BAND-GAP ENGINEERED, QCSE TUNED LASER WITH UNIFORM FREQUENCY MODULATION RESPONSE

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Abstract: We report the first post-growth band-gap engineered, quantum-confined Stark effect (QCSE) tuned two section ridge waveguide laser, having the widest and most uniform frequency modulation bandwidth (30kHz to 6GHz, 3dB) yet reported for field effect 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 (<10 MHz) have the opposite sign from plasma and band 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 10kHz to 20GHz has been achieved for a CIE tuned DFB laser/4, precise adjustment of the bias current is required and the FM sensitivity is bias current dependent. In contrast, an intrinsically uniform and repeatable FM response can be obtained using the quantum confined Stark effect (QCSE) in an MQW structure, which provides a comparable refractive index change to CIE/5 and involves no carrier injection, thereby eliminating thermal effects. In earlier work, we demonstrated the use of QCSE as a semiconductor laser tuning method, using an external cavity configuration/6,7/. More recently, a twin guide structure laser using QCSE tuning/8 (FM response uniform within 15dB from 300kHz to 4GHz) and a butt-jointed DBR structure laser tuned by the related Wannier-Stark effect/9 (no FM uniformity data, cut-off frequency less than 4GHz) 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 over the widest modulation bandwidth yet reported for tunable lasers using field effect tuning mechanisms.

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 to optimise the relationship between modal gain, threshold current in the gain section and refractive index change in the tuning 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.

Results and Discussion

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

![Fig. 2: FM response of QCSE tuned laser for gain section pumping currents 73 and 85mA.](image)

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 photon-electron resonance peak at about 3GHz.

Comparing these results with our earlier work[11], where the band gap of the tuning section was not shifted, giving an FM sensitivity of 20GHz/V (500μm laser with 200μm tuning section length) and an IM index of 0.05 for 4GHz peak frequency deviation, the residual IM index 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 less, from 0.013GHz to 0.011GHz, or by a factor of 1.13. This is expected as although absorption change, Δα, in the tuning section decreases with increasing bandgap blue-shift, it increases with increasing electric field change, ΔE, The refractive index change per unit electric field change, Δn, however, decreases with increasing bandgap blue-shift, resulting in a lower FM sensitivity. A larger electric field change is therefore needed to produce the same frequency deviation, offsetting the reduced Δn.

The FM response of the QCSE tuned laser is found to be independent of gain section pumping current, as shown in Fig.2, in contrast to that for CIE tuned lasers[3,4]. It is therefore possible to control the laser output power independently of tuning response. All lasers characterised displayed FM response uniformity within ±3dB over the frequency range 30kHz to 6GHz, illustrating the high reproducibility obtainable from the QCSE tuning mechanism.

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, an RC limited bandwidth of ~40 GHz can be achieved[13]. The ultimate limit to tuning speed arises from the round trip delay effect in the laser cavity[7], and is 20GHz for the laser described here.

**Conclusion**

We have shown the successful use of a QCSE tuning section integrated in an MQW ridge guide laser to give the widest and most uniform FM response yet reported for a field effect tuned laser (30kHz to 6GHz within ±3dB). The use of bandgap blue shift for the tuning section reduces the residual absorption loss. The FM response of the QCSE tuned laser is intrinsically uniform, rather than relying on an exact ratio between thermal and carrier density effects as in CIE tuning, leading to a reproducible response which is independent of laser output power. QCSE tuned lasers for the second and third optical communication windows based on the InP materials system could be realised using similar techniques.

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**References**