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Thin film DFB lasers utilizing dye-doped marine-biopolymer DNA-lipid complex films and etch-less gratings

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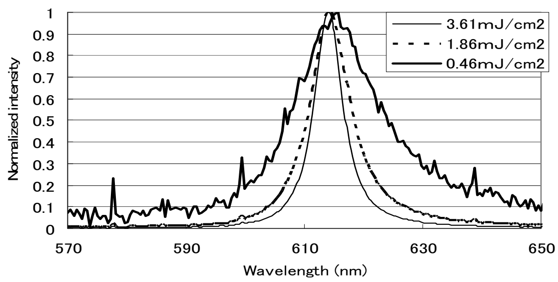
ABSTRACT
DFB laser structure utilizing dye-doped-DNA-lipid films have been studied for potential application to thin-film single longitudinal mode lasers. Although much improvement should be necessary for laser characteristic, we observed single longitudinal mode operation by using etch-less gratings fabricated on a PMMA substrate.

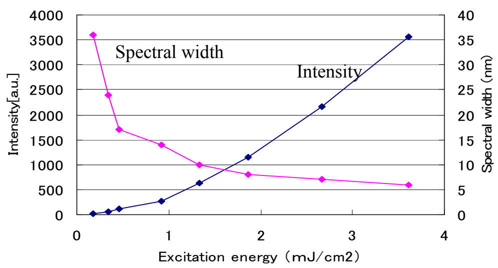
1. INTRODUCTION
Recent research results on DNA-lipid complexes have shown various attractive features such as strong fluorescence, light amplification, selective filtering etc., by the doping of organic dyes into DNA films. We have already reported[1-3] basic optical characteristics, such as refractive indices, absorbance and fluorescence intensity, and photochromic properties, of organic-dye-doped DNA-lipid complex films, which have been derived from marine biopolymers. On the other hand, waveguide type optical amplifiers have been indispensable for integrated photonic devices and their applications to optical signal processing. Recent studies[4-6] on organic dye doped waveguide amplifier structures or lasers show attractive features for realizing thin film integrated functional devices, even they still need further investigation on device structure and fabrication processes.
In this report, we have investigated thin-film lasers which utilize dye-doped DNA-lipid (cetyltrimethilammonium(CTMA)) for the active layer and the etch-less grating[7] for the DFB grating structure. The etch-less grating technology leads easier fabrication process of the gratings without sophisticated etching processes. Therefore, by combining these two key technologies, it is expected that enhanced optical characteristics due to DNA nature of fluorescence enhancement with simplified fabrication processes could result in the high-performance photonic integrated devices with reduced cost.

2. SAMPLE PREPARATION
Dye-doped-DNA-CTMA films were prepared by the same method described in our previous work[1-3], except for the solvent for DNA-CTMA complexes. Because of the substrate material is PMMA in our experiment, we used ethanol instead of ethanol/chloroform mixed solution. Regarding the laser-dye, we employed 4-[4-(dimethylamino) stylyl[-1-dococylpyridinium bromide (DMASDPB), one of the hemicyannine dye derivatives known as nonlinear optical materials. By using the same material system, spectral narrowing due to ASE has been reported[5] above about 0.5-1 mJ/cm^2 of the excitation energy density. In order to introduce the optical feedback mechanism, we utilized the etch-less grating[7] fabricated on the PMMA substrate. The etch-less grating is the grating structure fabricated by a replica formation process from the original photoresist grating pattern onto a polymer substrate such as PMMA. Details of the etch-less grating fabrication process has been reported elsewhere[7].
The laser-dye doped DNA-CTMA was spin-coated or poured on the etch-less grating , and dried for about 3-4 hours. Then, emission spectra excited by the SHG light of pulsed Nd:YAG laser were measured by using HR-2000 multi-channel spectrum analyzer.

3. FLUORESCENCE and ASE SPECTRA
Typical fluorescence and ASE spectra of the DMASDPB-doped DNA-CTMA film are shown in Fig. 1. Note that these spectra were measured for the film coated on a silica glass. The ASE dominated at the region above about 1 mJ/cm^2 of the excitation energy. This is consistent with the previously reported value by Y. Kawabe et al[5]. Figure 2 compares the fluorescence intensity of DMASDPB-doped DNA-CTMA and PMMA. This figure revealed that efficient fluorescence is attained by using DNA as the host material rather than using well-known organic material such as PMMA.



(a) Fluorescence and ASE spectra



(b) Peak intensity and linewidth

Fig. 1 Typical fluorescence and ASE characteristics of DMASDPB-doped DNA-CTMA film

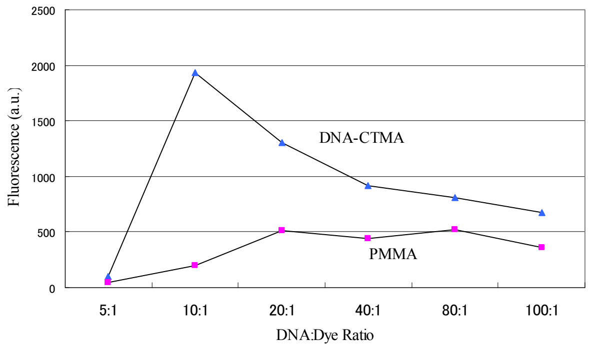


Fig.2 Fluorescence intensity variation with dye concentration in DNA-lipid films

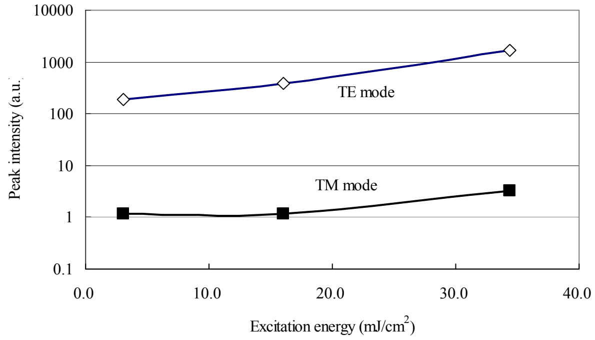
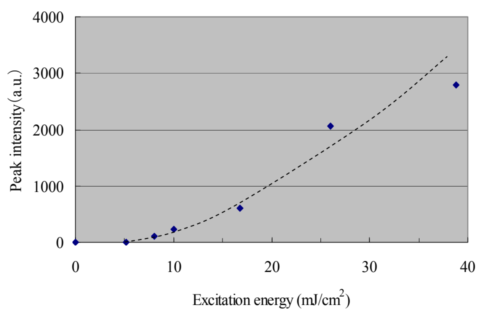


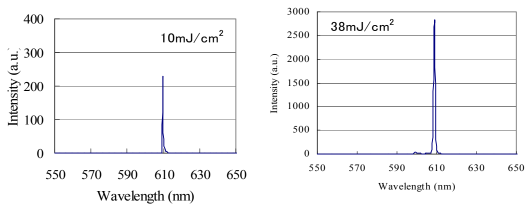
Fig. 4 Intensity of mode components of the lasing output

4. DFB LASER CHARACTERISTICS

Figure 3(a) shows typical I-O characteristics of the DFB laser structure. Lasing spectra are also shown in Fig. 3(b). As shown in this figure, single longitudinal mode operation is maintained whole range of excitation. Mode components of the lasing light are shown in Fig. 4. Although the single mode operation is obtained, the observed lasing threshold of about $4 mJ/cm^2$ is slightly higher than the ASE threshold described in §3. This will be due to imperfect guiding structure of the cavity. Overlap of the absorption band of the doped-dye with the emission spectra may cause some degradation of the efficiency. Therefore, to reduce the threshold, it is necessary to introduce proper waveguide structures such as ridge or channel, and to optimize the DFB grating parameters. Furthermore, examination of high-efficient laser-dyes may be also important[4] for achieving much lower lasing threshold.



(a) Input-output characteristics



(b) Spectral characteristics

Fig.3 Typical lasing characteristics of DMASDPB-doped DNA-CTMA DFB thin film laser

5. CONCLUSIONS

We have studied thin film DFB laser structure utilizing dye-doped-DNA-lipid films, and observed single longitudinal mode operation by using etch-less gratings fabricated on a PMMA substrate.

The lasing threshold of DMASDPB(one of the hemicyannine dye derivatives)-doped DNA-CTMA films was about $4 mJ/cm^2$. Although the value was almost consistent with the ASE threshold of about $1 mJ/cm^2$, it is relatively high compared with other system such as LDS798-doped polymeric waveguide structure[4]. Introduction of proper waveguide structures and selection of the laser dye which have minimum overlap of emission spectra with absorption spectra should be necessary for further reduction of the threshold energy.

ACKNOWLEDGMENTS

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