40 Å Continuous Tuning of a GaInAsP/InP Vertical-Cavity Surface-Emitting Laser Using an External Mirror

N. Yokouchi, T. Miyamoto, T. Uchida, Y. Inaba, F. Koyama, and K. Iga

Abstract—**Continuous tuning of 40 Å was achieved in a GaInAsP / inP vertical-cavity surface-emitting laser for the first time. The cavity length was directly changed by slightly moving an external mirror. The device was grown by chemical beam epitaxy (CBE) and the experiment was performed at low temperature. Our result indicates that a short cavity structure can provide pure continuous wavelength tuning because of its wide longitudinal mode spacing.**

I. Introduction

In future optical communication systems, such as high-density wavelength division multiplexed (WDM) transmission and coherent detection systems, the wavelength tunable semiconductor laser may become an important light source. Multielectrode tunable lasers based on conventional distributed Bragg reflector (DBR) [1], [2] and distributed feedback (DFB) [3] lasers have been demonstrated. Continuous tuning of 82 nm was also realized using an external grating mirror [4]. These devices employ cavity lengths of 500 μm ~ 5 cm and have rather complicated structures. Their tuning range is generally less than several tens of angstroms and may be discontinuous due to mode hopping. In order to avoid mode hopping, some phase controls, such as using the third electrode while changing the cavity length, must be introduced. This comes simply from the oversized cavity structure.

On the other hand, a vertical cavity surface emitting (SE) [5] laser has a comparatively large longitudinal mode spacing, which extends several hundred angstroms. In such a short-cavity structure, directly changing the cavity length is effective for wavelength tuning without mode hopping. For this purpose, an electrical intracavity tuner employing the quantum confined Stark effect [6] has been theoretically considered. A thermoelectric (Peltier) effect in a DBR section [7], [8] was used to tune the wavelength, and 12 Å of wavelength shift was observed. It is necessary to confirm full continuous tuning due to the very short cavity, and in parallel, to develop such a monolithic electrical tuner. Employing an external mirror, this tuning scheme can be easily realized and we can confirm the stability of the SE laser under tuning. An experimental demonstration of an external mirror to control the SE laser wavelength was reported [9], but the tuning was discrete. The external mirror is also useful for a coherent two-dimensional SE laser array [10], [11], if it is successfully used in short-cavity SE lasers.

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II. Experimental Procedure

The round-low mesa structure GaInAsP/InP SE laser used in this experiment was grown by chemical beam epitaxy (CBE) [12]. The laser cavity consists of the following epitaxial layers; a 0.3 μm p-GaInAsP (λ_g = 1.3 μm at room temperature, $n = 1 \times 10^{18}$ cm^{-3}) etch stop layer, a 1.4 μm n-InP ($n = 1 \times 10^{18}$ cm^{-3}) cladding layer, a 1.0 μm p-GaInAsP (λ_g = 1.53 μm, $p = 3 \times 10^{17}$ cm^{-3}) active layer, a 1.2 μm p-InP ($p = 5 \times 10^{17}$ cm^{-3}) cladding layer and a 0.10 μm p^+-GaInAsP (λ_g = 1.3 μm, $p = 2 \times 10^{19}$ cm^{-3}) contact layer. The 4 μm-thick epitaxial layers were left by removing the n-InP substrate and n-GaInAsP stop layer selectively. A 4-pair Si/SiO_2 multilayer mirror was formed on the light output side by electron beam (EB) evaporation using an optical thickness monitoring system [13]. At the same time, a Si/SiO_2 reflector, which was used as an external mirror, was also fabricated on a InP substrate. The reflectivity obtained is about 99% in the 1.3–1.6 μm range. The GaInAsP contact layer surface of the rear side is exposed to the air with a 10 $\mu m\phi$ circular shape. No antireflection (AR) coating was introduced. The external mirror was in contact with this surface.

The tuning experiment was carried out under CW conditions in liquid nitrogen (77 K). The experimental arrangement is shown in Fig. 1. The SE laser device was mounted on a heatsink. The external mirror was put on the chip and fixed by a plastic plate. In the initial state, the external mirror was set in contact with the chip surface. The cavity length was slightly changed mechanically by tuning the spacing between the chip and the external mirror.

III. Results and Discussion

A typical injection current versus light output characteristic is shown in Fig. 2. The CW threshold current is 7.5

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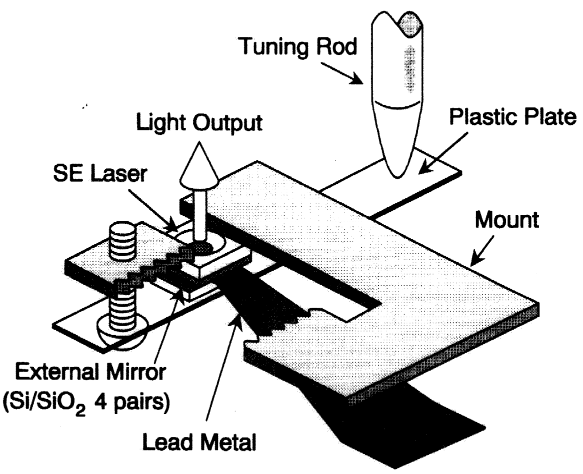

Fig. 1. Wavelength tuning procedure of vertical cavity SE laser using external mirror.

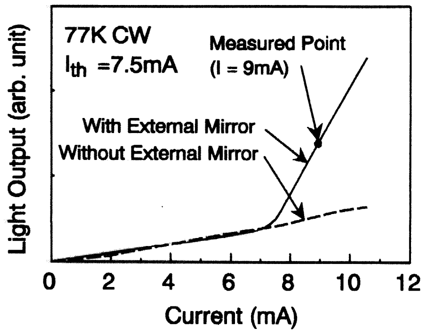

Fig. 2. L–I characteristics of SE laser with and without external mirror are shown. Lasing operation was obtained only with the mirror. In the tuning experiment, injection current was biased at 9 mA.

mA at 77 K. Without the mirror, lasing operation was not obtained. This indicates that the optical cavity is successfully formed by both the external and the output side monolithic mirrors. Because SE lasers with evaporated mirrors made from the same wafer had threshold currents of 4 ~ 10 mA at 77 K, the external mirror exhibits almost the same effective reflectivity.

In the tuning experiment, the injection current was fixed at 9 mA. The lasing spectra obtained are shown in Fig. 3. The initial lasing wavelength was 1.4439 μm. By pushing the tuning rod, the output shifted toward longer wavelength. The wavelength shift $\Delta\lambda$ associated with the mirror position change Δl can be expressed by

$$\Delta\lambda/\lambda = (n_{\text{med}}/n_{\text{eq}} \cdot l) \cdot \Delta l \qquad (1)$$

where n_{med} is the refractive index of the external cavity (liquid nitrogen in this experiment) and $n_{\text{eq}} \cdot l$ is the optical path length of the initial state. From Fig. 3, the wavelength shift is almost proportional to the rod position. The maximum lasing wavelength shift in this experiment is 40 Å. From (1), Δl must be about 250 Å, if the spacing between the external mirror and the laser chip is negligible. Using this procedure, the mirror position was

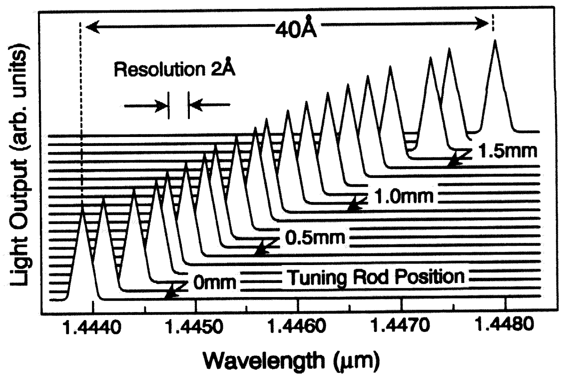

Fig. 3. Measured lasing spectra are shown. With tuning rod position, the lasing wavelength moved to the longer side. The maximum change is 40 Å. Although lasing operation stopped for further separation of the mirror, the emission peak moved to the longer side continuously up to 1.4525 μm.

found to be controllable to the order of 10 Å. Upon further separating the mirror, lasing operation stopped, because the threshold current increased to more than 9 mA due to misalignment between the mirror and the chip. In this region below laser threshold, the spontaneous emission peak can be seen instead of the lasing wavelength. Including this emission peak shift, one longitudinal mode moved up to 1.4525 μm ($\Delta\lambda$ = 86 Å) continuously at the rod position of 2.9 mm. With more precise alignment of the external mirror, much wider continuous tuning can be obtained.

IV. Conclusion

We have demonstrated 40 Å continuous wavelength tuning of a 1.44 μm GaInAsP/InP SE laser using an external mirror. The maximum wavelength shift including the spontaneous emission peak is 86 Å. This is the largest value of continuous wavelength tuning without mode hopping using the cavity length control scheme. From our results, direct cavity length change is effective for wavelength tuning. Our result also shows that an external mirror can have the same performance as a monolithic mirror in reflectivity. It is useful not only for wavelength tuning, but for a coherent two-dimensional laser array using a Talbot mirror, and integration with functional elements such as an external modulator, electrical tuning element, etc.

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References

[1] Y. Tohmori, K. Komori, S. Arai, Y. Suematsu, and H. Oobayashi, "Wavelength tunable 1.5 μm GaInAsP/InP bundle-integrated-guide distributed Bragg reflector (DBR) lasers," *Trans. IEICE Japan*, vol. E68, pp. 788–790, 1985.
[2] Y. Kotaki, M. Matsuda, H. Ishikawa, and H. Imai, "Tunable DBR

laser with wide tuning range," *Electron. Lett.*, vol. 24, pp. 503–505, 1988.

[3] M.-C. Amann, S. Illek, C. Schanen, W. Thulke, and H. Lang, "Continuously tunable single-frequency laser diode utilizing transverse tuning scheme," *Electron. Lett.*, vol. 25, pp. 837–839, 1989.

[4] F. Favre, and D. Le Guen, "82 nm of continuous tunability for an external cavity semiconductor laser," *Electron. Lett.*, vol. 27, pp. 183–184, 1991.

[5] K. Iga and S. Uchiyama, "GaInAsP/InP surface-emitting laser diode," *Opt. Quantum Electron.*, vol. 18, pp. 403–422, 1986.

[6] N. Yokouchi, F. Koyama, and K. Iga, "Estimation of tunable wavelength range in surface emitting laser using intra-cavity quantum well tuner," *Trans. IEICE Japan*, vol. E73, pp. 1473–1475, 1990.

[7] C. J. Chung-Hasnain, J. P. Harbison, C. E. Zah, L. T. Florez, and N. C. Andreadakis, "Continuous wavelength tuning of two-electrode vertical cavity surface emitting lasers," *Electron. Lett.*, vol. 27, pp. 1002–1003, 1991.

[8] P. R. Berger, N. K. Dutta, K. D. Choquette, G. Hasnain and N. Chand, "Monolithically peltier-cooled vertical-cavity surface-emitting lasers," *Appl. Phys. Lett.*, vol. 59, pp. 117–119, 1991.

[9] C. J. Chung-Hasnain, C. E. Zah, G. Hasnain, J. P. Harbison, L. T. Florez, and N. G. Stoffel, "Tunable wavelength emission of a 3-mirror vertical cavity surface emitting laser," *Int. Semiconductor Laser Conf.*, Davos, Switzerland, Sept. 1990.

[10] A. A. Golubentsev, V. V. Linkhanskii, and A. P. Napartovitch, "Theory of phase locking of an array of lasers," *Sov. Phys. JETP*, vol. 66, pp. 676–682, 1987.

[11] E. Ho, F. Koyama, and K. Iga, "Effective reflectivity from self-imaging in a Talbot cavity and its effect on the threshold of a finite 2-D surface emitting laser array," *Appl. Opt.*, vol. 29, pp. 5080–5085, 1990.

[12] T. Uchida, N. Yokouchi, T. Miyamoto, Y. Inaba, F. Koyama, and K. Iga, "GaInAsP/InP surface emitting lasers grown by chemical beam epitaxy (CBE)," *Electron. Lett.*, vol. 28, pp. 550–551, 1992.

[13] M. Oshikiri, F. Koyama, and K. Iga, "Flat surface circular buried heterostructure surface emitting laser with high reflectivity Si/SiO_2 mirrors," *Electron. Lett.*, vol. 24, pp. 2038–2039, 1991.