Reverse bias tuned multiple quantum well ridge guide laser with uniform frequency modulation response

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We report a multiple quantum well ridge guide laser tuned by the quantum confined Stark effect. In contrast to carrier-induced effect tuned lasers, the frequency modulation response of our laser is highly uniform (±0.7 dB) over the frequency range from 10 kHz to 100 MHz, and within ±2.5 dB from 5 kHz to 500 MHz, with the upper frequency parasitic capacitance limited. We predict that the response could be extended to over 20 GHz by using a low parasitic contacting structure.

Semiconductor lasers with uniform frequency modulation (FM) response are key components of frequency shift keyed optical communication systems, optical phase lock loops, and microwave optoelectronic systems. Conventional tunable semiconductor lasers employ current injection to achieve tuning by the carrier-induced effect (CIE). Whilst this is a convenient method, it suffers from the intrinsic limitation that thermal tuning mechanisms which dominate at low modulation frequencies (<10 MHz) have the opposite sign from plasma and band gap narrowing tuning mechanisms which predominate at higher frequencies, leading to a highly nonuniform FM response. Although a more uniform FM response can be achieved using the multisection distributed feedback approach, great care has to be taken in setting the currents in the different sections to flatten the response. In contrast, an intrinsically uniform FM response can be obtained by using field induced effects in the tuning section. Field effects in significantly reverse biased multiple quantum well (MQW) structures can offer response times in the picosecond region. Since there is no current injection, the only source of thermal heating in the device is the photocurrent variation with reverse bias. As the photocurrent and its variation with bias can be made very small, the thermal effect becomes negligible, yielding a uniform FM response. The large refractive index change introduced by the quantum confined Stark effect (QCSE) in a MQW structure with applied electric field is especially useful as a tuning mechanism. In earlier work, we demonstrated the use of QCSE as a semiconductor laser tuning method, using an external cavity configuration. More recently, a twin guide structure laser using QCSE tuning and a butt-jointed structure laser tuned by the related Wannier–Stark effect have been reported, both with very complicated fabrication requirements. In this letter, we present results on QCSE tuning of a monolithically integrated two section MQW ridge guide laser, offering much simpler fabrication requirements and suitable for applications where a uniform FM response over a limited tuning range is required.

Figure 1 shows the schematic cross section of the device. For demonstration of the QCSE tuning performance we use a simple Fabry–Perot ridge guide structure fabricated in the GaAs/AlGaAs material system. Gain and tuning sections share a single cavity optically, but are isolated from each other electrically by cap layer etching to allow a reverse bias to be applied to the tuning section. The device structure is grown on a (100) N⁺GaAs substrate by metalorganic vapor phase epitaxy with a separate confinement heterostructure containing five quantum wells, the number being chosen as a compromise between index change in the tuning section and threshold current in the gain section. The As and Zn, and the n-dopant Si. Wafers are processed into metal-clad ridge guide lasers, with Zn/Au/Ag/Au and NiGeAu/Au/Ag/Au as the p and n-contact metalization, respectively. The ridge is of width 5 μm and height 1.4 μm, with the GaAs contact layer between the gain and tuning sections removed. The laser was mounted p-side up on a gold plated copper heat sink. The cw threshold current, Ith, for devices having a gain section length of 300 μm and tuning section length of 200 μm is 20 mA with only the gain section pumped. The lasers exhibit single mode operation with mode suppression ratio (MSR) better than 20 dB from 1.355μm up to 2.1Ith. Using the etched isolation technique, 25 kΩ intersection resistance was achieved. However, due to the high carrier density in the gain section, significant diffusion leakage to the tuning section occurs. Our measurements show a gradual increase of the leakage current, Ileak, from the tuning section when increasing the gain section pumping current, Ig, with a sharp increase beyond lasing threshold,

FIG. 1. Schematic structure of the two-section tunable laser.
indicating that carrier diffusion and photocurrent both contribute to \( I_f \). At the normal operating point, \( I_f = 27 \) mA, \( I_f \) varies from 2 to 2.5 mA and MSR from 23 to 17 dB as the tuning section voltage, \( V_t \), is varied from 0 to −1 V.

Static tuning measurements showed that as \( V_t \) is varied from 0 to −0.6 V, continuous tuning with constant slope 20 GHz/V is achieved. At constant output power, a discontinuous tuning range of 600 GHz (1.41 nm) and continuous tuning over the mode space of 60 GHz were obtained. The FM tuning response\(^ {14} \) was determined from the modulated spectrum observed on a high resolution Fabry–Perot interferometer (Burleigh HiFase). Figure 2 shows the tuning response as a function of modulation frequency, over the frequency range 10 kHz to 100 MHz in which thermal effects are typically seen for CIE tuned lasers.\(^ {5,14} \) The response is seen to be uniform within ±0.7 dB over this range. Over the extended modulation frequency range from 5 kHz to 500 MHz, the measured modulation response is uniform within ±2.5 dB. During measurements, the MSR was monitored by an optical spectrum analyzer (HP 70951A), and remained within the range 23 to 20 dB. The residual intensity modulation over the modulation frequency range 5 kHz to 500 MHz is less than 5% for a peak frequency deviation of 4 GHz. For the same device the FM response using CIE tuning applied to the tuning section was measured over the frequency range 5 kHz to 100 MHz. The frequency deviation ranged from 1.7 GHz/mA at 5 kHz to 0.3 GHz/mA at 50 MHz, a variation of over 14 dB. Using CIE tuning, Kobayashi\(^ {5} \) reported measured FM responses on channeled-substrate planar (CSP), transverse-junction-ridge (TJS) and buried heterostructure (BH) lasers. Over the frequency range 10 kHz to 100 MHz, the peak deviations varied from 2 GHz/mA (CSP, p-side down mounting), 4 GHz/mA (TJS, p-side up mounting), and 5 GHz/mA (BH, p-side up mounting) at a modulation frequency of 10 kHz to 250 MHz/mA, 750 MHz/mA and 85 MHz/mA at 50 MHz modulation frequency, respectively, variations ranging from 14 to 35 dB. In contrast, our QCSE tuned laser exhibits an FM response variation of <1.4 dB over the same frequency range. The high frequency roll-off in the response of our device is caused by the 30 pF parasitic capacitance of the oxide isolated large area p contact bonding pad. By using an air-bridged structure on a semi-insulating substrate this parasitic capacitance can be reduced by a factor of 100 to give a cut-off frequency of over 20 GHz. Using special low parasitic capacitance fabrication techniques, a resistance-capacitance limited bandwidth exceeding 40 GHz can be achieved.\(^ {15} \) The ultimate limit to tuning speed arises from the round trip delay effect in the laser cavity.\(^ {16,11} \) For a tuning section optical length \( L_t \) and total cavity optical length \( L \), the relative response at modulation frequency \( \omega \) due to the round trip effect is given by

\[
\Delta f(\omega) = \frac{\text{sinc}(\omega L_t/c)}{\text{sinc}(\omega L/c)},
\]

giving a +3 dB modulation frequency limit of 22 GHz for our 500 μm long laser with 200 μm tuning section length.

We have shown that the use of a QCSE tuning section integrated in a MQW laser gives a highly uniform FM response free of thermal effects. The technique described could readily be applied to lasers in the InP/InGaAsP system for operation at 1550 nm wavelength, although wide range tuning would probably require the combined use of CIE and QCSE because of the wavelength localized nature of QCSE.\(^ {9} \)

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