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Beam-Scannable Light Source with the Grating Output Coupler

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A deflection of a narrow divergence output beam (with the FWHM less than 2 degrees) was demonstrated in a semiconductor laser, which utilizes a grating output coupler and has a mechanism to tune the lasing wavelength. A new functional light source, where the output beam can be scanned continuously with the gate field by extending the size-effect modulation light source, was also proposed.

§1. Introduction

Functional semiconductor light sources will play an important role to expand the application fields of the semiconductor optical devices. For example, a beam-scannable light source is of great practical interest especially in the field of laser printing, integrated optics and so on. There have been several attempts to realize beam-scannable semiconductor lasers.[1),2)] We have also proposed a beam-scannable light source which utilizes a grating output coupler and have demonstrated a beam deflection in a superluminescent mode.[3)] But in that demonstration, the divergence angle was too wide compared to the deflection angle. That result became a serious problem to realize a practical beam-scannable semiconductor light source.

In this paper, we demonstrate, for the first time, a deflection of a narrow divergence output beam in a semiconductor laser. We also propose a new light source where the output beam can be scanned continuously with the gate field. This device is based on a size-effect modulation (SEM) light source,[4)] where the gain peak shifts with the gate field. this idea was tested by photoluminescence (PL) measurements on a GaAs single quantum well (SQW) structure subject to an electric field at room temperature.

§.2 Fundamental Theory of Beam-Scanning

Figure 1 shows a fundamental configuration of

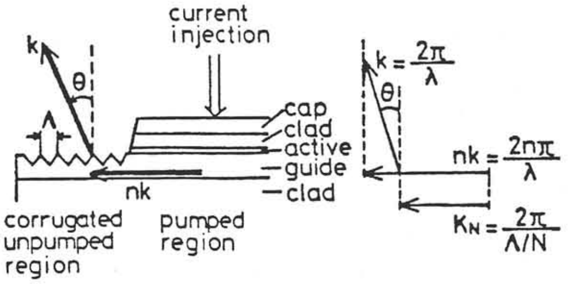


Fig. 1 Fundamental configuration of a beam-scannable light source and the phase-matching condition in the grating region.

a beam-scannable light source we proposed. In this structure, the grating does not feed back light waves and operates only as an output coupler by setting the suitable pitch of the grating. Light waves which are incident in the grating region are radiated out in a direction given by the following phase-matching condition;

$$\theta = \sin^{-1}\left(n - \frac{\lambda}{\Lambda/N} \right) \qquad (1) \quad ,$$

where n is the effective refractive index and N is the harmonic order of the grating. The angle θ is measured from the normal of the layers to the wave-propagation direction.

The above equation shows that the beam deflection angle changes with the light wavelength. Therefore, the output beam from the grating coupler can be scanned by the wavelength-tuning of light waves which are incident in the grating region. In a typical GaAs/GaAlAs system, a beam-scanning rate $d\theta/d\lambda$ is -2.93×10^{-2} deg./Å for θ around 0 degrees.[3)]

§3. Beam-Scanning in A Semiconductor Laser

To realize a practical beam-scannable light source, it is important to make the divergence angle as narrow as possible. In our early demonstration with LED,[3)] the divergence angle (ranged from 5 to 7 degrees) was too wide compared to the deflection angle. One of the main factors influencing the divergence angle is the spread of the spectrum of the light waves which are incident in the grating region of Fig.1. Therefore, to improve this point, it is necessary to employ a lasing mode.

In our proposed idea, lasing wavelength must be tunned to realize a beam-scanning in a laser mode. One of the possible structure to employ is a cleaved-coupled-cavity laser.[5)]

Here, we demonstrate a beam deflection using another simpler laser structure. The threshold gain g_{th} is decided by the following oscillation condition;

$$g_{th} = \alpha_i + \frac{1}{L}\,\mathrm{In}(1/R) \qquad (2) \quad ,$$

where α_i is the total internal loss and R is the reflection coefficient. The variation of the cavity length L will offer that of the g_{th} and the lasing wavelength will be tunned by the variation of the gain peak wavelength.

From the above oscillation condition, the wider tunning range of the lasing wavelength for the variation of the cavity length L is expected for the smaller reflectivity R of the reflector. So, we adopted a etched mirror as a reflector. The abrupt etched step in the waveguide layer between the active and passive region of Fig.1 causes a reflection. This so-called etched mirror seems to have a small reflectivity.

We estimated the reflectivity of the etched mirror using the measured values of the threshold current density J_{th} in the following manner. The expression for the threshold current density of the cavity laser is written as follow;

$$J_{th} = \frac{d}{\eta}\left[\,4.5\times10^{3} + \frac{20\alpha_i}{\Gamma}\left(1 + \frac{\mathrm{In}(1/R)}{\alpha_i L}\right)\right] \quad (3) \ ,$$

where d is the thickness of the active layer, η is internal quantum efficiency, Γ is the confinement factor and $R=\sqrt{R_1R_2}$, where R_1 and R_2 are the reflectivity of each mirror of the cavity laser. So, by measuring J_{th} as a function of cavity length, reflectivity R may be numerically evaluated.

Experiments were performed using cavity lasers with 1 etched, 1 cleaved mirror, whose cavity length was changed by cleaving. The value of α_i and η can be determined from eq.(3) by measuring J_{th} for normal cavity lasers (with 2 cleaved mirrors) of different cavity lengths. Figure 2 shows the results of the experiments. The estimated power reflectivity of a etched mirror was R_e=0.0018, and is much smaller than that of a cleaved mirror R_{cl} =0.31

Figure 3 shows the estimations of the wavelength-tuning with the cavity length of the lasers. A solid line shows that for cavity lasers with 1 etched and 1 cleaved mirror, and a dashed line for cavity lasers with 2 etched mirrors. Experiments were also performed for cavity lasers with 1 etched and 1 cleaved mirror, and the results were plotted in this figure. This experimental results agree well with the estimation except for the constant shift to the shorter wavelength due to the unexpected Al contaminating in the active layer.

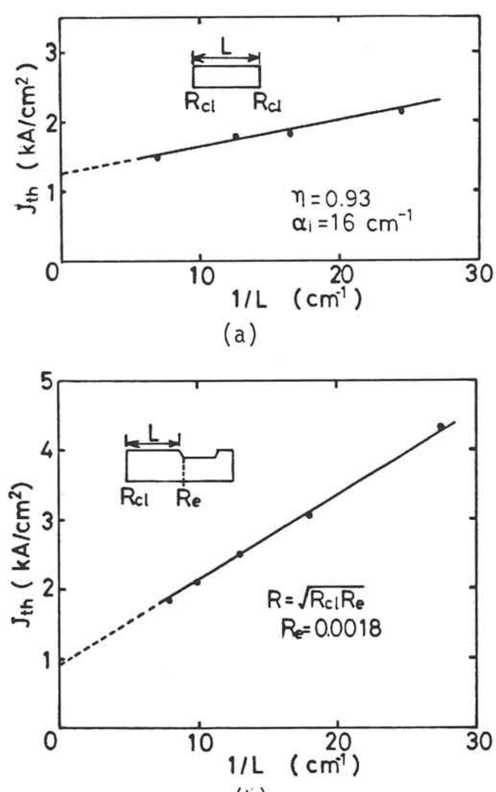


Fig. 2 Variation of threshold current density J_{th} with cavity length L (a) for cavity lasers with 2 cleaved mirrors (b) for cavity lasers with 1 etched, 1 cleaved mirror.

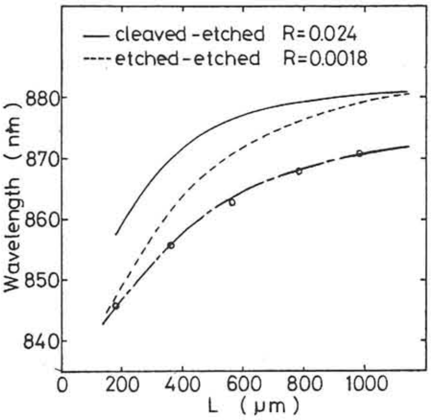


Fig. 3 Estimated variation of the lasing wavelength with cavity length for cavity lasers with 1 etched and 1 cleaved mirror (solid line) and with 2 etched mirror (dashed line). Experimental results for cavity lasers with 1 etched and 1 cleaved mirror is also plotted (dot and dashed line).

Based on the above-mentioned theme, a laser beam deflection was examined in a segmented electrodes structure shown in Fig. 4. In this structure, the length of the lasing region is varied by the choice of the current injection regions, using the reflections at the etched mirrors and the absorptions at the unpumped regions.

Figure 5 shows the observed far-field pattern along the cavity length. The narrow output beam (with the FWHM less than 2 degrees) was deflected by 5 degrees in this semiconductor laser by switching the injection region. The divergence angle of the coupled out beam can be made more sharpened by employing a single-fundamental mode operation.

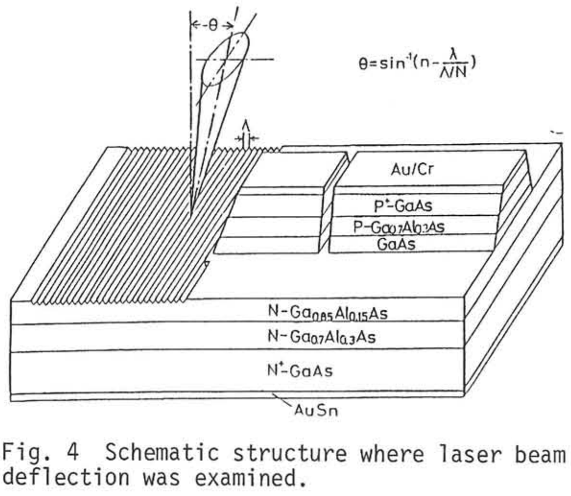


Fig. 4 Schematic structure where laser beam deflection was examined.

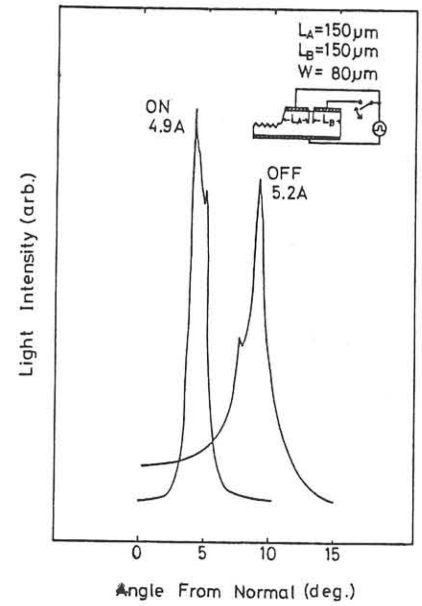


Fig. 5 Obserbed far-field pattern along the cavity length. W is the stripe width.

§4. Beam-Scannable Size Effect Modulation Light Source

We also propose a new beam-scannable light source extending the SEM light source[4] shown in Fig. 6. A grating region is fabricated on a mesa etched surface of the SEM light source. We expect beam-scanning operation by the wavelength-tunnable character of the SEM light source.

Figure 7 shows the calculated gain spectra in the SEM light source considering a SQW structure which consists of an active GaAs (100 Å) and insulating $Ga_{0.1}Al_{0.9}As$ layers at 300 K. The gain peak shifts to the lower energy side (about 250 Å in this example) with increasing the gate field, which originates from the shifts of the subband energies. Using the beam-scanning rate mentioned in section 2, the continuous beam deflection of about 8 degrees is expected in this numerical example.

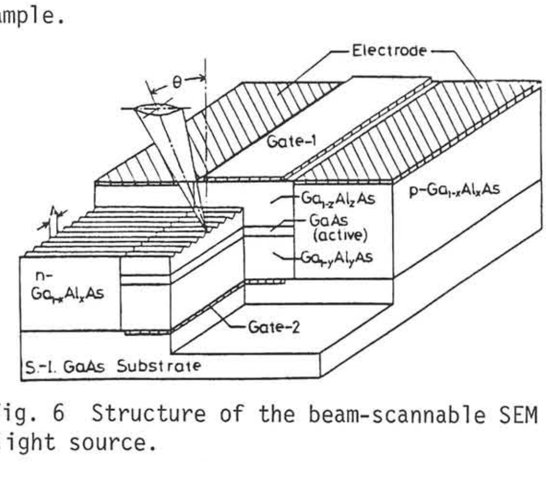


Fig. 6 Structure of the beam-scannable SEM light source.

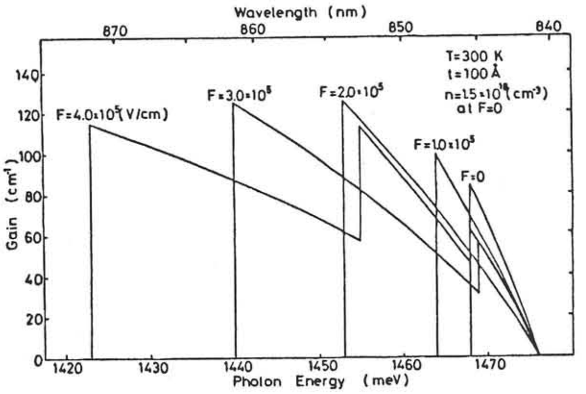


Fig. 7 Estimated gain spectra for various gate field at 300 K in the SEM light source.

§5. PL Measurements on GaAs SQW

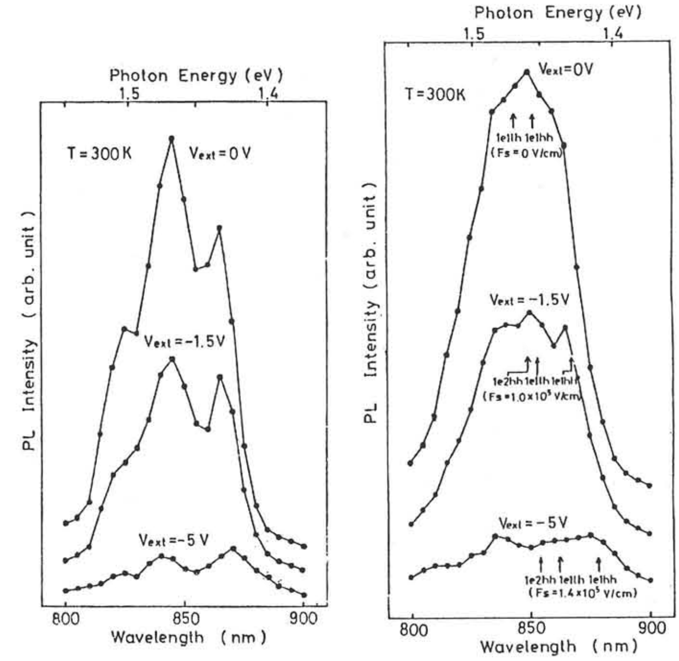
Here, we shall show the results of photoluminescence (PL) measurements on a GaAs SQW structure subject to an electric field. At cryogenic temperature, some results of such PL measurements were reported.[6),7)] We performed the experiments at room temperature for the first time to test our proposed idea under a more practical situation.

Figure 8 (a) shows the experimental results on the PL from the GaAs SQW consists of 120 Å GaAs well and $Ga_{0.3}Al_{0.7}As$ barrier layers which are grown by a MBE technique. The sample were excited with the 6328 Å laser line corresponding to a photon energy of 1.96 eV. It is sufficiently lower than the band gap of the GaAlAs barriers (2.05 eV) so that the GaAs well may be excited selectively. The obserbed spectra include the effect of the Fabry-Perot resonances due to the front and back surfaces of the sample.

Figure 8 (b) shows the PL spectra, where that effect of resonance is excluded numerically. In this figure, the calculated optical transition energies are also shown with symbols for each subband transitions. The PL spectra shifted to the lower energy side with increasing the field. Although the detailed comparison between the theory and the experiment is difficult due to the remaining errors, this shift in the PL spectra almost agree with those of the arrows.

§6. Conclusion

In conclusion, we demonstrated a deflection of a narrow divergence output beam in a semiconductor laser with etched mirrors and segmented electrodes. We also propose a new device extending the SEM light source. This device has the



(a) (b)

Fig. 8 (a) Measured photoluminescence spectra at 300 K. (b) Estimated photoluminescence spectra from the experimental ones shown in (a) taking the Fabry-Perot resonance into account. The arrows show theoretical transition energies.

excellent characteristics that the output beam can be scanned continuously with the gate voltage. This idea was proved by measuring the PL shifts on a GaAs SQW with the electric field at room temperature.

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