# Polarization control of 1.3 μm-wavelength vertical cavity surface emitting laser (VCSEL) fabricated by orientation-mismatched wafer bonding

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**Abstract**

A technique to control the polarization of long-wavelength VCSELs is presented. The active region, grown on (311)B InP, is wafer-bonded to (100) GaAs-based mirrors.

Control of the polarization of the output of short wavelength VCSELs has been extensively investigated, but relatively little has been done on polarization control of long-wavelength (LW) VCSELs. 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 reads to a fixed in-plane polarization axis. However, crystal growth on an asymmetric plane such as (311) is not as easy as that on a conventional (100) plane. Therefore, growing the whole LW VCSEL structure on an asymmetric crystal plane is difficult, since the structure would be very thick.

Wafer bonding is a technique that has enabled LW VCSELs to lase continuously up to 115 $^{o}$C [3,4,5]. With this technique we can combine two dissimilar materials without degrading their quality [6]. Therefore, wafer-bonded VCSELs can be fabricated from an InP-based active region and GaAs-based DBR mirrors. Also, it is possible to have an active region and DBR mirrors grown on different crystal planes. Here we present a new type of wafer-bonded LW VCSEL which utilizes (311)B InP-based active region and (100) GaAs-based DBR mirrors with a prospect to achieve polarization control.

Figure 1 shows a schematic of our VCSEL structure. By changing the crystallographic orientation of the active region to (311), we can expect to have not only an asymmetric in-plane gain, but also an asymmetric stress provided from two bonded interfaces of (311)B InP and (100) GaAs. That is, at the lattice- and orientation-mismatched interface, effective lattice mismatch would be very different between two orthogonal in-plane axes [6]. This asymmetric stress is expected to have an effect on the control of polarization axes. To focus on this effect, the MQWs were designed to have a small lattice mismatch so that the asymmetry of in-plane gain would be small. The 2.5 λ-cavity active region consisted of 3 identical sets of InGaAsP MQWs and each set consisted of five wells and six barriers. It was grown by metalorganic chemical vapor deposition (MOCVD) with growth conditions optimized for the (311)B substrate. DBR mirrors were grown by conventional molecular beam epitaxy. The wafer bonding procedure was similar to that previously reported [3]. This VCSEL was intended to be optically pumped, hence, the whole structure was undoped. Optically pumped LW VCSEL have been demonstrated elsewhere with excellent characteristics of 2 mW power at room temperature and 0.5 mW at 85 $^{o}$C, and is integrated on a wafer scale with an 850 nm pump VCSEL [5].

Figure 2 shows an X-ray diffraction spectrum from the as-grown active region. The net strain in the MQWs is almost zero as designed, and side peaks with ripples show good structural properties. Figure 3 shows photoluminescence (PL) spectra of the MQWs. The PL of as-grown MQWs on (311)B substrate exhibit a peak shape as good as that of MQWs grown on (100), but with a large wavelength shift of about -50nm. With the aid of X-ray diffraction measurements, this shift was attributed to a large decrease of In incorporation and a little decrease of As incorporation on the (311)B surface compared to those on (100). Hence, lattice constants of InGaAsP materials were very different on the two substrates, and the MQWs on (100) had a large compressive strain. On the other hand, the PL of wafer-bonded MQWs suffers an intensity drop to about half of that of as-grown, and shows a wavelength shift. These changes are due to annealing during the wafer bonding which was done at a temperature higher than the MOCVD growth temperature.

Figure 4 shows polarization-dependent lasing characteristics of the VCSEL measured by an optical spectrum analyzer. It was optically pumped by a 980nm edge-emitting laser via free-space optics. Since the pump laser was TE polarized, the VCSEL polarization behavior was examined by aligning the pump laser polarization axis to one of two orthogonal crystal axes of the VCSEL. Power extinction ratio between two axes was 37 dB at the largest point. The VCSEL was bonded with no index guiding structure, and showed a single mode spectrum at 1273 nm with side-mode suppression ratio of 41 dB.

In conclusion, a polarization controlled wafer-bonded LW VCSEL was demonstrated with a (311)B InP-based active region. A maximum extinction ratio of 37 dB was obtained.


**References**

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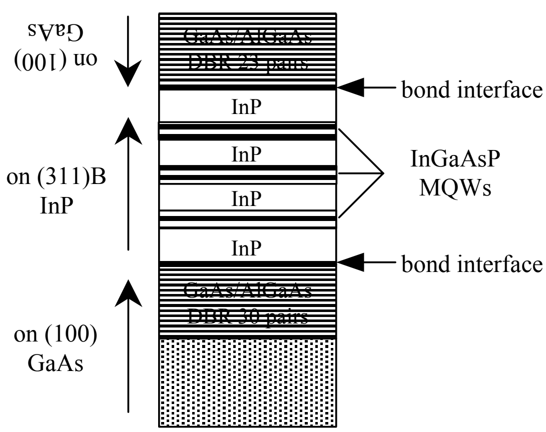


Figure 1 Structure of VCSEL

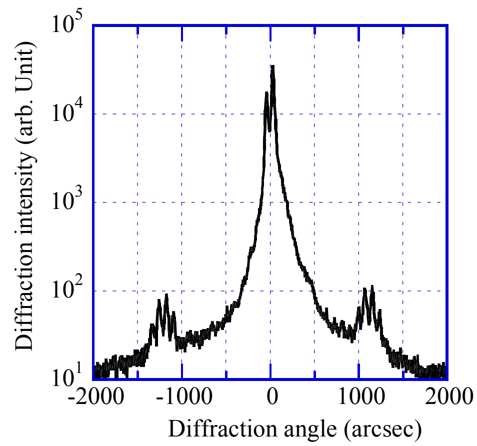


Figure 2 X-ray diffraction from active region

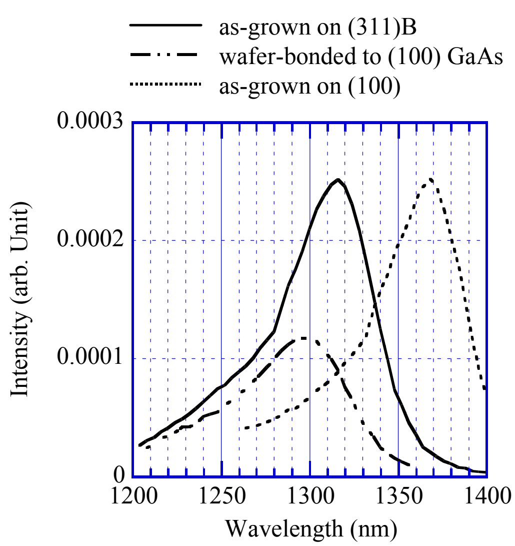


Figure 3 PL spectra of MQWs

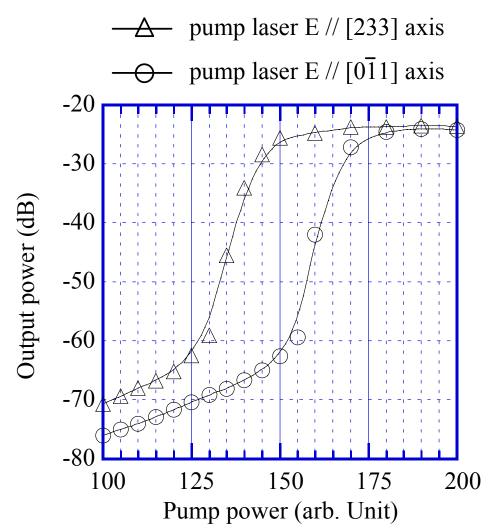


Figure 4 Output power from VCSEL