100°C, 10 Gbps Operation of Buried Tunnel Junction GaInNAs VCSELs

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Abstract

10 Gbps operation of BTJ GaInNAs VCSELs is achieved over temperature range of 25°C to 100°C with operation current of 5.6 mA and extinction ratio of 4.2 dB.

Introduction

Long-wavelength vertical-cavity surface-emitting lasers (LW-VCSELs) are promising as light sources with high speed and low power consumption. InP-based LW-VCSELs have improved their performances with buried tunnel junction (BTJ) structure [1]-[3]. High speed GaAs-based BTJ-VCSELs were reported at 25°C in the wavelength range of 1100 nm [4].

In this paper, we demonstrate 10 Gbps operation of BTJ GaInNAs VCSELs over the temperature range of 25°C to 100°C.

GaAs-based BTJ-VCSELs

BTJ-VCSELs based on GaAs substrates are attractive alternatives for oxide-VCSELs that require a precise control in an AlGaAs oxidation step to form a desired current aperture. The BTJ structure can solve this problem because the current aperture is determined by a tunnel junction aperture which is formed by well-established photolithography and etching processes. In addition, the tunnel junction converts holes to electrons so that p-type layers can be replaced by n-type layers. This leads to a reduction of the electrical resistance and the optical absorption loss. The n-type current spreading layer allows us to use a lossless dielectric DBR or an undoped semiconductor DBR as a top mirror without any increase in the electrical resistance.

Generally, penetration depth of the dielectric DBR is shorter than the semiconductor DBR due to the larger refractive index contrast. Thus, higher resonance frequency is obtained at a lower bias current with a help of the shorter effective cavity length. On the other hand, the dielectric DBR has a poor thermal conductivity compared to the semiconductor DBR. The performance of VCSELs is usually limited by the self-heating. When the semiconductor DBR is used as a bottom mirror, the heat generated in the active region escapes efficiently through the bottom mirror. Therefore, a combination of the dielectric DBR and the semiconductor DBR as upper and lower mirrors is suitable to achieve high speed and high temperature operations.

Device structure

Top emitting VCSEL structures were grown on a GaAs substrate. An n-type bottom mirror consisted of a GaAs/AlGaAs DBR. GaInNAs-multi QWs were sandwiched by the bottom DBR and a p-type spacer. A heavily doped GaAs-based tunnel junction was grown on the p-type spacer. To avoid the optical absorption loss, the tunnel junction was placed at the minimum of the optical field intensity. A tunnel junction mesa was formed by conventional photolithography and etching techniques. An n-type current spreading layer and a contact layer were grown to cover the tunnel junction mesa. Before forming a circular mesa to reduce the device capacitance, the contact layer was removed to reduce the optical absorption loss. Finally, a dielectric DBR was deposited on the top of the device after forming a top electrode.

Characteristics

Figure 1 shows temperature dependence of light-current (L-I) characteristics for a tunnel junction aperture of 5 um. At 25°C, the threshold current and the maximum output power are 1.2 mA and 2.3 mW, respectively. The slope efficiency at 5 mA is 0.25 W/A. Even at 100°C, the threshold current is 1.8 mA and the maximum output power is as high as 0.7 mW. It should be noted that the threshold current increases with increasing the temperature, thus, lower threshold current and higher output power are expected at 100°C by adjusting the wavelength detuning between the cavity resonance and the gain peak. These results indicate that the GaInNAs QWs have a high characteristic temperature and the heat generated in the active region can efficiently escape through the bottom DBR.

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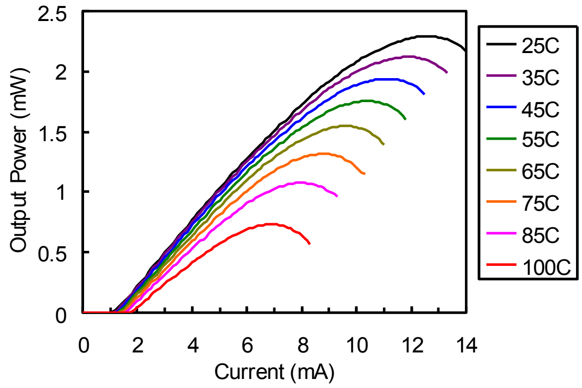


Figure 1: Temperature dependence of L-I characteristics. Tunnel junction aperture is 5 um.

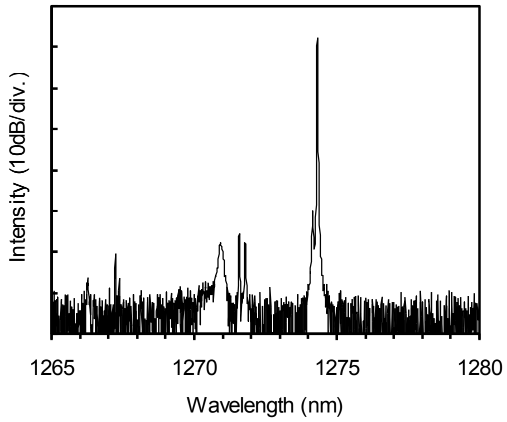
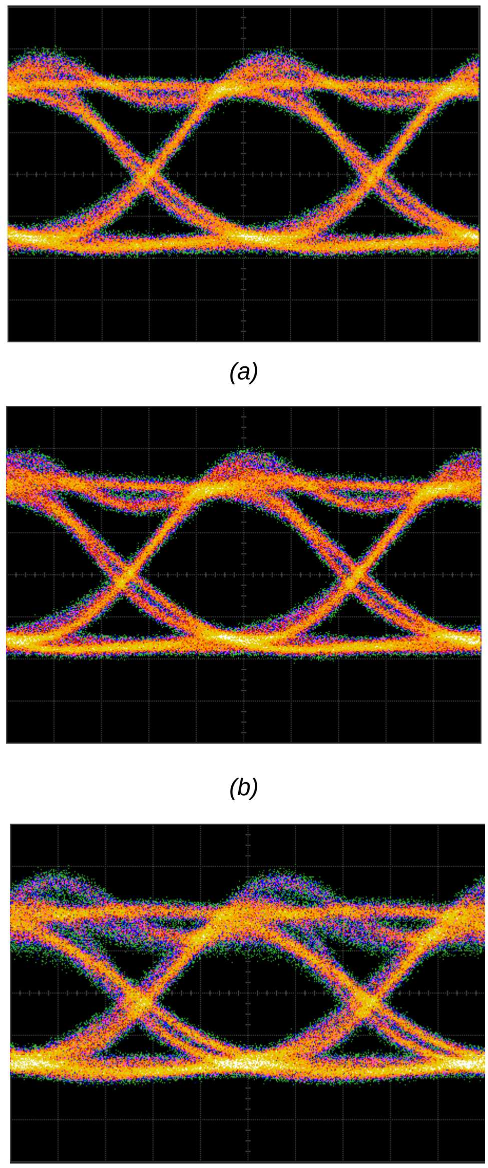


Figure 2: Lasing spectrum with a bias current of 7 mA at 25°C. Tunnel junction aperture is 5 um.

The lasing spectrum with a bias current of 7 mA at 25°C is shown in Fig. 2. The lasing wavelength is 1274 nm and the side-mode suppression ratio is more than 40 dB.

Figure 3 shows 10.3125 Gbps eye diagrams at three temperatures of 25°C, 55°C and 100°C. Output signals from the sample were coupled to a lensed fiber. Modulation voltage and extinction ratio were kept to be 0.21 $V_{p\text{-}p}$ and 4.2 dB at three temperatures. Bias currents at 25°C, 55°C and 100°C were 3.4 mA, 3.8 mA and 5.6 mA, respectively. Clear eye openings were obtained over the temperature range of 25°C to 100°C. Again, a better eye diagram is expected at 100°C by adjusting the wavelength detuning between the cavity resonance and the gain peak. To the best of our knowledge, this is the first demonstration of 100°C, 10 Gbps operation of GaInNAs VCSELs with buried tunnel junction structures.



(a)

(b)

(c)

Figure 3: 10.3125 Gbps eye diagrams at (a) 25°C, (b) 55°C and (c) 100°C.

Conclusions

We have demonstrated 10 Gbps operation of the BTJ GaInNAs VCSELs over the temperature range of 25°C to 100°C. It has been shown that only 5.6 mA and 0.21 $V_{p\text{-}p}$ are required to achieve 10 Gbps operation with extinction ratio of 4.2 dB, even at 100°C.

References

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