Stable polarization operation of 1.3 μm-wavelength vertical cavity surface emitting laser (VCSEL) fabricated by orientation-mismatched wafer bonding

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Abstract
We present stable polarization of a long-wavelength VCSEL under DC operation and high-speed modulation. It was fabricated by wafer bonding of a (311)B InP-based active region to (100) GaAs-based DBRs.

It is important to control the polarization of the output from VCSELs to be used in many applications, since the conventional VCSELs are fabricated on (100) substrates and do not have fundamental polarization selection rule. To make the polarization fixed to one axis, there has to be some asymmetry introduced in VCSEL structure. It has been shown theoretically[1)] and experimentally[2)] that multi-quantum wells (MQWs) grown on an asymmetric crystal plane has asymmetric in-plane gain, which leads to a fixed in-plane polarization axis. Another approach is to fabricate a VCSEL in an asymmetric shape to introduce asymmetric loss[3)].

We have fabricated polarization-controlled long-wavelength (LW) VCSEL which has (311)B InP-based active region[4)]. The LW VCSEL has a problem of not having adequate material for distributed Bragg reflector (DBR), and for this problem, we integrated (100) GaAs-based AlGaAs/GaAs DBRs by wafer bonding. With this unique technique, we obtained 31dB maximum/minimum polarization suppression ratio of single mode power[4)]. In this paper, we show very stable polarization of such VCSELs with index guiding mesas etched in asymmetric shapes, by statistical data and high-speed modulation experiment.

Figure 1 shows the structure of our VCSEL. The 2.5 λ-cavity active region was grown on (311)B InP substrate by MOCVD. Three sets of InGaAsP MQWs were placed at peaks, and each set consisted of five wells with 1% compressive strain separated by InP barriers. Two DBRs, top DBR with 23 pairs of $Al_{0.9}Ga_{0.1}As/GaAs$ and bottom DBR with 30 pairs of the same, were grown on (100) GaAs substrate by MBE. Then the surface of the bottom DBR was mesa-etched by about 500Å deep for index guiding. The etching was done in an elliptic shape in two different orientations and in three different sizes. The dimensions and orientations of the mesa relative to (311)B active region are summarized in Figure 2. The [233] is known to be the maximum gain axis on (311) plane, and its orthogonal [011] is the minimum gain axis. Hence, the ellipse elongating in [233] is expected to enhance [233] polarization, whereas the [011] ellipse may distract it. The active region was wafer-bonded to two DBRs by a procedure similar to that previously reported[4)], and the VCSEL fabrication was completed. The VCSELs were optically pumped by 980nm edge-emitting laser which was linearly TE-polarized. The VCSELs were positioned in a way that their [233] and [011] axes are both 45° off from the pump laser's TE axis as shown in Fig. 2, so that there was no pumping preference between them.

Figure 3 shows examples of polarization-resolved pump power vs. light output power (P-L) curves for a VCSEL with [233]-oriented elliptic mesa and another with [011] elliptic mesa, both with d=12μm. The output power was measured by an optical spectrum analyzer and not calibrated. Both lased at wavelength around 1310nm and showed multi-mode operation. As can be seen, [233]-elliptic VCSELs showed very stable polarization at [233] axis, whereas most of [011]-ellipses showed increase of [011]-polarized power at high pump power and/or at threshold. From all the P-L measurements performed, the best and worst suppression ratio (SR) between [233]- and [011]-polarized power were extracted for each VCSEL in a way as shown in Fig. 3, and their distribution is shown in Figure 4. The worst SR values are those observed at pump power higher than 1.5 times of threshold pump power (P_{th}). The figure shows that most of [233]-elliptic VCSELs had best SR higher than 20dB, and very few showed SR degradation below 20dB. Meanwhile, [011]-elliptic VCSELs show not only the lower best-SR values overall, but also worst SR under 5dB on many of them. Hence, the effect of asymmetric mesa etching is statistically shown. However, all [011]-elliptic VCSELs still had [233] as overall maximum power axis, and some of them had high best-SR values and did not show major SR degradation. Therefore, it means that the gain anisotropy of MQWs on (311)B plane is dominant over the shape asymmetry.

We also performed bit error rate measurement on a [233]-elliptic VCSEL by modulating the pump laser at 1Gb/s. As shown in Figure 5, we obtained exactly the same result with and without a polarizer, which means that its polarization was stable under fast modulation.

In conclusion, we showed polarization-stable operation of wafer-bonded LW VCSELs which had the (311)B InP-based active region. With a help of elliptic index guiding, they had statistically stable polarization under DC operation, and showed no polarization-associated deterioration under high-speed modulation experiment. This research was supported by National Science Foundation (NSF) and Walsin Lihwa Corporation.

References

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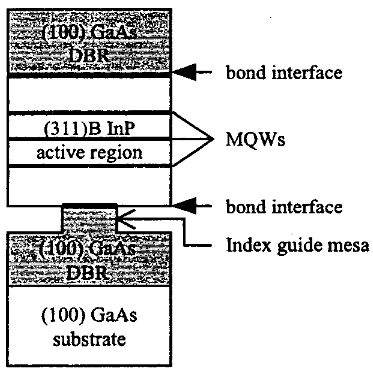

Figure 1 Structure of VCSEL

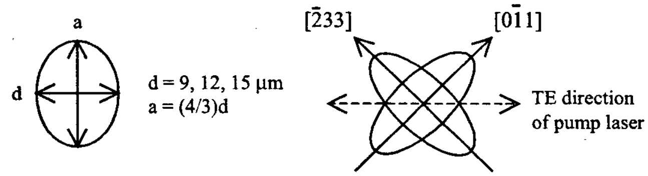

Figure 2 Dimensions and orientations of index guide mesa

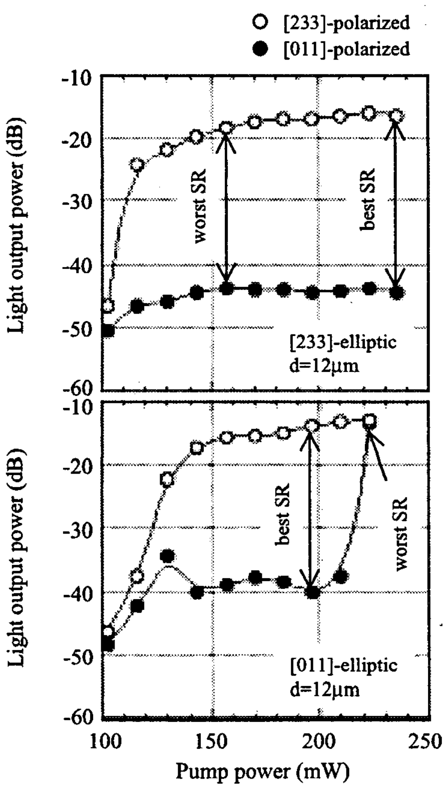

Figure 3 Polarization-resolved P-L curves for VCSELs with [233]-elliptic and [011] elliptic mesa etching.

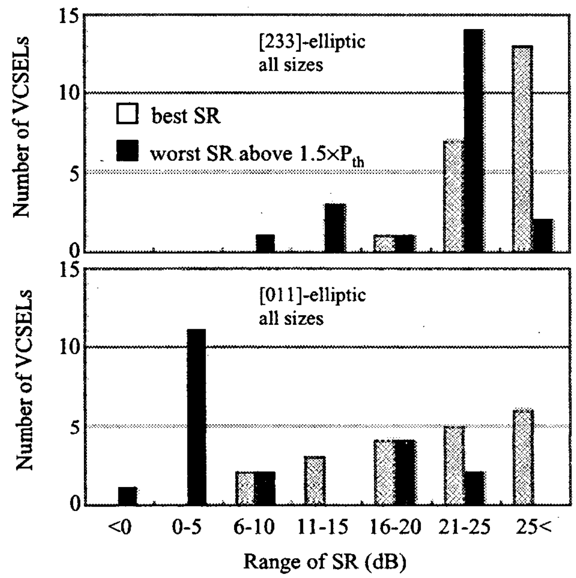

Figure 4 Distribution of best and worst SRs from each VCSELs with [233]-elliptic and [011]-elliptic mesa etching

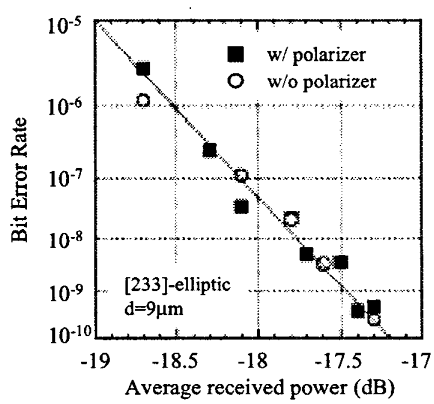

Figure 5 BER of [233]-elliptic VCSEL at 1Gb/s