Study on Optical Confinement of Small Size VCSEL Using Index Change of QWI

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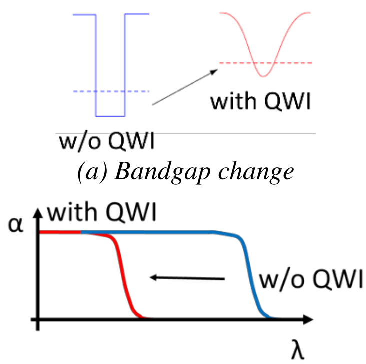
Abstract: We investigated the applicability of quantum well inter-mixing (QWI) for VCSEL to use its low refractive index difference. As the result of numerical simulations, we shows that by combining an oxidation layer and a QWI layer appropriately, an small sized VCSEL is realizable.

1. Introduction Since amount of the information increases with advanced and diversified needs of information, it is necessary to improve the performance of information systems like computers continuously. Metal wirings that transmit the electrical signal have become the bottleneck of the improvement in system performance due to band-limitation, cross-talk, and high power consumption. Therefore, introduction of optical interconnection is required.

Vertical-cavity surface-emitting laser (VCSEL) which has been used in board-to-board optical-interconnection has advantages of low power consumption and dense array light source. However, it is necessary for VCSEL to become more low power consumption for future applications. To achieve it, 1μm diameter class of active region of VCSEL is needed. VCSEL has used selective oxidation technology for reducing the active region diameter.[1] However the selective oxidation technology has large refractive index difference around the oxidation aperture. It causes the scattering of light and the diffraction, and these influences are increased when the device size is decreased. Therefore, a novel technology which can suppress the light scattering and apply a waveguide effect is necessary for solving the problems.

In this study, we proposed and investigated novel VCSELs that consist of a low refractive index difference structure formed by the quantum well inter-mixing (QWI) technology. We report the numerical analysis results of the improved cavity characteristics of small sized VCSELs.

2. Refractive Index Change by QWI The QWI technology has been used for control the position dependent bandgap energy. The structure is formed by introducing the vacancy or defects around quantum wells and then heating. The interdiffused atoms between well and barrier layer causes change of the bandgap in quantum well.[2] In this study, we use the refractive index change in the QWI which is caused by change of the absorption spectrum shown as Fig. 1. The refractive index change by the QWI has been studied and the change of up to 0.09 was reported.[3, 4] In the following numerical analysis, we assumed that the refractive index change was 0.05.



(a) Bandgap change
(b)Change of absorption spectrum
Fig. 1: Principle of QWI.

3. Numerical Simulation Model of QWI-VCSEL A schematic structure of QWI-VCSEL is shown in Fig. 2. The QWI layers are inserted in the DBR. The QWI is introduced in the outer area of VCSEL mesa and the center area is maintained the original QW. The structure is considered as a waveguide using relatively low index difference. Therefore it can reduce light scattering and light diffraction.

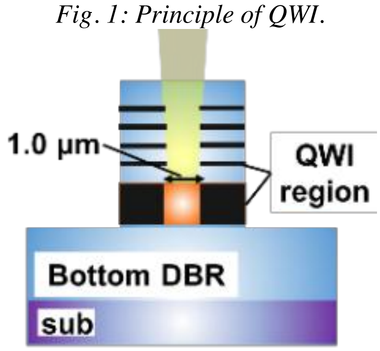


Fig. 2: Analyzed VCSEL model.

Assumed VCSEL model has the 0.98μm band of GaInAs active layer on the GaAs substrate. Upper and bottom DBRs have 25 and 30 pairs, respectively. As the detail of QWI structure, one pair of three-QW layer which has shorter wavelength than 0.98 μm is inserted near a node of the standing wave in the upper DBR. The total thickness of the one pair of QWI is 35 nm. We inserted one selective oxidation layer for the purpose of current confinement. In this study, the target aperture diameter of the QWI and the oxidation area is 1 μm. The cavity loss was analyzed as photon lifetime, from the time decay of the light intensity using the two-dimensional FDTD.

4. Results and Discussions Figure 3 shows the photon lifetime dependence on the number of QWI layer. A oxidation layer is inserted just above the active layer and the QWI layers are inserted above the oxidation layer. The plot on the left y-axis shows a conventional VCSEL structure which has one oxidation layer without QWI layer. In these structures, by decreasing the aperture diameter, photon lifetime decreased due to increase of the scattering and diffraction. In the case of 1 μm aperture, by introducing the QWI layer, photon lifetime was increased to 12.1 ps at 10 QWI layers, that is about three times of the conventional VCSEL. The value is larger than that of the conventional VCSELs with large apertures. It means that low power consumption almost proportional to the aperture size will be expected. On the other hand, it is noted that increased layers of more than 10 caused decrease of the photon lifetime.

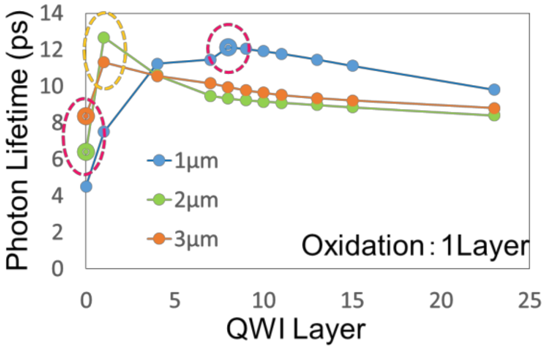


Fig. 3 Photon lifetime dependence on the QWI layer in DBR.

We can consider three effects of the QWI layers. The first one is that the QWI structure suppresses the diffraction loss because it is regarded as a waveguide, and the increase of the number of QWI layers cause increase of the photon lifetime. Secondly, since the QWI layer does not form a completely waveguide, the light is scattered in each layer without QWI. It lead to the reduction of photon lifetime by increasing the number of QWI layers. Thirdly, there is a mode coupling between the oxidation aperture and the QWI aperture. As a result, effect of the first comes out strongly when the number of layers is small, but if the number of layers is large, the effect of secondly comes out strongly. So there are the optimum number of layers. The highest photon lifetime was obtained at a few QWI layer when aperture is 2 and 3 μm. This is because that the beam spot is large and the effect of the light diffraction is small. Therefore scattering effect was increased by increase of the QWI layer.

Figure 4 shows the effect of the coupling loss between the oxidation aperture and the QWI aperture. In this calculation, oxide aperture diameter is fixed at 1 μm. When the QWI aperture is smaller than 1 μm, photon lifetime is reduced. On the other hand, the photon lifetime become highest when the 1.2 μm QWI aperture. It is because that the transverse mode size of the light in the QWI layer has larger spot size due to small index –step in comparison with oxidation layer.

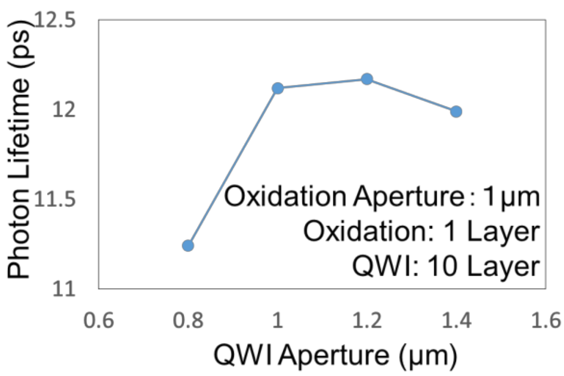


Fig. 4 QWI aperture dependence of photon lifetime.

5. Conclusions We investigated VCSELs which uses the refractive-index change by QWI for optical confinement. By combining an oxidation layer and a QWI layer appropriately, a small size VCSEL with decreased cavity loss is realizable.

References

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