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Long Wavelength VCSELs for Sensing Applications

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Abstract: InP-based tunable singlemode VCSELs in the 1.3 – 2.3μm wavelength range are presented. The relevant laser parameters are discussed and several applications in trace-gas-sensing are demonstrated.

Introduction: Vertical-cavity surface-emitting lasers (VCSELs) in the sub-1μm wavelength range have previously emerged as high-performance commercial products for datacom-applications. This is because of their intrinsic advantages against edge-emitting lasers, such as sub-milliamp threshold currents, low beam divergence and simple fiber-coupling, high slope efficiencies and low power consumption. Accordingly, various efforts have been paid so far to extend the wavelength range of the VCSELs further into the near- and mid-infrared approach the interesting regimes for single-mode medium range optical communications or environmental gas sensing applications.

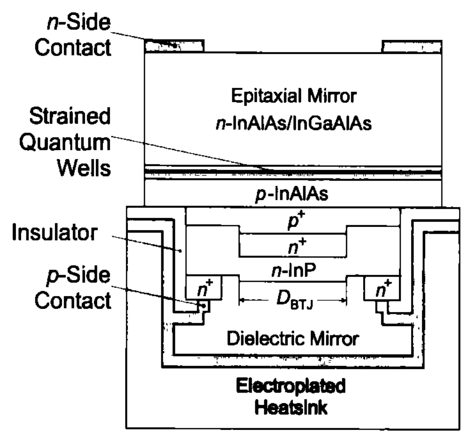

Fig. 1: Schematic cross-sectional view of BTJ-VCSEL.

Laser structure: The major obstacles for the development of long-wavelength VCSELs compared to the sub-1-μm GaAs-based devices were the smaller index contrast and the smaller thermal conductivity of the mirror layers, the stronger temperature dependence of the optical gain and, from the viewpoint of technology, the issue of self-aligned lateral index and current confinement. In this talk, we present a very successful approach for InP-based long-wavelength VCSELs based on buried tunnel junctions: the buried-tunnel-junction (BTJ) VCSEL as shown schematically in Fig. 1 /1/. To achieve low thermal resistance, the lasers are operated upside-down with a hybrid dielectric-Au bottom mirror consisting of a short period stack of 2.5 - 3.5 layer pairs of CaF/*a*-Si. Due to the Au-coating, the reflectivity of the hybrid bottom mirror exceeds 99.7 %. To minimize absorption losses, the tunnel junction is placed in a node of the electromagnetic field. The overgrowth with binary and, consequently, thermally low-resistive InP of 0.5-1μm thickness results in further improved heat dissipation. Since the spreading layers are *n*-doped, negligible voltage drop occurs in this region (<0.1V) and lateral current injection can be applied in conjunction with the high-reflective but electrically insulating dielectric mirror. The substrate on top is completely removed while an electroplated metal layer on bottom provides mechanical stability and serves as an excellent heatsink similar as for the previous Burrus-type LED.

Measurement: Excellent cw laser performance has meanwhile been achieved for the entire 1.3-2.3μm /2/ wavelength range (Fig. 2), such as sub-mA threshold currents, 0.9 V threshold voltage (at λ=1.55μm), operation voltages below 1.2V, 30-70 Ω series resistance, differential efficiencies >25%, up to 3mW single-mode optical output power, >100°C cw operation, stable polarization and single-mode operation with SSR of the order 50 dB (Fig. 3). Electro-thermal wavelength-tuning over ~4 nm and micromechanical tuning over more than 40 nm both in the continuous tuning-mode and with SMSR> 30 dB can be accomplished. Continuous wavelength tuning can either be accomplished electrothermally via the laser current or using a MEMS-actuted membrane as the upper laser mirror. While the first technique is most simple, the tuning range is limited to about 3-4 nm. With the latter technique, on the other hand, tuning over more than 40 nm has been reported /3/.

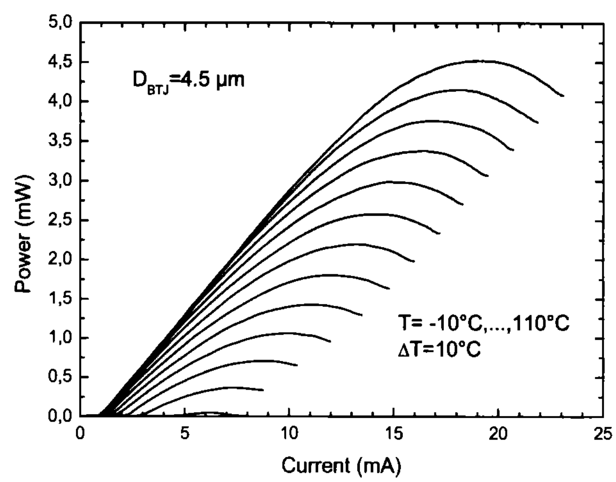

Fig. 2: Typical temperature-dependent P(I)-characteristics.

Besides the device design and technology, we will discuss present achievements on high-speed and wavelength-tunable long-wavelength VCSELs and demonstrate some recent experiments on spectroscopic trace-gas sensing /4/ with long-wavelength and wavelength-tunable BTJ VCSELs.

Conclusion: In summary, the BTJ-concept for long-wavelength InP-based VCSELs leads to superior device performance in the 1.3 to 2.3μm wavelength range. The results indicate the capability of the long-wavelength VCSELs to yield light sources for sensing and measurement applications in the near infrared.

Acknowledgement: This work has been financially supported by the German research council (DFG) and by the BMBF of the Federal Republic of Germany.

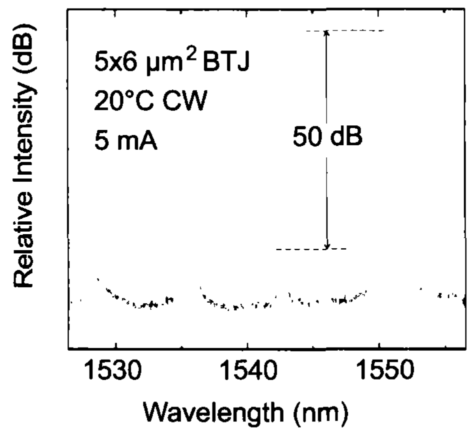

Fig. 3. Spectrum of a 1.55μm BTJ VCSEL at 20°C and 5mA laser current (P=1mW).

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Markus-Christian Amann received the Diplom degree in electrical engineering in 1976 and the Dr.-Ing. degree in 1981, both from the Technical University of Munich. During his thesis work he studied superluminescent diodes and low-threshold laser diodes and developed the AlGaAs-GaAs metal-clad ridge-waveguide laser. From 1981 to 1994 he was with the Corporate Research Laboratories of the Siemens AG in Munich where he was involved in the research on long-wavelength InGaAsP-InP laser diodes. In 1994 he joined the Department of Electrical Engineering at the University of Kassel as a full professor for "Technical Electronics". Since 1997 he holds the Chair of Semiconductor Technology at the Walter Schottky Institute of the Technical University of Munich, where he is currently engaged in the research on tunable laser diodes for the near infrared, quantum cascade lasers, long-wavelength vertical-cavity laser-diodes and laser diode applications.

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