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Epitaxy of GaAs-based long-wavelength vertical cavity lasers

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Abstract

Vertical cavity lasers (VCLs) are of great interest as low-cost, high-performance light sources for fiber-optic communication systems. They have a number of advantages over conventional edge-emitting lasers, including low power consumption, efficient fiber coupling and wafer scale manufacturing/testing. For high-speed data transmission over distances up to a few hundred meters, VCLs (or arrays of VCLs) operating at 850 nm wavelength is today the technology of choice. While multimode fibers are successfully used in these applications, higher transmission bandwidth and longer distances require single-mode fibres and longer wavelengths (1.3-1.55 μm). However, long-wavelength VCLs are as yet not commercially available since no traditional materials system offers the required combination of both high-index-contrast distributed Bragg reflectors (DBRs) and high-gain active regions. Earlier work on long-wavelength VCLs has therefore focused on hybrid techniques, such as wafer fusion between InP-based QWs and AlGaAs DBRs, but more recently the main interest in this field has shifted towards all-epitaxial GaAs-based devices employing novel 1.3-μm active materials. Among these, strained GaInNAs/GaAs QWs are generally considered one of the most promising approaches and have received a great deal of interest.

The aim of this thesis is to investigate monolithic GaAs-based long-wavelength (>1.2 μm) VCLs with InGaAs or GaInNAs QW active regions. Laser structures - or parts thereof - have been grown by metal-organic vapor phase epitaxy (MOVPE) and characterized by various techniques, such as high-resolution x-ray diffraction (XRD), photoluminescence (PL), atomic force microscopy, and secondary ion mass spectroscopy (SIMS). High accuracy reflectance measurements revealed that *n*-type doping is much more detrimental to the performance of AlGaAs DBRs than previously anticipated. A systematic investigation was also made of the deleterious effects of buried Al-containing layers, such as AlGaAs DBRs, on the optical and structural properties of subsequently grown GaInNAs QWs. Both these problems, with their potential bearing on VCL fabrication, are reduced by lowering the DBR growth temperature.

Record-long emission wavelength InGaAs VCLs were fabricated using an extensive gain-cavity detuning. The cavity resonance condition just below 1270 nm wavelength occurs at the far long-wavelength side of the gain curve. Still, the gain is high enough to yield threshold currents in the low mA-regime and a maximum output power exceeding 1 mW, depending on device diameter. Direct modulation experiments were performed on 1260-nm devices at 10 Gb/s in a back-to-back configuration with open, symmetric eye diagrams, indicating their potential for use in high-speed transmission applications. These devices are in compliance with the wavelength requirements of emerging 10-Gb/s Ethernet and SONET OC-192 standards and may turn out to be a viable alternative to GaInNAs VCLs.

Descriptors: GaInNAs, InGaAs, quantum wells, MOVPE, MOCVD, vertical cavity laser, VCSEL, long-wavelength, epitaxy, XRD, DBR