Polarization Control in VCSELs by Elliptic Surface Etching

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We have fabricated 850 nm-wavelength VCSELs with an elliptical shallow surface relief having various aspect ratios and orientations. Using appropriate etch dimensions, VCSELs of up to 12.5 µm active diameter are forced to operate on the fundamental mode for a certain current range. By aligning the longer axis of the etched ellipse with the [011] *or* $[01\bar{1}]$ *crystal axes, the polarization of the fundamental mode is pinned accordingly with a polarization suppression ratio of about 30 dB.*

1. Introduction

Much attention has been given to the investigation of polarization in vertical-cavity surface-emitting lasers (VCSELs) [1]. Consequently, many approaches have been suggested to control the polarization state, more specifically to eliminate spontaneous polarization switching. These include elliptical mesas [2], misoriented substrates [3], external polarization selection elements [4], and more. However, these previous attempts are either rather difficult to implement, or do not provide sufficiently strong polarization selection for applications such as high-speed data transmission. Strong polarization selection with a simple method is desirable to achieve lowest noise for highest modulation speed, low susceptibility to polarization-sensitive loss or to enable polarization state selection e. g. to carry additional information. In this letter, we present the extension of our self-aligned surface-etching method, which has been very successful in fabricating large-area single-mode VCSELs [5, 6], to include elliptical surface etch patterns. This approach stabilizes single-mode emission and polarization simultaneously with one simple additional fabrication step.

2. Device Fabrication

The epitaxial structure consists of 34.5 n-Bragg pairs, three 8 nm GaAs quantum wells, a 30 nm $Al_{.98}Ga_{.02}As$ layer for selective oxidation and 27 p-Bragg pairs. An additional $\lambda/2$ $Al_{.1}Ga_{.9}As$ cap layer allows for the 50 nm deep surface etching without exposing high-aluminum content layers. To achieve anisotropic spatially varied loss, self-aligned surface etching [5] is carried out using elliptical etch patterns. The lithography mask includes ellipse orientations 0°, 30°, 45°, 60°, 90°, and 135° versus the [011] crystal axis with aspect ratios ranging from 1/2 to 1/4. Five device sizes with oxide apertures between 2.5 and 12.5 μm diameter have been fabricated. In this letter, we present the results of four selected devices whose fabrication parameters are given in Table 1. Consistent results have been obtained for the other devices.

Tab. 1. Fabrication parameters for the presented devices.

device	aperture diameter (μm)	short axis (μm)	long axis (μm)	angle to [011]
5_90	5.0	2.25	4.5	90°
5_45	5.0	1.95	5.9	45°
5_0	5.0	1.8	7.2	0°
5_U	5.0	unetched		

3. Measurement Results

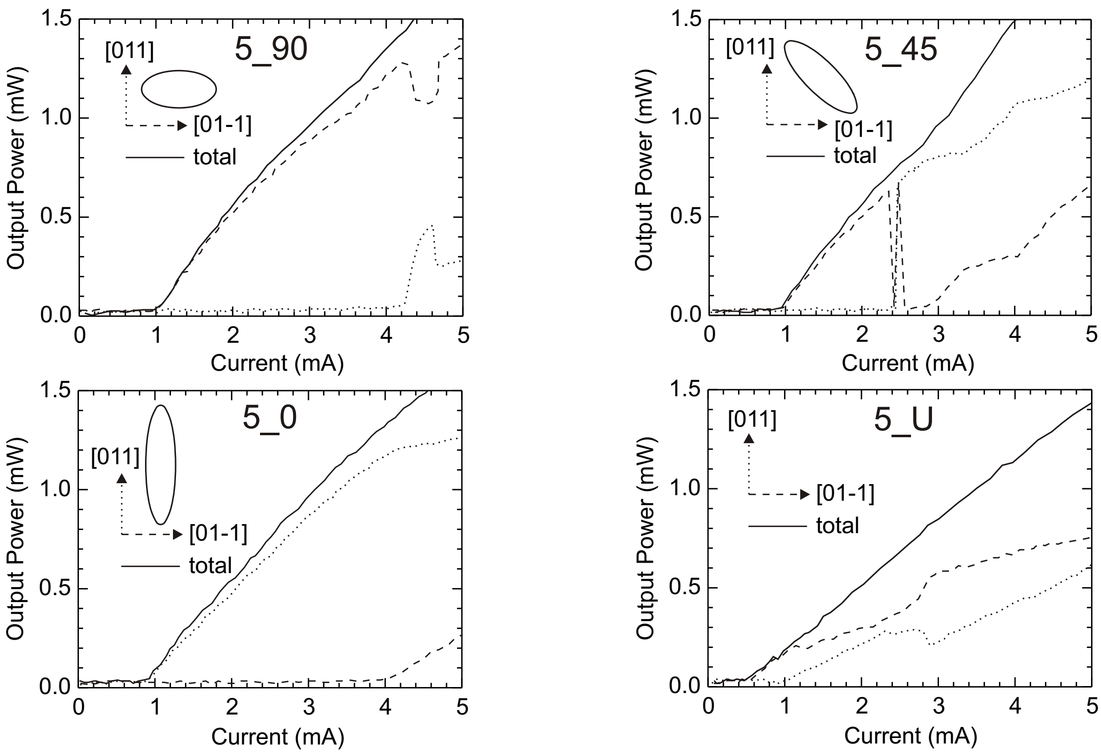

Fig. 1. Polarization-resolved LIV-characteristics of the four differently etched 5 μm aperture diameter devices. The insets illustrate orientation and aspect ratio of the etched ellipses.

The polarization-resolved LIV-characteristics of the four devices are shown in Fig. 1. No temperature control is employed for these devices held by vacuum on a copper block. As can be seen easily, the two devices 5_90 and 5_0 with ellipses oriented along the low-index crystal axes are forced to emit on the polarization parallel to the longer ellipse axis for the single-mode regime up to about 4 mA. Due to the surface etching, device 5_45 also displays an increased single-mode regime, but exhibits a polarization switch from $[01\bar{1}]$ to [011] at about 2.4 mA current. The unetched reference device 5_U only has a very small single-mode range with no significant polarization selection. For unetched devices of different aperture size, polarization switching can also be observed. A slight output power increase depending on the surface etch size can also be seen as previously reported in [6].

To confirm these results, a large number of devices has been tested using polarization resolved LIV-characteristics. Out of 58 5_90 devices and 62 5_0 devices, only 1 5_90 device exhibited switching, whereas only 5 5_U reference devices out of 60 measured did **not** switch polarizations. The polarization-resolved spectra in Fig. 2 taken at 3 mA confirm the strong polarization suppression of about 30 dB within the single-mode operation regime of device 5_90.

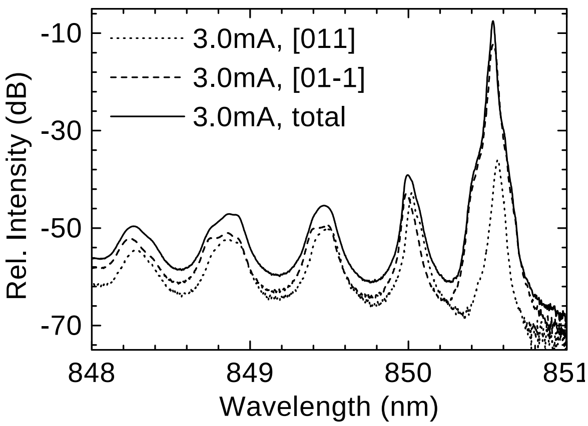

Fig. 2. Polarization-resolved spectra of device 5_90 for a current of 3 mA.

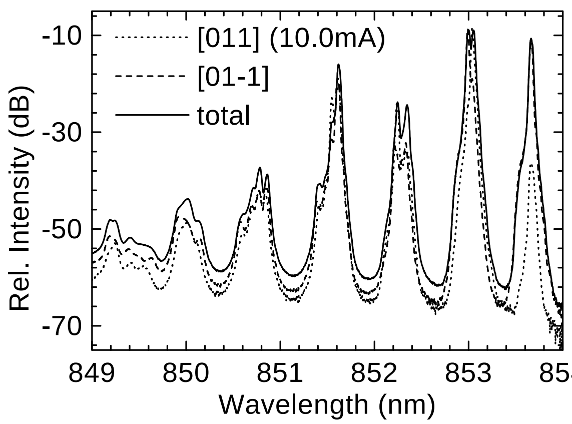

Fig. 3. Polarization-resolved spectra of device 5_90 for a current of 10 mA.

The spectral behavior of device 5_90 at a current of 10 mA, well into the multi-mode regime, is shown in Fig. 3. Even though higher-order modes contain various fractions of both polarizations, the fundamental mode polarization is still pinned to the $[01\bar{1}]$ crystal direction with a similar suppression ratio as before. This indicates that the polarization selection mechanism may be strong enough for applications like high-speed data transmission.

4. Conclusion

We have successfully fabricated for the first time 850 nm selectively oxidized VCSELs with a self-aligned elliptical shallow surface relief. CW measurements at room temperature with the bare die sample held by vacuum on a copper block have been carried out on a large number of devices. These measurements show deterministic polarization selection of the fundamental mode with about 30 dB suppression ratio over the complete operating range if the ellipse is aligned along the [011] or [01$\bar{1}$] crystal axis. By using a layer structure with lower p-side reflectivity in the future, we expect to much augment the effect, resulting in a much higher single-mode, single-polarization current range and optical output power. Additionally, the strength of the polarization pinning will be evaluated by applying mechanical strain, elevated temperatures and high-speed modulation.

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