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Recent Progress of Long Wavelength VCSEL Research

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1. Introduction

The important advantages of vertical-cavity surface-emitting lasers (VCSELs) against edge emitting lasers such as longitudinal monomode emission, small power consumption, easy fibre coupling as well as simplified fabrication and testing has led to the development of high-performance 850 nm VCSEL which are nowadays the preferred light sources for short distance datacom applications. On the other hand, the market for medium- and long-haul telecommunication systems strongly requires low-cost light sources with emission wavelengths from 1.3–1.55 μm matched to silica fibre based transmission windows. Adequate VCSELs would be highly attractive light sources and could even replace 850 nm lasers. The development of these devices on InP, however, faces a number of severe problems. The major obstacles are the smaller thermal conductivity of the epitaxial mirror layers leading to increased self heating and the stronger temperature dependence of the optical gain. From the viewpoint of technology, self aligned lateral index guiding and current confinement are also important issues.

While numerous approaches including wafer-bonding [1] or InGaAsN active regions for extended wavelengths on GaAs substrates [2] have still not proven to yield application suitable devices, our recently reported Buried Tunnel Junction (BTJ) structure shows superior performance and promises to fulfill the required system performances.

The BTJ-concept yields a sharply reduced device heating due to reduced series resistance [3]. Furthermore, self adjusted current and optical confinement are accomplished [4] which is difficult to achieve in other structures. Significantly improved performance including record output power, quantum efficiency and low threshold current have already been demonstrated for 1.5 μm VCSELs [5].

In this paper we present the stationary spectral and output beam characteristics of long-wavelength BTJ-VCSELs.

2. Device Structure

Fig. 1 shows a schematic cross section of the BTJ-VCSELs.

As can be seen, the lasers are operated upside-down with a short period stack of dielectrics coated with Au. Because of the large reflectivity of Au for long wavelengths together with the large refractive index difference between amorphous materials that can be used for this purpose, the hybride Au-dielectric mirror may provide reflectivities well beyond 99 % with only 1.5 or 2.5 layer pairs.

Regrowth of the structured tunnel junction with binary and, consequently, thermally low-resistive InP results in an effective spreading of the generated heat.

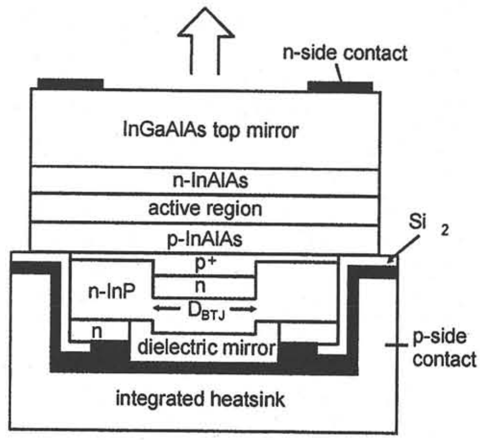

Fig. 1 Schematic cross-sectional view of InP-based BTJ-VCSEL.

Since the spreading layers are *n*-doped, negligible voltage drop occurs in this region and lateral current injection can be applied in conjunction with the highly reflective but electrically insulating dielectric mirrors. The substrate on top is completely removed while an electroplated metal layer on the bottom side provides mechanical stability and serves as an excellent heatsink. Depending on the emission wavelength, the epitaxial front mirror has an appropriate composition and pair number. The active region typically consists of five 8 nm thick compressively strained quantum wells separated by 7 nm thick tensile strained barriers.

3. Results and Discussion

Fig. 2 shows the light-current characteristics for different aperture sizes of the tunnel junction diameter.

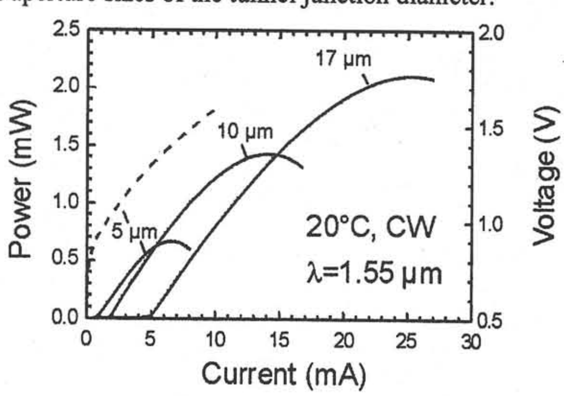

Fig. 2 Optical output power versus current of 1.55 μm BTJ-VCSELs with D_{BTJ} as parameter. The dashed line is the current-voltage curve for D_{BTJ} = 5 μm.

With 17 μm diameter, record output powers exceeding 2 mW with threshold currents of 5 mA can be achieved.

While these VCSELs are multi-mode, single-mode devices as shown in Fig. 3 are feasible with the smaller 5 µm diameters with threshold currents of 0.5-0.7 mW and maximum output powers of 0.7 mW.

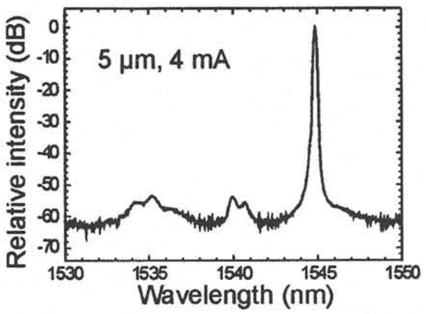

Fig. 3 Spectrum of a 1.55 µm BTJ-VCSEL with a slightly elliptic BTJ of 5 µm diameter.

The differential quantum efficiency is well beyond 20 % for all diameters. The lasers also show a remarkable electrical performance with series resistances around 60 Ω for the 5 µm VCSELs and threshold voltages approaching 0.9 V for all diameters.

High performance BTJ-lasers could be also demonstrated for extended wavelengths around 1.8 µm. Fig. 4 shows the room temperature CW output power versus current for different BTJ diameters.

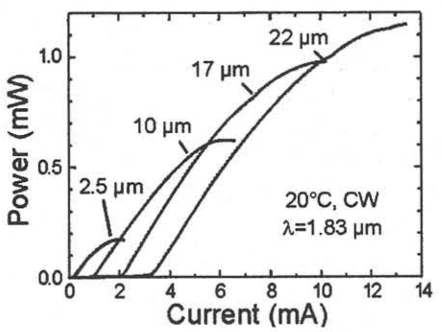

Fig. 4 Optical output power versus current for 1.83 µm BTJ-VCSELs.

Here, the BTJ-diameter has been varied from 22 µm down to 2.5 µm. The possibility for the realization of such small apertures with ultralow threshold currents of 190 µA is a consequence of the strong index guiding associated with the BTJ-technique. The maximum CW operating temperature is between 70°C and 90°C and depends on the aperture size.

By using elliptical BTJ-shapes, the polarization degeneracy can be lifted and stable single-mode operation with side mode suppression ratios exceeding 30 dB can be achieved.

As an example, Fig. 5 shows an elliptic BTJ after regrowth and the corresponding far field profile for a 1.83 µm device with 7 µm aperture size. The full width at half maximum is 25° for the long half axis and 20° for the perpendicular direction.

The relevant laser parameters of 1.55 and 1.83 µm BTJ-VCSELs are summarized in Table 1.

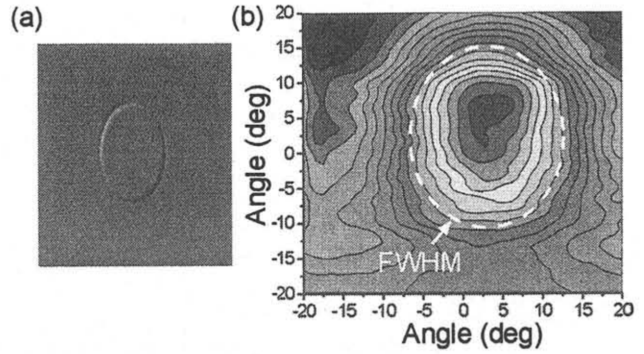

Fig. 5 (a) Optical micrograph of elliptic BTJ with 7 µm long axis and an axis ratio of 0.7. (b) Corresponding far field pattern of 1.83 µm BTJ-VCSEL.

Table I Lasing parameters of 1.55 and 1.83 µm BTJ-VCSELs

D_{BTJ} (µm)	5 µm	10 µm	17 µm
λ=1.55 µm			
I_{th} (mA)	0.71	1.79	4.72
U_{th} (V)	0.92	0.91	0.95
P_{max} (mW)	0.7	1.4	2.1
η_d (%)	22	23	22
λ=1.83 µm			
I_{th} (mA)	0.42	0.96	2.1
U_{th} (V)	1.05	1.15	1.37
P_{max} (mW)	0.2	0.5	1.0
η_d (%)	17	26	28

4. Conclusions

In summary, we presented the design of the novel InP-based BTJ-VCSELs for wavelengths between 1.5 and 1.8 µm and discussed the most important stationary laser characteristics. The results indicate the capability of this design to yield light sources for the important telecommunication wavelength range.

Acknowledgments

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