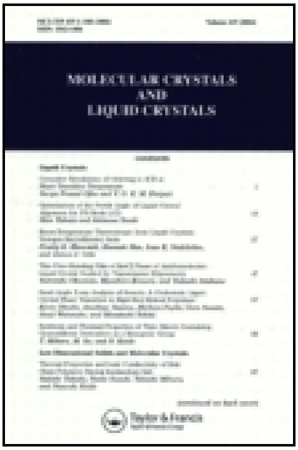

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Wavelength Programmable Organic Distributed Feedback Laser Using a Photoinduced Surface Relief Grating

Takashi Ubukata [a] [b] , Takashi Isoshima [b] & Masahiko Hara [b] [c]

[a] Department of Advanced Material Chemistry, Yokohama National University, Yokohama, Japan

[b] Local Spatio-Temporal Functions Lab., Frontier Research System, RIKEN (The Institute of Physical and Chemical Research), Saitama, Japan

[c] Department of Electronic Chemistry, Tokyo Institute of Technology, Kanagawa, Japan

Version of record first published: 23 Aug 2006

To cite this article: Takashi Ubukata, Takashi Isoshima & Masahiko Hara (2006): Wavelength Programmable Organic Distributed Feedback Laser Using a Photoinduced Surface Relief Grating, Molecular Crystals and Liquid Crystals, 445:1, 269/[559]-273/[563]

To link to this article: http://dx.doi.org/10.1080/15421400500366704

Mol. Cryst. Liq. Cryst., Vol. 445, pp. 269/[559]–273/[563], 2006
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ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400500366704

Wavelength Programmable Organic Distributed Feedback Laser Using a Photoinduced Surface Relief Grating

Takashi Ubukata
Department of Advanced Material Chemistry, Yokohama National University, Yokohama, Japan and Local Spatio-Temporal Functions Lab., Frontier Research System, RIKEN (The Institute of Physical and Chemical Research), Saitama, Japan

Takashi Isoshima
Local Spatio-Temporal Functions Lab., Frontier Research System, RIKEN (The Institute of Physical and Chemical Research), Saitama, Japan

Masahiko Hara
Local Spatio-Temporal Functions Lab., Frontier Research System, RIKEN (The Institute of Physical and Chemical Research), Saitama, Japan and Department of Electronic Chemistry, Tokyo Institute of Technology, Kanagawa, Japan

Novel organic distributed feedback (DFB) laser has been designed and fabricated, utilizing surface relief grating (SRG) on an azobenzene polymer. Introducing double-layered structure in which an azobenzene polymer layer is located on top of an active polymer layer, DFB lasing was observed by photoexciting the element, and oscillation wavelength was widely tuned by selecting the laser dye and period of SRG structure.

Keywords: azobenzene polymer; distributed feedback laser; surface relief grating; wavelength programmable

We thank Dr. S. I. Matsushita and Dr. Y. Aoki in our group of RIKEN for kindly taking cross-sectional SEM images. This work was in part supported by Industrial Technology Research Grant Program in 2002–2004 from New Energy and Industrial Technology Development Organization (NEDO) of Japan.

Address correspondence to Takashi Ubukata, Department of Advanced Material Chemistry, Yokohama National University, 79-5 Tokiwadai, Hodogaya, Yokohama, Kanagawa 240-8501, Japan. E-mail: ubukata@ynu.ac.jp

INTRODUCTION

Thin films of azobenzene-containing polymer (azopolymer) are stimulative and attractive materials because of its ability to form a photoinduced surface relief structure due to mass transfer on micro and nanometer scales [1–3]. When a flat azopolymer film is exposed to an interference pattern of coherent beams, surface relief grating (SRG), that is regular surface relief modulation with same period as that of the interference pattern, is generated on it. In the above background, we expect that the azopolymer can be applied to dynamic devices [4], such as wavelength programmable organic distributed feedback (DFB) laser in which optical feedback is provided by a periodic modulation of the refractive index and/or gain [5–7].

EXPERIMENTAL

The laser dyes, sulforhodamine (SR) and malachite green (MG), were purchased from Exciton Inc. and were used without further purification. The matrix polymer, poly(vinyl alcohol) (PVA), was purchased from Junsei Chemical. The azobenzene polymer, pDR1M, was synthesized as described in the literature [8]. Double-layered structure was fabricated by spin-coating method: a mixed water solution composed of a poly(vinyl alcohol) (10 wt%) and laser dye (0.5 wt%) was spin-coated onto a cleaned quartz substrate as the first layer and annealed at 100°C for 7 h in vacuum; then chloroform solution of pDR1M was spin-coated on it.

Film thickness and refractive index were measured by variable angle spectroscopic ellipsometer (M-2000, Woollam). Optical properties were measured by UV-visible absorption spectroscopy (UV-3100PC, Shimadzu) and fluorescence spectroscopy (FP6500, JASCO). Surface relief structure was inscribed using a Lloyd interferometer [9], and was characterized with atomic force microscope (AFM) (SPA300/SPI3800N, SII) and scanning electron microscope (SEM) (S-5200, Hitachi).

The double-layered films were photoexcited transversally from the substrate side by an optical parametric amplifier (OPA9400, Coherent). The excitation wavelength λp was 605 nm and the pulse width was 150 fs. The pump beam was focused elliptically, 9.4 μm in short axis and 2.3 mm in long axis, on the film using a cylindrical lens. The polarization direction and long axis of the elliptic excitation area were normal to the surface relief gratings. The emitted light from the end edge of the film or that diffracted by the periodic structure was collected with a lens and coupled into an optical fiber to be measured by an optical multichannel analyzer (PMA-11, Hamamatsu Photonics).

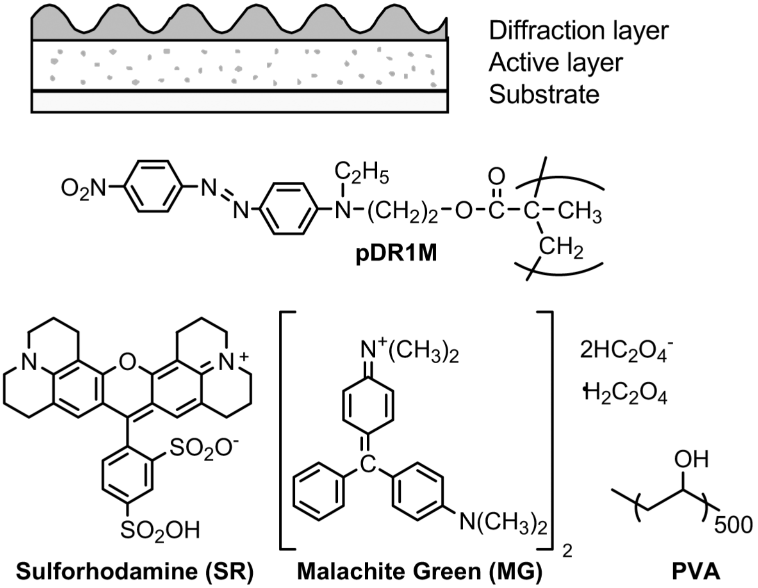

FIGURE 1 Schematic illustration of our DFB laser, and chemical structures of the compounds used in this study.

RESULTS AND DISCUSSION

We designed and fabricated a double-layered DFB laser composed of a diffraction layer of pDR1M and an active layer of SR doped PVA on synthetic quartz substrate (Fig. 1). Fluorescence property of SR-PVA/pDR1M double-layered film was investigated before inscribing SRG on the azopolymer layer. Sufficient photoluminescence was observed from the film. Fluorescence maximum was 613 nm, and full width half maximum (FWHM) of the fluorescence band was 32 nm.

Figure 2(a) shows a topographical AFM image of a periodically modulated surface fabricated on the azopolymer layer after interference exposure. The surface modulation depth (Δh) was ca. 100 nm, equal to the initial azopolymer layer thickness, and the grating period was identical with the interfringe spacing of 666 nm. SEM confirmed the double-layered structure composed of diffraction layer and active layer as shown in Figure 2(b).

The lasing properties were investigated by photoexciting the double-layered film transversally from the substrate side with a pulse laser. The wavelength of the excitation beam was set to 605 nm, longer than π-π^* band of the azobenzene chromophores, in order to avoid film

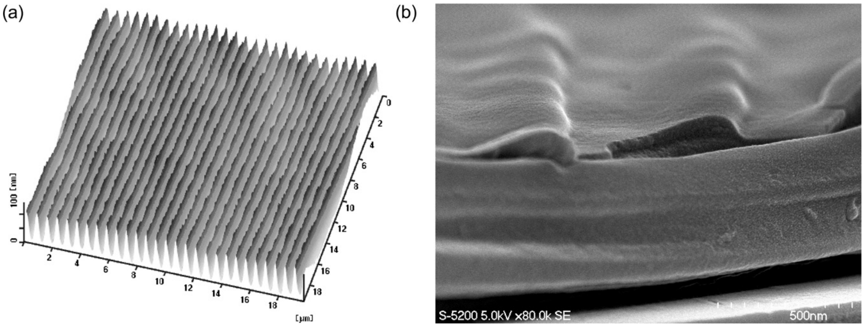

FIGURE 2 Topographical AFM (a) and cross-sectional SEM (b) images of double-layered polymer film.

flattening by photoisomerization. Thus another important factor for selecting SR and MG as the laser dyes was their efficient fluorescence with excitation at 605 nm.

When the SR-PVA/pDR1M film without SRG structure was photoexcited, only broadband emission ($\lambda_{max} = 672$ nm, FWHM $= 10.6$ nm) was observed and assigned to amplified spontaneous emission (ASE). On the other hand, when the SR-PVA/pDR1M film with SRG structure was photoexcited with the pulse laser exceeding the threshold, a very sharp line spectrum was detected at 668 nm as shown in

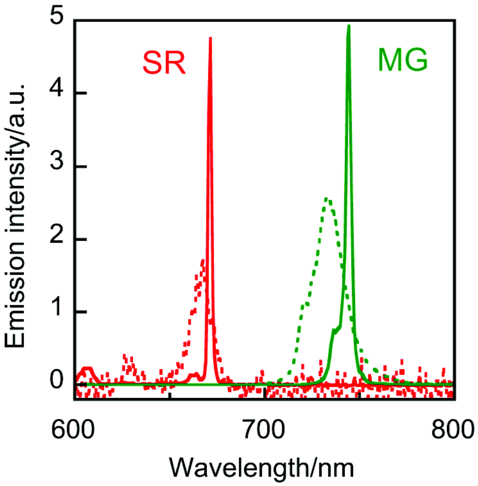

FIGURE 3 DFB laser emission (solid line) and ASE (dotted line) from double-layered films doped with SR and MG.

Figure 3. The FWHM of the sharp band was 1.8 nm, which is approximately equal to the wavelength resolution of the detector. Considering the effective refractive index of 1.51 calculated from the waveguide analysis, the observed sharp line spectrum was ascribed to the lasing from distributed feedback by the SRG structure. Moreover, using the laser dye of MG enabled us to change the oscillation wavelength widely, about 70 nm longer than the SR doped film.

CONCLUSION

The double-layered structure composed of the diffraction layer of SRG and sufficient fluorescence layer allowed us to fabricate wavelength programmable organic DFB laser. This DFB laser element provides us lasing with expected oscillation wavelength simply by setting the incidence angle of the writing beams.

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