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Highly strained oxide confined InGaAs VCSELs emitting in the 1.3 ì m regions

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1. Introduction

Recently much attention has been focused on the development of GaAs-based VCSELs emitting in the 1.3 ì m regions. Previously, the fabrication of GaAs-based LDs and VCSELs emitting in the 1.3ì m regions with GaAs/GaAsSb and InGaAsN/GaAs multiquantum well (MQW) active regions have both been demonstrated. It has also been shown that self-assembled InAs/InGaAs quantum dots (QDs) can also be used to fabricate GaAs-based LDs and VCSELs emitting in the same wavelength regions. However, the reliabilities of these materials still need to be further improved in general. Very recently, it has been shown that one can also achieve an optical gain in the 1.3 ì m regions from highly strained InGaAs layers grown on GaAs substrates [1]. Although oxide confined VCSELs with the highly strained InGaAs/GaAs MQW active regions were also demonstrated, no oxide modes were reported in 1.3ì m region. In this report, oxide confined VCSELs with the highly strained InGaAs/GaAs MQW active regions were fabricated. The oxide modes and other related DC characteristics of the fabricated VCSELs are reported.

2. Experiments

Samples used in this study were all prepared by metalorganic vapor phase epitaxy (MOVPE) on 2-inch n^+-GaAs substrates. The VCSEL structure consists of a highly strained InGaAs/GaAs MQW active region sandwiched by a fully Si-doped n-distributed Bragg reflector (DBR) mirror and a fully C-doped p-DBR mirror. The MQW active region consists of 2-period of 6.8nm-thick InGaAs well layers and 10.5nm-thick GaAs barrier layers. The indium composition in the well layers was around 0.38. Both the n- and p-DBR were composed of interlaced 1/4ë-thick GaAs and $Al_{0.89}Ga_{0.11}As$ layers with a 20nm-thick interface grading to reduce the series resistance. 40.5 and 26 AlGaAs/GaAs pairs were used for the n- and p-DBR mirrors, respectively. A 20nm-thick AlAs layer was inserted at the interface of the first p-DBR pair and the active region to define the oxide aperture after oxidation. The detail process method had been reported in our previous work [2]. After VCSEL fabrication, we randomly picked six devices to measure their optical properties.

3. Results and Discussion

Figure 1 shows lasing spectra of the six VSCELs measured near thermal rollover. The driving currents are marked near each spectrum. As shown in figure 1, it was found that lasing wavelengths of these oxide confined VCSELs varied from 1.19 to 1.245 ì m. As shown in the lasing spectrum of sample F, we did successfully achieve a GaAs-based oxide confined VCSEL with the highly strained InGaAs/GaAs MQW active region emitting in the 1.3 ì m regions.

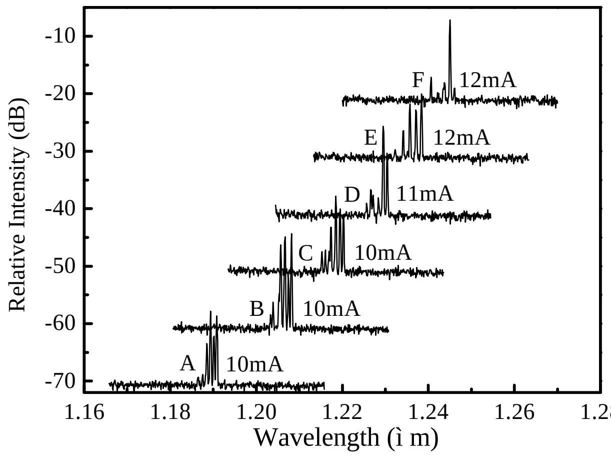

Fig. 1 Lasing spectra of the six VSCELs measured near thermal rollover.

Figure 2 shows measured output power as a function of injection current (i.e. L-I characteristics) for these six devices. It was found that turn-on voltage seems to increase and the maximum available output power seems to decrease as the lasing wavelength increases.

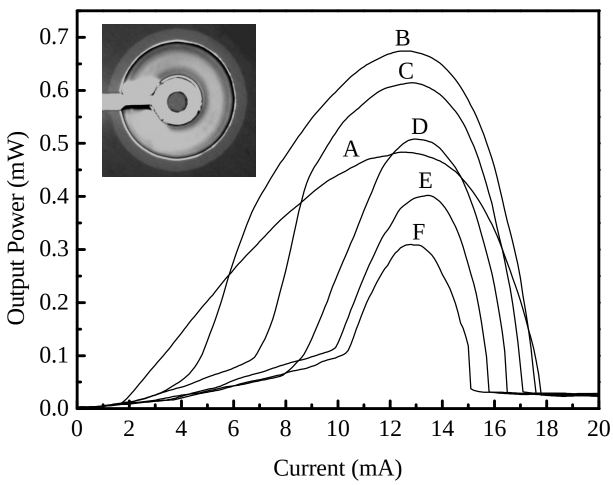

Fig. 2 L-I characteristics for these six devices. Inset shows top view of the fabricated VCSELs.

Figure 3 shows a more detailed L-I characteristics of sample F. It was found that we can divide this L-I curve into 4 regions. In region I, only spontaneous emission occurred when the driving current was smaller than 4 mA. In regions II, the device was operated under stimulated emission as the injection current was increased. However, the slope efficiency was poor in this region. When the drive current was further increased, the device began to lase with the designed cavity resonant wavelength in region III. When the driving current was larger than 15 mA, the gain spectrum of the device will misalign with the cavity resonance. Thus, the stimulated emission will cease and only spontaneous emission was observed again, as shown in region Ⅳ.

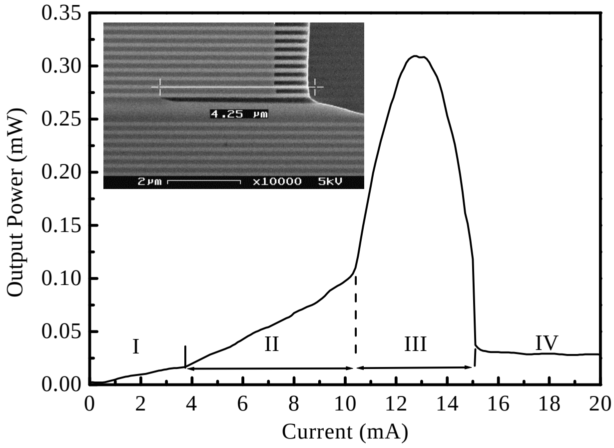

Fig. 3 A more detailed L-I characteristics of sample F. Inset shows SEM picture of the oxidized layers.

Lasing spectra of sample F with various driving currents were also investigated. As shown in figure 4, it was found that the device lased at 1.249 ì m when the drive current was larger than 10 mA. In contrast, the device lased at 1.22 ì m when the driving current was smaller. It should be noted that we designed the cavity resonance wavelength so that this VSCEL should lase at 1.249 ì m. In other words, lasing wavelength blue shifted when the driving current was small. Such an observation can be attributed to the effective optical thickness shrinkage of the oxide layer.

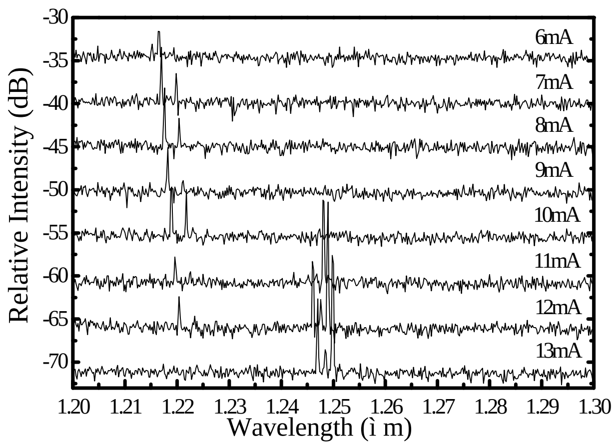

Fig. 4 Lasing spectra of sample F with various driving currents.

From the SEM picture, it was found that the thickness of the tapered oxide layer front was around 77.7 nm. Using this value, we calculated the reflectance spectrum which corresponds to the lasing spectrum of sample F with a 12 mA driving current, as shown in figure 5.

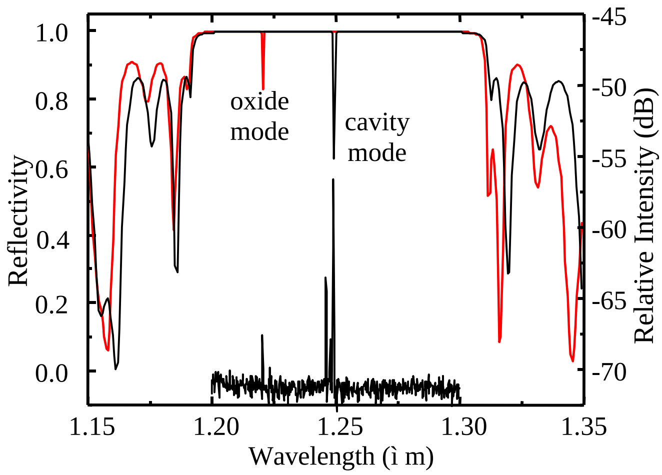

Fig. 5 Simulated reflectance spectra of oxidized and unozidized sample F with a 12 mA driving current. Lasing spectrum of sample F was also plotted.

In the simulation, the refractive index of AlO_x used was 1.55. For comparison, the reflectance spectrum of the unoxidized sample and the measured lasing spectrum were also plotted in the same figure. It was found that the simulated reflectance spectrum agrees well with the measured results. An oxide mode which was 29 nm away from the cavity resonance was observed in these spectra. Such an oxide mode can also be used to explain the blue shift shown in figure 4. It should be noted that the 29 nm blue shift observed in this study was much larger than the 17 nm blue shift observed from a GaAs-based all epitaxial oxide confined VCSEL emitting in the 1.0 ì m regions [3]. Such a large blue shift is potentially useful for wavelength division multiplexing applications.

4. Conclusions.

The highly strained GaAs-based all epitaxial oxide confined VCSELs emitting in the 1.3 ì m regions were fabricated. Compared with cavity resonance, it was found that lasing wavelength blue shifted by 29 nm when the driving current was small. The observation of such oxide mode is attributed to the effective thickness shrinkage of the oxide layer.

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