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Application of Hybrid Polymer as a Two Dimensional Grating and It's Lasing Characteristic

(Aplikasi Polimer Hibrid sebagai Parutan Dua Dimensi dan Ciri Lasernya)

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ABSTRACT

A two dimensional grating has been fabricated from hybrid polymer incorporated with organic dye-laser. The precursor hybrid polymers were synthesized from TMSPMA by sol-gel method. The precursor was mixed with photo-initiator to make sensitive with UV light. The photosensitive film was irradiated by laser interference of THG Nd-YAG laser (λ = 355 nm) yield 2D grating with hexagonal structure. The characteristic of lasing was investigated using strip-line excitation light of SHG Nd-YAG laser (λ = 532 nm). The lasing wavelengths are observed at 606 and 621 nm for grating period of 400 and 410 nm, respectively. The spectral width (FWHM) of lasing is about 3 nm at pumping power 14.88 mJ/pulse cm^2.

Keywords: 2D-grating; hexagonal structure; hybrid polymer; laser

ABSTRAK

Parutan dua dimensi bahan polimer hibrid yand dicampur dengan dai-laser organik telah difabrkasi. Prekursor polimer hibrid disintesis daripada monomer TMSPMA dengan kaedah sol-gel. Prekursor polimer hibrid ditambah dengan foto-pemula sehingga menjadi sensitif terhadap cahaya ultraviolet. Filem polimer hibrid yang fotosensitif telah disinari dengan pembelauan laser THG Nd-YAG (λ = 355 nm), menghasilkan parutan dua dimensi dengan struktur heksagonal. Ciri laser dikaji dengan menggunakan garis strip pengujaan cahaya laser SHG Nd-YAG (λ = 532 nm). Panjang gelombang laser dicerap pada 606 dan 621 nm untuk kala parutan masing-masing pada 400 dan 410 nm. Lebar spektrum (FWHM) laser adalah sekitar 3 nm untuk daya pam 14,88 mJ/denyut cm^2.

Kata kunci: laser; parutan dua dimensi; polimer hibrid; struktur heksagonal

INTRODUCTION

In recent year, much effort has been exerted to develop optical devices in order to realize the integrated optical circuit. Some transparent materials have been developed such as inorganic glasses and organic polymer. Inorganic glasses have some disadvantages for optical and optoelectronic devices since they have low flexibility and need high temperature for processing. On the other hand, utilizing organic polymers in optical devices can overcome some of the disadvantages of inorganic glasses, but they exhibit a low heat resistance and poor adhesion in some substrate.

Blending of two components is expected to combine the advantages of inorganic glasses and organic polymer. Characteristics of hybrid polymer are appropriate for optical application. They have several advantages, such as easy in synthesizing process (low temperature processing), adhere very well upon various substrate, posses a good thermal stability (decomposition temperature ≈ 270°C), easy customized by add some functional material, and able photo-patterning (Oliveira et al. 2006; Soppera et al. 2002).

Many papers have proposed hybrid polymer as a good candidate for optical devices. One of these is application of hybrid polymer as laser material. Maier et al. (1999) have reported fabrication and analysis of laser resonator with two dimensional distributed feedbacks from photonic crystal. The gain medium consists of 2-(4-biphenylyl)-5 (4-tert-butylphenyl) -1,3,4-oxadiazole host doped with Coumarin 490 and DCM and is deposited on patterned Si/SiO_2 substrate. Two dimensional structure of Si/SiO_2 substrate was fabricated using electron beam lithography. In that case, laser devices made from corrugate substrate up-covered with organic dye laser (Meier et al. 1999).

In this paper, we proposed a more compact laser system using a hybrid polymer as base material. The laser device can be made from hybrid polymer incorporated with organic dye laser (DCM). DCM can be doped into hybrid polymer matrices by means of solution method at room temperature. Furthermore, the 2D grating was fabricated upon the film of hybrid polymer incorporated with DCM. Lloyd mirror interference method was used to fabricate 2D micro-structure.

MATERIALS AND METHODS

The gel precursor of hybrid polymer was synthesized by sol-gel method using 3-(Trimethoxysilyl)-propyl-methacrylate (TMSPMA) as monomer. TMSPMA was obtained from Aldich. Chloroform ($CHCl_3$), ethanol (C_2H_5OH), and HCl (aq) were obtained from Merck. Generally, the step of synthesis is same as that described by Soppera but different in monomer (Soppera et al. 2002). TMSPMA and ethanol were mixed then stirred for 1 h at room temperature yielding the monomer solution. The process of hydrolysis was carried out by add deionized water gradually to the monomer solution. The next step is condensation reaction that was carried out by adding 0.1 M HCl. The solution was stirred over night at 65°C yielding the gel hybrid polymer. The final step is purification process for removing undesirable reactant using chloroform.

For fabrication of two dimensional grating, a suitable photo-initiator (IRGACURE 369, Ciba) was added into precursor hybrid polymer followed by the addition of organic dye laser (DCM). In order to easily control the thickness of film on the substrate, the mixture was diluted using chloroform. Then the precursor films were prepared by spin coating at 500 rpm for 5 s following 2000 rpm for 30 s.

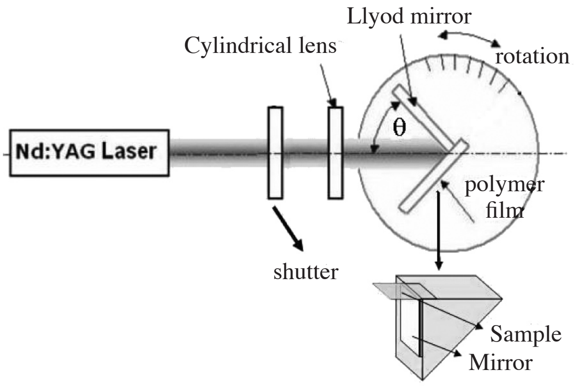

FIGURE 1. Lloyd mirror interferometer setup

The Lloyd mirror interference method was used to make light patterns in sub-micrometer order on the precursor film. The two dimensional gratings can be fabricated by double exposures with rotation of precursor film between the exposure. The photo-polymerization process will occur in irradiated area and the etching process can remove the unirradiated part. The Lloyd mirror interferometer set up is shown in Figure 1. The third harmonic generation (THG) of Nd:YAG laser (λ=355 nm) was used as light source for patterning process. The irradiation power of 200 mWatt and irradiation time of ¼ second were used in this experiment (Gadonna & Grosso 2003; Hidayat et al. 2009). The grating period Λ corresponding to the space between fringes in the interference pattern is given by:

$$\Lambda = \frac{\lambda}{2\sin\theta} \quad (1)$$

where λ is the curing wavelength and θ is the angle between the incident beam axis and the mirror plan.

Some characterizations have been conducted, i.e. absorption and emission spectroscopy, surface profile, and lasing characteristic. The absorption and emission were investigated using UV-Vis spectrophotometer, the formation of grating was investigated using the Atomic Force Microscopy (AFM), and the lasing characteristic was investigated using strip-line excitation light from second harmonic generation (SHG) of Nd:YAG laser (λ=532 nm)

RESULTS AND DISCUSSION

The precursor of hybrid polymer was prepared by the sol-gel method. The sol-gel process consists of hydrolysis and condensation reactions of inorganic part resulting inorganic silicate network. The photo-polymerization process will construct the cross linking in the organic side chains. After photo-polymerization process, the infra red band at 1638 cm^{-1} was significantly decreased. It indicates the reduction of C=C double bond and conversion into C-C bond. The process will be followed with alteration of hybrid polymer phase from gel into solid. The chemical reaction during photo-polymerization process can be seen on Figure 2 (Soppera et al. 2002).

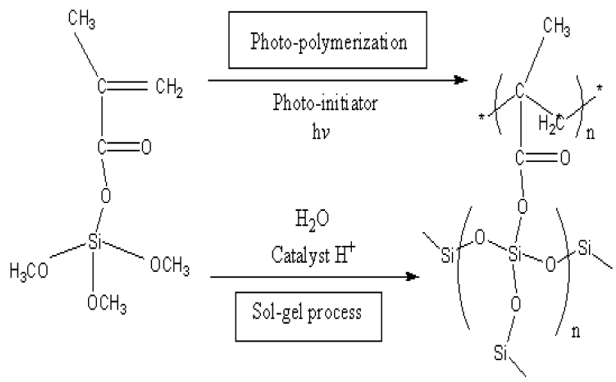

FIGURE 2. The formation of hybrid polymer from TMSPMA

Figure 3 shows the AFM image of 2D surface grating for hexagonal structure. The periodicity of grating is ≈400 nm, and the depth is ≈100 nm. In this experiment, the grating structures were fabricated at two kind incident angle of the interference laser-beam. In principle, the dependence of grating period (Λ) on the incident angle (θ) can be estimated as shown in (1). The choosing of incident angle must match with wavelength in band-gap structure of 2D photonic crystal that corresponds to the lasing wavelength (Hidayat et al. 2009).

Figure 4 shows the photonic band structure of TM mode for 2D surface-grating with hexagonal symmetry that was calculated within the effective 2D model. The parameter structures were assumed as follow: n_{rod} =1.5, n_{hole} =1, and r_{rod} =0.25a, where a is lattice constant. We can assume that

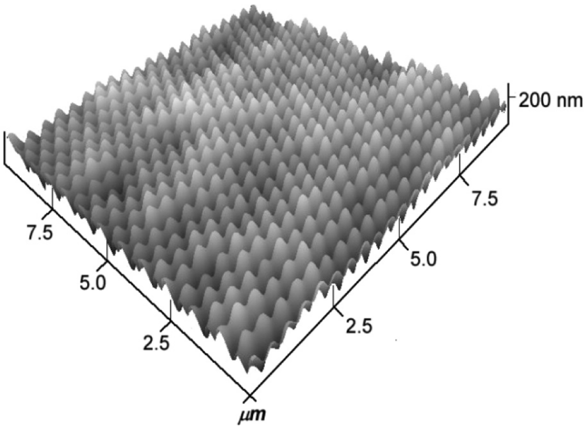

FIGURE 3. AFM surface profile of 2D grating with hexagonal structure

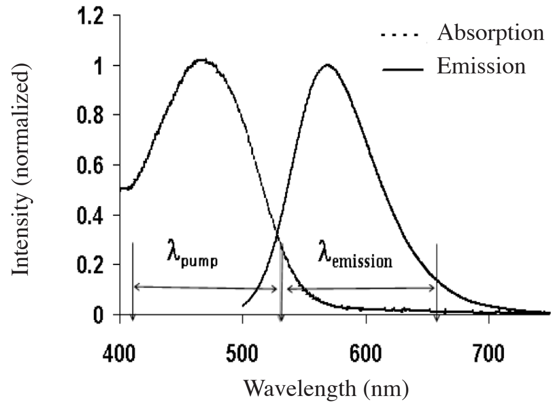

FIGURE 5. Absorption and emission spectrum of Hybrid polymer doped with DCM

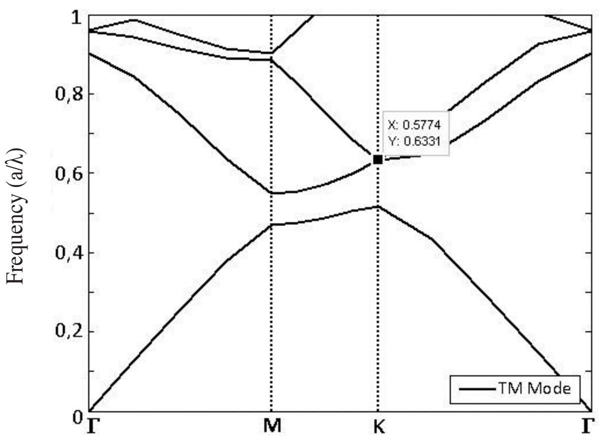

FIGURE 4. Photonic band gap of 2D grating with hexagonal structure

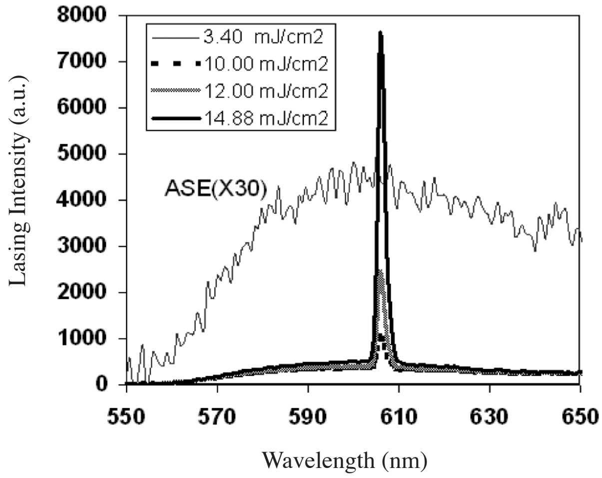

FIGURE 6. Lasing action at various pumping power

distributed feedback occurs at the edge of upper band or frequency at 0.633 (a/λ), where a is grating-period and λ is lasing wavelength (Hidayat et al. 2008).

Figure 5 shows the emission wavelengths are in range between 530 and 660 nm. If these values are substituted into equation $a/\lambda = 0.633$, then the grating periods must be in the range of 335 till 418 nm. In this experiment, we have fabricated grating with the incident angle of 25° and 26°, which correspond to grating period of 410 nm and 400 nm, respectively.

Figure 6 shows the lasing action of 2D grating from hybrid polymer doped with DCM. The samples were optically pumped at frequency 532 nm from SHG of Nd-YAG laser. If the pumping power is less than pumping threshold, then emission spectrum only amplified spontaneous emission (ASE). Increasing pumping power will sharpen the ASE. If pumping power is higher than the power threshold, then lasing action will occur. For both grating periods, the power thresholds are around 10 mJ/pulse.cm^2. We can observe the lasing action at 606 and 621 nm for grating period of 400 and 410 nm, respectively. If the lasing action shoots to the screen, we can observe the orange laser. From Figure 6, the computed spectral widths (full width half maximum, FWHM) are around 3 nm at pumping power 14.88 mJ/pulse cm^2. The increasing of pumping-power will make the spectral width sharper. Furthermore, the lasing action can be observed in various directions in the plane of grating sample that is perpendicular to the pumping beam. The lasing actions appear at the angles around of 0° and 65° with difference of wavelength and intensities as shown in Figure 7.

CONCLUSION

In this paper, we have reported the characteristics of a laser based on distributed feedback of 2D grating with hexagonal structure. Theoretically, the lasing wavelength can be predicted by simulation of 2D band structure within the effective model. The distributed feedback occurs at the edge of photonic band where the group velocity is equal to zero. The prediction of simulation is quite well where the lasing action can be observed at 606 and 621 nm for grating period of 400 and 410 nm, respectively.

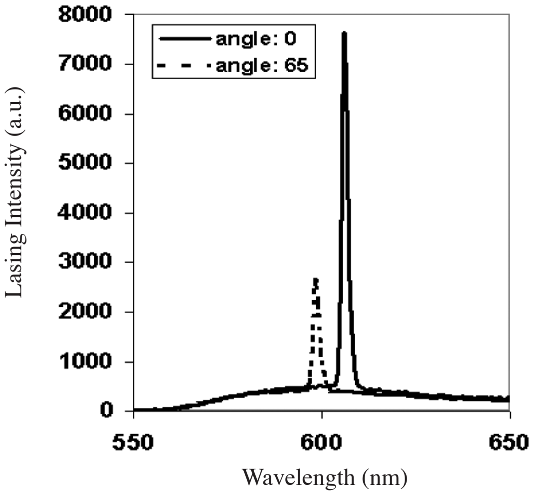

FIGURE 7. Lasing action in different view

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