Design and Fabrication of GaInAsP/InP Vertical Microcavity for Optically Pumped Tunable Surface Emitting Laser

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Abstract **-------** We propose a novel optically pumped tunable surface emitting laser. The lasing wavelength of the device can be varied by changing the photo-pumped position of a vertical cavity with spatial gradient in the cavity length. A possibility of mode-hop-free wide wavelength tuning is presented over current existing tunable lasers. We fabricated a GaInAsP/InP short cavity and measured the resonant spontaneous emission of an optically pumped cavity without intentional spatial gradient. The change of the resonance peak is as large as 40 nm. The obtained result supports a possibility of large continuous wavelength tuning.

1. Introduction

The wavelength division multiplexing (WDM) is a key technology for enlargement of transmission capacity. One of the important components for WDM systems is a set of light sources which can access every channel. Many lasers with different wavelengths are required to meet this demand in rapidly increasing number of WDM channels. In conventional WDM transmitters, each laser has to be fabricated individually, resulting in large system size and high production cost. A tunable laser is a key device for reducing overall cost of transmitters. Also, a tunable source provides us with more flexibility and functionality to be built in future WDM networks. Several types of tunable lasers such as multi-section DFB and DBR lasers have been demonstrated [1,2]. However, there has been a difficulty in achieving wide continuous tuning in the case of those long-cavity lasers. We proposed and demonstrated a widely tunable vertical cavity surface emitting laser (VCSEL) using a movable mirror [3]. Currently, a micro-electro-mechanical structure vertical cavity surface emitting laser (MEMS VCSEL) [4] is attracting much interest for realizing wide continuous wavelength tuning beyond 50nm because of its short cavity [5,6].

In this paper, we propose an optically pumped tunable VCSEL which has a potential of providing us with a wide wavelength tuning over current existing tunable lasers. The structure and unique features of the proposed tunable VCSEL are described. We also carried out photo-pumping experiment of a 1550 nm GaInAsP/InP vertical cavity structure. Moving the photo-pumped position of a vertical cavity with a spatial gradient in its cavity length can provide us with a large change in resonant emission wavelength.

2. Structure

Figure1 shows the schematic structure of a proposed optically pumped tunable VCSEL array. The VCSEL array chip has a spatial gradient in growth layer thickness and the lasing wavelengths can be varied according to the spatial gradient. In this VCSEL structure, we can easily control the wavelength using spatial gradient in thickness of epitaxial layers [7,8]. The VCSEL array will be fabricated monolithically by using such as selective area growth The special gradient in thickness can be realized by growing on a patterned substrate. The growth rate is strongly dependent on the area of SiO_2 mask as shown in Fig.2. Thus, the cavity length can be increased by increasing the area of the SiO_2 mask, the cavity length with spatial distribution can be formed in a single step epitaxy. Such a selective growth technique has been reported for the integration of optical devices [9].

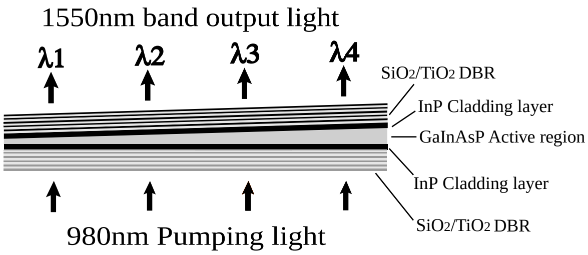

Fig.1 Schematic structure of this device

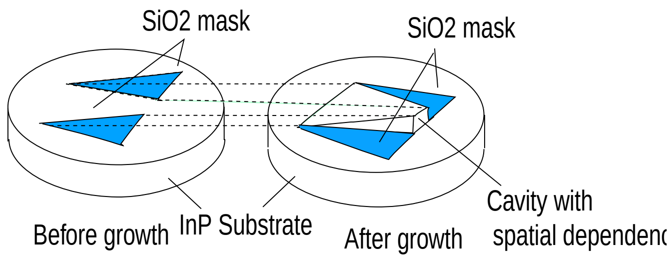

Fig.2 Scheme of selective growth

We can obtain different wavelengths by pumping different positions. Moreover, we can tune the emitting wavelength continuously by moving the pumping position. While the tuning range of MEMS tunable VCSELs is limited by the free spectral range of the cavity, our proposed VCSEL is free from this limitation. Both of spatial change in cavity length and composition of an active region can avoid the free-spectral-range limitation. Optimization of selective area epitaxial growth is one of the ways to realize spatial gradient in cavity length and the composition at the same time. As shown in Fig.3, a vertical cavity is pumped by 0.98μm light from one side of the device, 1550nm-band output light comes out on the other side. We can also pump this device on one side and take out 1550nm-band output from the same side by using a WDM coupler.

Figure3 shows the calculated change of the resonance wavelength depending on the change of the cavity length for various cavity lengths. The center wavelength is assumed to be 1550nm. In the case of 1000 and 2000nm of the cavity length, we can expect a tuning range of 100nm resulting from changes of 65 and 129 nm in the cavity length, respectively. These correspond to a thickness variation of about 6% and such a variation can be controlled by choosing the mask pattern of the selective area

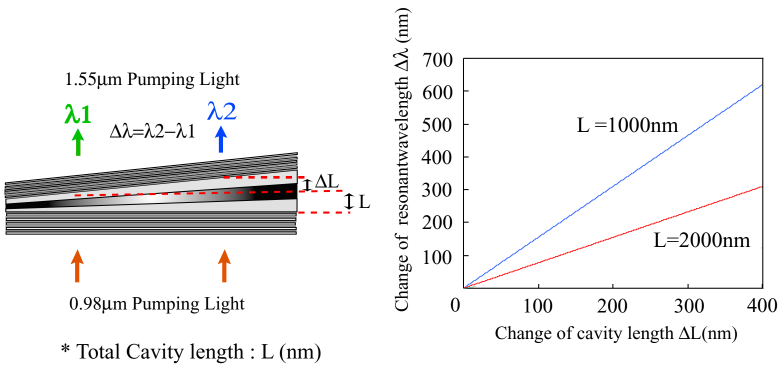

Fig.3 Change of resonant wavelength depending on change of cavity length

growth [9].

3. Fabrication

We fabricated a vrtical cavity structure for feasibility study. The grown wafer structure is shown in Fig.4. On an InP substrate, two InP cladding layers and an active region consisting of three quantum wells (QWs) and an optical absorption layer were grown by MOCVD. The active region consists of 0.7 % compressively strained GaInAsP wells with a thickness of 60 Å and lattice matched GaInAsP optical absorption layer with a total thickness of about 1000 nm. The bandgap wavelengths of wells and optical absorption layers are 1550nm and 1170nm, respectively. The 1000 nm thick optical absorption layer is required to increase the absorption of pumping light. After the growth of the wafer, an InP substrate was selectively etched to form a short cavity. In that fabrication, 400μm-diameter holes with 800μm pitch were fabricated. 10 pairs SiO_2/TiO_2 dielectric distributed Bragg reflector (DBR) was evaporated only on the substrate side. The reflectivity necessary for laser oscillation will be higher than 99% in top and bottom DBRs. These laser structure is now under fabrication.

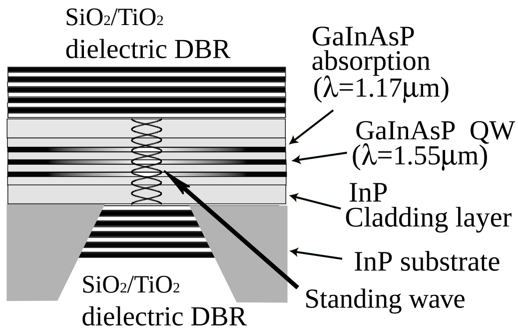

Fig.4 Schematic structure of grown wafer

This photo-pumped VCSEL has an advantage of low internal absorption loss for 1550nm, resulting in high efficiency because the cavity is formed by undoped layers. The cavity is designed as QWs locate at anti-nodes of standing waves for gain matching. The VCSEL can operate in single longitudinal mode because of its short cavity. By controlling the profile of the excitation spot, fundamental lateral mode can be also expected. If pumping light profile is fundamental lateral mode, carriers will be existed at like as pumping light profile, then the fundamental lateral mode may be observed easily.

4. Experimental result

We carried out photo-pumped experiments with changing the excited position. A 980 nm semiconductor laser is used as a pump source. Vertical cavities are excited by 980nm light through a lensed multi-mode fiber. The pumping power density was 5 kW/cm^2. Three different cavities formed on the same chip were pumped by moving the chip while the distance between VCSEL1 and VCSEL2 was 800μm and that between VCSEL2 and VCSEL3 was 1600μm. Figure 5 shows resonant spontaneous emission spectra of three different cavities in the same chip. Resonance modes were clearly observed from each cavity. The broadened spectra are due to low reflectivity in

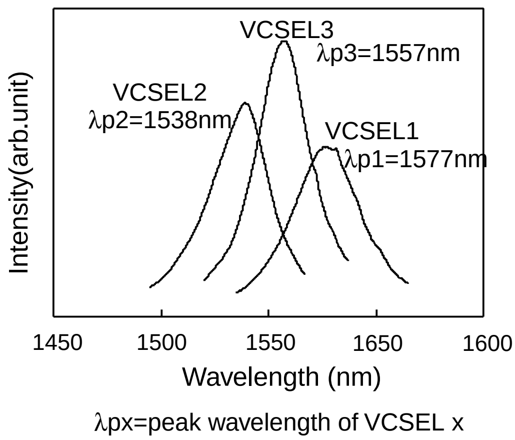

Fig.5 Resonance spectra depending on spatial position

one side. We observed a large change of over 40 nm in emission wavelength. The wavelength change was due to unintentional non-uniform etching process when the short cavity was formed and partly would be due to original non-uniform in grown layers. The wavelength change would be according to original non-uniformity is 15nm. Controlled and larger gradient in cavity length may be realizable by using selective area growth and by improving the selective etching process.

5. Conclusion

We proposed a novel tunable VCSEL with moving the photo-excited position. By introducing thickness gradient and composition change in vertical cavities at the same time, we can expect a large wavelength tuning range beyond the free spectral range. A preliminary experiment of an optically pumped GaInAsP vertical cavities shows a large wavelength change of 40 nm in the same chip. This new device may provide system flexibility in future WDM systems.

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