TWO-SECTION TUNABLE LASER WITH UNIFORM FREQUENCY MODULATION RESPONSE USING QUANTUM CONFINED STARK EFFECT

X. Huang (1), A.J. Seeds (1), J.S. Roberts (2), A. Knight (3)

(1) Department of Electronic & Electrical Engineering, University College London, London WC1E 7JE, UK
(2) EPSRC III-V Semiconductors Facility, University of Sheffield, Sheffield S1 3JD, UK
(3) EPSRC Ion Beam Technology Facility, University of Surrey, Guildford GU2 5XH, UK

Abstract: We report on the first post-growth band-gap engineered, quantum-confined Stark effect (QCSE) tuned two section ridge waveguide laser, having the most uniform frequency modulation response (±3 dB) in the widest modulation bandwidth (30 kHz to 6 GHz) yet reported for QCSE tuned lasers.

Introduction

Tunable semiconductor lasers with uniform frequency modulation (FM) response are key components in microwave over fibre analogue links. Conventional tunable semiconductor lasers which employ current injection to achieve tuning by the carrier induced effect (CIE)/2/, suffer from the intrinsic limitation that thermal tuning mechanisms which are dominant at low modulation frequencies (<1 MHz) have the opposite sign from plasma and band gap filling tuning mechanisms which pre-dominate at higher frequencies, leading to an highly non-uniform FM response/3/. Although very flat FM response over the modulation frequency range 10 kHz to 20 GHz has been achieved by a CIE tuned multi-segment DBR laser/4/, precise adjustment of the bias current to each section is required and poor repeatability from laser to laser, even for lasers from the same laser bar is expected. In contrast, an intrinsically uniform FM response can be obtained by using quantum confined Stark effect (QCSE) in an MQW structure, which provides a comparable refractive index change to CIE/5/ and involves no carrier injection, therefore eliminating thermal effects. In earlier work, we demonstrated the use of QCSE as a semiconductor laser tuning method, using an external cavity configuration/6/. More recently, a twin guide structure laser using QCSE tuning/7/ (FM response uniform within 15 dB from 300 kHz to 4 GHz) and a butt-jointed DBR structure laser tuned by the related Wannier-Stark effect/8/ (no FM uniformity data, cut-off frequency less than 4 GHz) have been reported, both with very complicated fabrication requirements. We report here the first post-epitaxy band gap engineered QCSE tuned two section ridge guide laser, offering the most uniform FM response in the widest modulation bandwidth yet reported for tunable lasers using QCSE tuning mechanism.

Device Fabrication

Fig.1 shows the schematic cross section of the device. The MQW active layer is grown on a (100) Si GaAs substrate by MOVPE in a single epitaxy step and contains 5 quantum wells, a number chosen as a compromise between refractive index change in the tuning section and threshold current in the gain section. Gain and tuning sections share a single cavity optically, but are isolated from each other electrically by a 30 μm wide etched isolation gap in the contact and cladding layers between them.

Fig.1 The cross section schematic diagrams of two-section tunable laser.

In order to reduce tuning section absorption, impurity-free vacancy diffusion technique/10/ was used to blue-shift the band gap of the tuning section by about 10 nm. Wafers were then processed into metal-clad ridge guide lasers, with air-bridges to connect the ridge to the bonding pads. The completed laser was mounted on a microwave sub-mount. The threshold current for a laser having a gain section length of 400 μm and a tuning section length of 200 μm was 35 mA with only the gain section pumped. The measured parasitic capacitance of this laser was 1 pF at 0 V bias. The mode suppression ratio (MSR) was better than 20 dB at pumping currents greater than 2 Ith. Continuous tuning of 22.5 GHz (red shift) was obtained for a change in tuning section reverse bias from 0 V to 1.8 V (12.5 GHz/V). The linewidth, changed only slightly, from 8 MHz at 0 V to 12 MHz at 1.8 V reverse bias, due to the loss of the band gap shifted tuning section.

Results and Discussion

The FM tuning response/3/ was obtained using a Michelson interferometer combined with an 18 GHz bandwidth GaAs photodiode and an HP8753D network analyser. A 50 Ω shunt resistance was used to terminate the microstrip line feeding the tuning section. Sinusoidal RF drive at ~5 dBm power level was fed to the tuning section via a bias-tee. The tuning section was operated at 0.4 V reverse bias, to ensure that the tuning section is remained reverse biased throughout the modulation cycle. Fig.2 shows the FM sensitivity of the laser as a function of modulation frequency from 30 kHz to 6 GHz. It is seen the FM response is uniform within ±3 dB up to 6 GHz, and the FM phase response is uniform and in phase with the RF signal showing that, there is only one
dominant mechanism responsible for optical frequency shift, that is the QCSE tuning. Due to the band gap detuning, the lasing wavelength is located at the red side of the exciton peak of the tuning section. Consequently, the refractive index change at the lasing wavelength increases with increasing electric field change, resulting in a red shift with increasing reverse bias, in agreement with the measured results.

Fig. 2: FM response of QCSE tuned laser.

The residual intensity modulation (IM) has also been measured. For 4.5GHz peak frequency deviation the residual IM index is 0.05 at a modulation frequency of 100kHz. The IM response is uniform within ±2dB from 30kHz to 6GHz, with a photo-electron resonance peak at about 3GHz. Comparing these results with our earlier work[1], where the band gap of the tuning section was not shifted, the FM sensitivity was 20GHz/V (500μm laser with 200μm tuning section length) and 4GHz peak frequency deviation gave an IM index of 0.05, the residual IM per unit bias applied is improved by a factor of 1.8 (from 0.25V to 0.14V), indicating the success of band gap engineering in reducing the tuning section absorption loss. However, the residual IM index improvement per unit frequency deviation is improved less, from 0.013/GHz to 0.011/GHz, or by a factor of 1.13. This is expected as although absorption change, Δα, decreases with increasing wavelength de-tuning, it increases with increasing electric field change[12,13]. The refractive index change, Δn, is smaller per unit electric field change for a blue-shifted tuning section, resulting in lower FM sensitivity, larger electric field change is therefore needed to produce the same frequency deviation.

The uniform FM response of the QCSE tuned laser is found being independent to gain section pumping current. It is therefore convenient to control laser output power independently. The uniform FM response is also found highly repeatable from laser to laser, demonstrating the intrinsic uniform FM response nature of QCSE tuned laser.

The present laser has a junction width of 24μm and 1pF parasitic capacitance, leading to a calculated ~3dB cut-off frequency of 6.4GHz in a 50Ω system. Using special low parasitic capacitance fabrication techniques, a RC limited bandwidth of ~40 GHz can be achieved[14]. The ultimate limit to tuning speed arises from the round trip delay effect in the laser cavity[7].

Conclusion

We have shown the successful use of a QCSE tuning section integrated in an MQW ridge guide laser giving the most uniform FM response yet reported (±3dB from 30kHz to 6GHz) for a QCSE tuned laser. The use of band gap blue shift on the tuning section reduces the residual absorption loss. Using also air-bridged contact technique, the widest modulation frequency bandwidth for a QCSE tuned laser, from 30kHz to 6GHz has been achieved. Due to the intrinsic uniform FM response is reproducible and independent on laser output power, QCSE tuned lasers for optical communication windows based on InP material system are expected.

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References