Measurement of linewidth enhancement factor in self-assembled quantum dot semiconductor lasers emitting at 1310 nm

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Measurements of the linewidth enhancement factor (also termed the α-parameter) for quantum dot semiconductor lasers emitting at 1310 nm in both single and multiple transverse modes are presented. Values between 1.5 and 3.0 were measured depending on the device length. In addition, its spectral dependence within the inhomogeneously broadened ground and excited state is investigated.

Introduction: Research into self-assembled quantum dot semiconductor lasers has intensified recently as many groups demonstrate the advantages of these structures over their quantum well counterparts. These include low temperature sensitivity [1], improved spatial coherence [2] and reduced sensitivity to feedback [3], as well as extending current GaAs technology into the communications band [4]. The linewidth enhancement factor, also termed the α-factor, is a key parameter in semiconductor lasers [5], determining the spatial coherence, the modulation-induced chirp and the sensitivity to external optical feedback. It is usually defined as

$$\alpha = -\frac{\partial\chi'/\partial N}{\partial\chi''/\partial N} = -2k_0\frac{dn/dN}{dg/dN} \qquad (1)$$

where χ' and χ'' are the real and imaginary parts of the electric susceptibility, respectively, N is the injected carrier density, k_0 is the free space wave number, n is the refractive index of the laser and g is the gain per unit length [6]. Typical values for quantum well lasers are around 2–3 although strain engineering has been shown to reduce it to $\simeq$0.5 [7, 8]. For communication band quantum well devices the α-factor is usually higher although α as low as 0.1 has been measured in GaAs-based quantum dot devices emitting around 1220 nm [6]. A recent value of 0.7 has been demonstrated in a quantum dot structure at 1057 nm [9]. In this Letter we report measurements of α for quantum dot, separate confinement heterostructures around 1310 nm against cavity length. As short devices require higher carrier densities to achieve lasing, we can measure α near saturation of the ground state gain. Longer devices were used to measure α near the transparency carrier density. Measurements were performed just below lasing threshold on 1 mm-long, ridge waveguide and broad stripe lasers yielding typical values of $\simeq$3. However, for longer devices ($\simeq$2 mm) this value reduces substantially to 1.5, indicating an increase of the alpha-factor with carrier density. This dependency presents opportunities to design novel telecommunications devices as, for example, lasers could be coated HR-HR in order to operate at low carrier density with a low chirp and low sensitivity to optical feedback [3, 10].

Experiment: The self-organised quantum dot active region heterostructure consisted of six InAs QD layers embedded in quantum well using DWELL technology (see [10] for further details). Both broad stripe (35 μm wide) gain guided and ridge waveguide (3–5 μm wide) index guided lasers were fabricated with lengths of 1, 1.5 and 2 mm. These devices were mounted *p*-side up on Peltier controlled copper heatsinks. Devices were operated at room temperature in pulsed mode (100 ns) to avoid self-heating effects. In addition, the duty cycle was carefully adjusted to further ensure no heating occurred while maintaining adequate levels of light. The duty cycles used ranged from 1% at very low currents to 0.02% at higher currents where the heat generated per pulse increased. The gain and refractive index shift measurements follow the technique presented in [6], i.e. gain measured using the Hakki-Paoli method [11] and refractive index change by measuring the frequency shift of the Fabry-Perot resonances. Light from the laser was coupled into a singlemode fibre (after an optical isolator) and its spectrum recorded on an Ando AQ6317b spectrum analyser (0.015 nm resolution). In the case of the broad stripe lasers, the singlemode fibre ensured measurement in a narrow range of transverse wave-vectors and avoids errors in the gain calculation, as discussed in [12].

Results: Graphs of wavelength shift against gain are shown in Fig. 1 for the broad area lasers and in Fig. 2 for the ridge waveguide devices. In each case, almost linear behaviour is observed. However, the corresponding value of α depends strongly on the length of the device. For broad area and ridge waveguide lasers of length 1 and 1.5 mm, α-factors in the range of 3–2.4 were measured. However, the longer devices of length 2 mm gave a much lower value of 1.5. Thus, by designing devices of different lengths, we were able to measure the alpha parameter for different gains, i.e. shorter devices reach threshold at higher gain. A longer device allowed us to analyse the alpha parameter near transparency carrier density due to increased luminescence. We also note that shorter devices operated near the gain saturation level and thus had a low differential gain compared with the longer lasers.

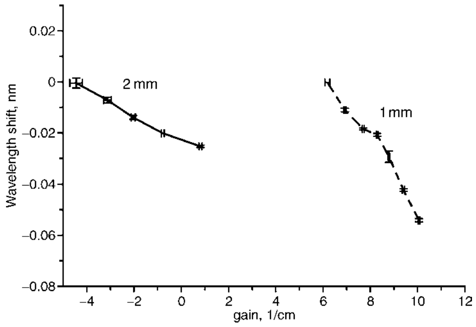

Fig. 1 *Fabry-Perot peak resonance shift against gain for broad area lasers of length 2 and 1 mm*

Note reduced wavelength blue-shift in longer device which corresponds to α-factor of 1.5. This contrasts with value of 3 for shorter device.

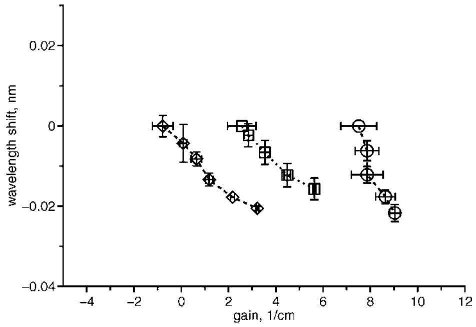

Fig. 2 *Fabry-Perot peak resonance shift against gain for ridge waveguide lasers of length 2 mm (diamonds), 1.5 mm (boxes) and 1.0 mm (circles)*

α-factors in each case are 1.5, 2.4, 2.4, in good agreement with broad area lasers. Note, however, increased size of error boxes resulting from reduced subthreshold luminescence available for coupling into fibre.

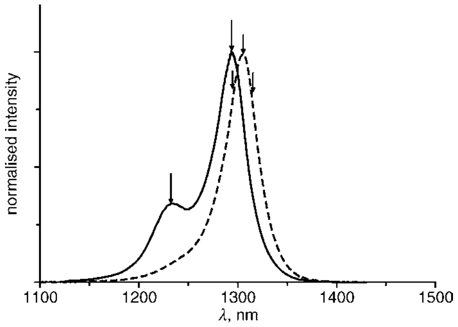

Fig. 3 *Broadband optical spectra, characteristic of 2 and 1 mm-long devices just below threshold with arrows to illustrate where α-factor measured*

Note that Fabry-Perot resonances not visible due to reduced resolution of spectrum analyser.

We also determined the effect of detuning from the gain peak by measuring α for detunings of ±7 nm, as shown in Fig. 3. Unlike quantum well lasers, measurement at both high and low energy sides did not result in a change of α. This may be associated with the inhomogeneous broadening as dots of different size have different resonance frequencies and, as a result, the alpha-factor is almost constant across the spectrum in the ground state. The value of α at the first excited state was also measured for the 1 mm-long devices, where the onset of gain saturation at ground state energies results in measurable gain at the first excited states (see Fig. 3). At the gain peak for the first excited state, α was reduced to 1 while remaining at 3 for the ground state. It is important to note that the difference in these values comes primarily from the differential gain, which is reduced due to the onset of gain saturation in the ground states.

Discussion: The linewidth enhancement factor (α) for self-assembled quantum dot lasers emitting at 1300 nm has been measured for a variety of device parameters. An important result is the measured length dependence of the quantity, where the value reduces from 3 to 1 when the length is increased from 1 to 2 mm. This result should have important consequences for the design of high brightness laser structures. In addition, the variation of α on operating wavelength was investigated and found to remain constant within the ground-state inhomogeneous linewidth. However, the first excited state displayed a much lower value of 1, due primarily to an increased differential gain. These results are important for the development of quantum dot based, broad gain block devices, where the device properties should not vary over wide ranges of tuning and temperature.

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