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MQW Tuned Semiconductor Lasers With Uniform Frequency Response

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Abstract—**A tunable semiconductor laser with an intrinsically wideband uniform frequency response has been developed, using the quantum confined Stark effect in quantum well material as the tuning mechanism. A frequency response uniform within 3 dB from 20 kHz to 1.2 GHz was achieved, limited by the measuring system at low frequencies and by device capacitance at high frequencies. Analysis shows that with optimised tuning elements an uniform frequency response to over 50 GHz should be achievable with this technique.**

I. INTRODUCTION

ELECTRONICALLY tunable semiconductor lasers are key components in all-optical networks [1], microwave analogue transmission systems [2] and optical frequency synthesisers [3]. Most previously reported devices achieve tuning by changing the current injection or its spatial distribution within the laser cavity [4]. The complex interaction of thermal and carrier density effects tends to give a highly non-uniform tuning frequency response, although Ogita et al [4] were able to achieve a −3 dB bandwidth of 100 kHz to 15 GHz by critical current adjustment in a multi-section DFB laser.

We describe an alternative tuning technique using the quantum confined Stark effect (QCSE) in quantum well (QW) material; this offers an intrinsically wideband uniform frequency response with single terminal control.

II. LASER DESIGN

The change in absorption spectrum of QW material with applied electric field leads to a corresponding change in refractive index through the Kramers-Kronig relations. If the QW material is placed within a reverse biased PIN structure the field can be applied without significant current flow (other than any photo-current), thus eliminating current induced thermal effects. Using this principle Wakita et al [5] have realised a phase modulator with an uniform frequency response to 10 GHz, limited by junction capacitance. We have previously reported an external cavity laser tuned by a normal incidence, reverse biased QW structure [6]. By modifying this design to give continuous tuning the tuning frequency response can be explored.

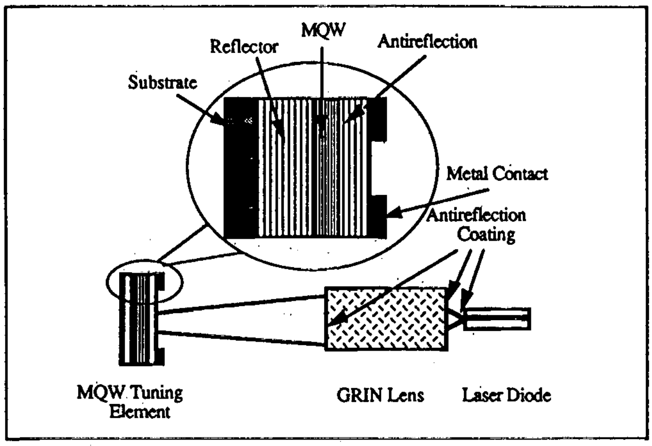

Fig. 1. MQW-tuned Semiconductor Laser Setup.

Fig. 1 shows the experimental system. A 300 μm long GaAs/AlGaAs CSP laser diode (Hitachi HLP 1400) was used as the laser gain section. One of the laser diode facets was antireflection coated with a single quarter wavelength SiO layer to reduce the *Q* factor of the laser diode internal cavity modes. The output from this facet was coupled into the tuning element through a GRIN lens of 0.29 pitch to form an external cavity laser of optical resonator length 15 mm. Due to coupled cavity effects [6], the residual reflectivity of the AR coated facet (0.1 to 0.5%) gives a measured side mode suppression ratio better than 20 dB for external cavity modes and 30 dB for internal laser modes. The laser diode and MQW tuning element were temperature controlled independently and their positions were aligned with PZT devices.

The tuning element was a PIN type device with three sections: the *P* doped Bragg reflector section used 12 pairs of 692 Å AlAs/594 Å $Al_{0.2}Ga_{0.8}As$ layers to give 95% power reflection; the intrinsic MQW section comprised 75 pairs of 60 Å $Al_{0.3}Ga_{0.7}As$ barriers and 52 Å GaAs wells, giving a maximum refractive index change of 3%; the *N* doped antireflection section used 3 1/2 pairs of 692 Å AlAs/587 Å $Al_{0.17}Ga_{0.83}As$ layers giving a 15 nm wide antireflection band with residual reflection of the device front surface less than 1%. The whole structure was grown using atmospheric pressure MOVPE and the conventional reagents of trimethylgallium, trimethylaluminium and arsine. Mesa type tuning elements of area 120 μm × 190 μm with 50 μm × 50 μm windows were fabricated from this material using conventional processing techniques.

With 5 V reverse bias change on the MQW PIN tuning element, a continuous tuning range of more than 2 GHz

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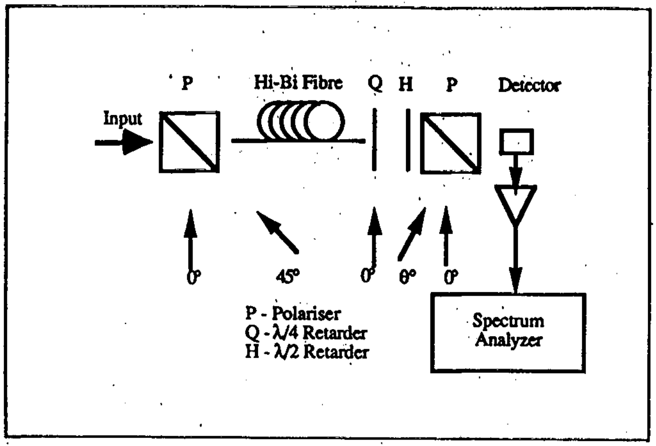

Fig. 2. Hi-Bi Fibre Optical frequency Discriminator FM Measurement System.

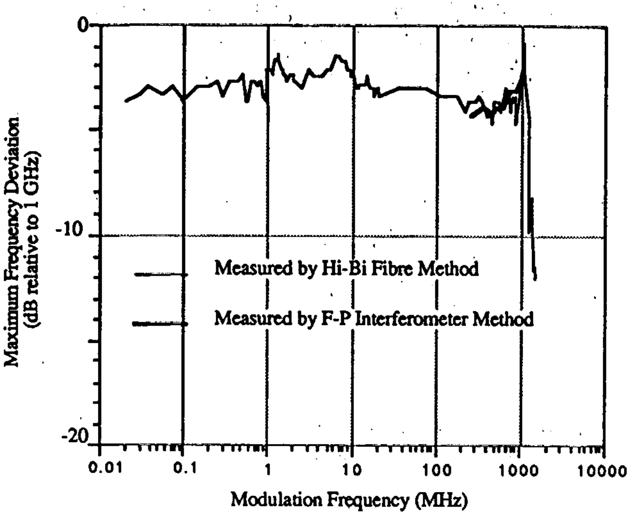

Fig. 3. Frequency Response of MQW-tuned Semiconductor Laser.

was achieved. Good linearity and about 0.3 dB output power change was maintained within a tuning range of 1.5 GHz. The tuning range could be increased by either reducing the external cavity length or increasing the thickness of the MQW section in the tuning element. As the tuning range achieved was sufficiently large for observation, no special effort was made to achieve larger tuning range.

Measured with a delayed self homodyne system, the laser was found to have a linewidth of less than 100 kHz at the output wavelength of 828 nm.

III. FM RESPONSE MEASUREMENT

The frequency response of the MQW tuned laser was measured using the Hi-Bi fibre optical frequency discriminator shown in Fig. 2. An optical waveplate phase shifter, consisting of a rotatable half-wavelength retarder and a quarter-wavelength retarder, was introduced to replace the traditional birefringent crystal compensator [7]. By rotating the half-wavelength retarder a differential phase shift from 0 to π can conveniently be introduced to optimise frequency-amplitude conversion sensitivity with minimum disturbance to system alignment. The measurements covered high (20 to 1500 MHz), low (2 to 20 MHz) and very low (10 kHz to 2 MHz) modulation frequency ranges using a maximum frequency deviation of 500 MHz. The measured results are combined and plotted in Fig. 3. In order to verify the results, the FM frequency response from 300 MHz to 1500 MHz was also measured by analysing optical modulation sidebands using a high resolution Fabry-Perot interferometer and the results are superimposed on Fig. 3 for comparison. The two sets of results show very good agreement.

The measured results show an uniform frequency response within 3 dB from 20 kHz up to 1.2 GHz and verify the elimination of thermal effects which dominate the low frequency response for the carrier injection tuning technique. The high frequency limit was not caused by the QCSE tuning mechanism itself, but by the capacitance of the device used. By using low parasitic fabrication techniques the tuning element response could be extended to above 20 GHz [8]. However, the tuning speed of a laser is also limited by laser resonator round-trip time effects. When the modulation is applied to the laser resonator non-uniformly, it takes finite time to equilibrate the energy change caused. Derived from Siegmann's theory [9], for a tunable laser with total resonator optical length l_0 and tuning section optical length l_t, the round-trip time effect on the FM frequency response is given by

$$\frac{\Delta\omega_f}{\Delta\omega_0} = \frac{sinc(\omega_m l_t/c)}{sinc(\omega_m l_o/c)}$$

where c is the velocity of light in vacuo, $\Delta\omega_f$ and $\Delta\omega_0$ are the maximum frequency deviations at modulation frequency ω_m and at low frequencies respectively. For our laser system this limits the 3 dB bandwidth to 6 GHz. However, by integrating the tuning and gain sections monolithically this limit could be raised to in excess of 50 GHz.

IV. CONCLUSION

Following our first demonstration of an MQW-tuned semiconductor laser based on the QCSE tuning technique [6], we have reported the first continuously tuned system based on the same technique. Measurements of FM frequency response of such a system were carried out with a Hi-Bi fibre optical frequency discriminator and modulation sideband analysis using a high resolution scanning Fabry-Perot interferometer. The constructed system was also used as a transmitter in a demonstration wideband analogue optical FM link which showed an uniform frequency response within its 1 GHz bandwidth [2]. The results show clearly the absence of the thermal tuning effect which is dominant at low frequencies for current injection tuning. The upper frequency limit was caused by the tuning element capacitance and package parasitics rather than by the tuning mechanism itself, and it should be possible to extend the response into the millimetre-wave region. As the material system is highly compatible with that for semiconductor lasers, the technique can also be used in integrated tunable semiconductor lasers. The wavelength localised nature of the refractive index change due to QCSE is likely to restrict the application of the technique to narrow wavelength range tuning. However, modifications to the quantum well structure could overcome this limitation substantially [10].

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