Monolithic, GaInNAsSb VCSELs at 1.46 µm on GaAs by MBE

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Lasing at 1.460 µm from a monolithic, GaInNAsSb vertical cavity surface emitting laser (VCSEL), the longest wavelength on GaAs to date, is demonstrated. Threshold current was 0.58 A (17 kA/cm^2), pulsed with a duty cycle of 0.1%. The VCSEL was cooled to reach threshold, from 700 mA at 0°C to 580 mA at −10°C.

Introduction: VCSELs operating at fibre wavelengths from 1.3 to 1.6 µm have been a tantalising goal ever since Kondow and co-workers first added dilute amounts of nitrogen to gallium arsenide (GaAs) [1]. GaAs-based lasers have pioneered high performance communications at 0.85 to 0.98 µm, due to low wafer cost, mature processing technology, good thermal conductivity, AlGaAs/GaAs mirrors (DBRs), and the availability of selective oxidation for making apertures. When nitrogen was introduced as GaN_yAs_{1-y} or $GaInN_yAs_{1-y}$, early milestones were quickly reached, and continuous-wave (CW) VCSELs were reported at 1.2 µm [2] and 1.3 µm [3] in rapid succession. However, nonradiative recombination in GaInNAs becomes severe with increasing nitrogen. There has been good progress in edge emitting lasers [4, 5], but we are not aware of any electrically pumped VCSELs on GaAs beyond 1.3 µm to date. In this Letter, we describe pulsed lasing from a GaInNAs(Sb) VCSEL at 1.46 µm.

Device structure and growth: The bottom mirror of the VCSEL was composed of 29 alternating pairs of silicon-doped $Al_{0.92}Ga_{0.08}As$ and GaAs, making a distributed Bragg reflector (DBR). The cavity was a one-lambda-thick layer of GaAs, designed for 1.485 µm, with three quantum wells (QWs) at the centre. The QWs were 7 nm $Ga_{0.62}In_{0.38}N_{0.016}As_{0.958}Sb_{0.026}$ with 20 nm GaNAs barriers. The top DBR consisted of 24 pairs with carbon for *p*-doping. Nitrogen was supplied by an SVT Associates rf plasma cell at 300 W and 0.5 sccm. The Sb flux was 1.15×10^{-7} torr, and the arsenic overpressure was 20 times the group III flux in the quantum wells and 15 times elsewhere. Due to a shortage of ports on our nitride MBE system, both DBRs were grown in a separate MBE machine, with the wafer transferred under ultra-high vacuum. Plasma conditions were optimised to minimise damage during growth, as reported elsewhere [6]. Liftoff provided top and bottom contacts, and a self-aligned dry etch through the top DBR defined the mesa. The sample was laterally oxidised roughly 10 µm in water-saturated nitrogen gas, at 435°C for 65 min, to provide a current aperture.

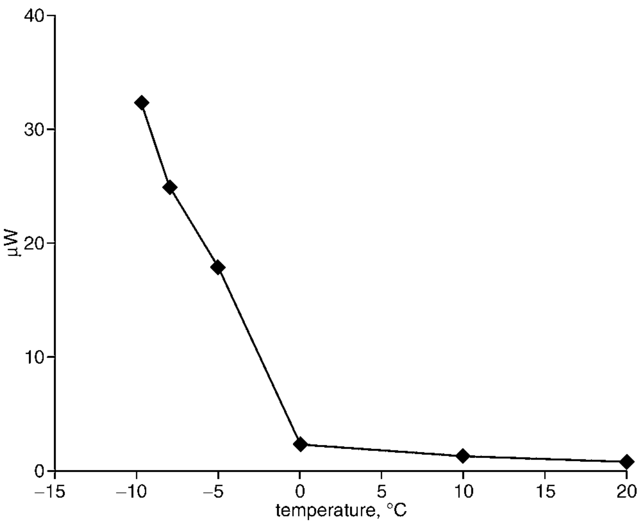

Fig. 1 *Peak optical power against temperature at 700 mA, 2 µm pulses, −10°C*

Device characteristics: Metal liftoff problems forced us to etch the top metal contact with aqua regia before performing the liftoff. This etch severely damaged both the wafer and the metal, which doubled as an etch mask. Furthermore, the selective oxidation layer was too thin, so the entire top DBR had to be oxidised laterally by 10 µm, rather than the intended single, current confining aperture layer. The partial oxidation of so many layers of DBR increased series resistance and added optical scattering. The VCSEL was designed with three of the same basic QWs as our earlier CW edge emitting lasers [6] and a cavity resonance to match (i.e. 1.49 µm), but the actual cavity resonance was at 1.46 µm, so the VCSELs needed to be cooled in order to blueshift the gain towards the cavity resonance. Fig. 1 shows the increase in optical output power against chuck temperature, with 700 mA, 2 µs pulses at a 0.1% duty cycle. The thermoelectric cooler on our chuck could only reach −10°C, but we believe the VCSEL would operate better at a slightly lower temperature. Fig. 2 shows the optical spectrum from another VCSEL with a 66 µm aperture, cooled to −10°C. The VCSEL was driven up to 1000 mA, limited by the maximum voltage of our pulse driver. The duty cycle was 0.1%, with 2 µs pulses every 2 ms. Multiple transverse modes are visible in the Figure owing to the large mesa area. Fig. 3 shows fibre-coupled emission from the same VCSEL against peak pulse current. The threshold current, I_{th}, was 580 mA (pulsed), corresponding to current density J_{th} of 17 kA/cm^2, or 5.7 kA/cm^2 per QW. Neighbouring VCSELs produced up to 33 µW peak (not shown). This modest power is surprisingly high given the problems outlined above and also the mismatch between the cavity resonance and the actual emission wavelength (gain peak). The VCSEL was held only by a plastic leaf spring to a copper chuck with a thermoelectric cooler; poor thermal contact may have contributed to the need for low temperatures (−10°C).

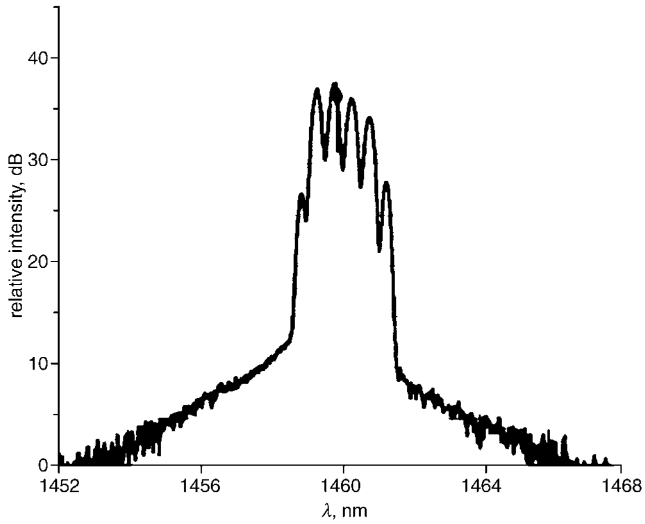

Fig. 2 *Optical spectrum of 86 µm diameter VCSEL at 800 mA, 66 µm oxide aperture, 0.1% pulsed duty cycle, −10°C*

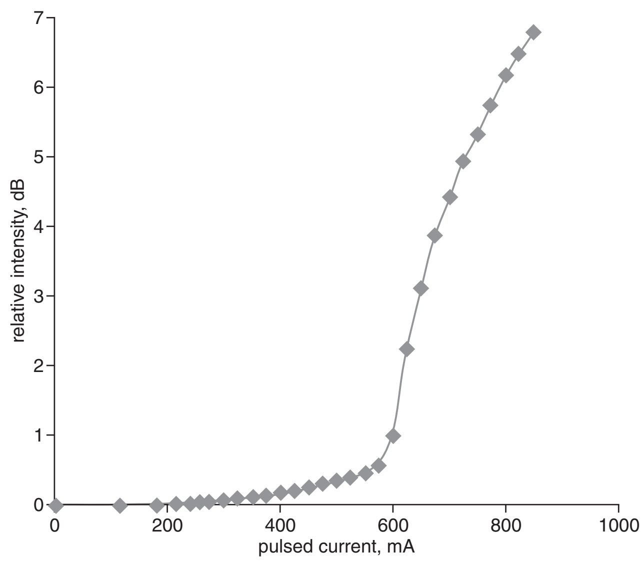

Fig. 3 *L–I curve, same conditions as Fig. 2, showing onset of lasing at 580 mA*

Conclusion: We have shown that GaInNAs(Sb) can be extended beyond 1.45 μm by optimising the nitrogen plasma to minimise ion damage during growth. VCSELs lased at a wavelength of 1.460 μm despite damaged surfaces, rough sidewalls and poor cavity/mirror resonance. The chuck was cooled as low as −10°C, and the VCSELs were electrically pulsed with a duty cycle of 0.1%, with a threshold current of 580 mA (5.7 kA/cm^2/QW). With better processing and thermal mounting, we believe GaInNAsSb VCSELs should be able to reach 1.55 μm with performance comparable to 1.3 μm devices.

Acknowledgments: This work was supported by DARPA Optoelectronics Materials Center, contract MDA972-00-1-0024, DARPA/ARO contract DAAG55-98-1-0437 and ONR contract N00014-01-1-0010, as well as NSF and Stanford graduate fellowships.

16 October 2003
Electronics Letters Online No: 20031139
DOI: 10.1049/el:20031139

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