

Tuning Superluminescent Diode Characteristics for Optical Coherence Tomography Systems by Utilising a Multi-Contact Device Incorporating Chirped Quantum Dots

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Abstract – Multi-contact chirped quantum dot superluminescent diodes are characterized with regard to key parameters for image quality in optical coherence tomography systems. By independently tuning power and spectral shape, the penetration depth and resolution are decoupled.

I. INTRODUCTION

There is currently significant interest in developing broadband high power light sources for use in medical imaging applications, such as optical coherence tomography (OCT). For OCT imaging of human tissue, one of the wavelengths of interest is 1050 nm associated with zero dispersion in aqueous tissue, (e.g., the eye).¹

Quantum dots (QDs) have a naturally broad gain spectrum due to their inhomogeneous distribution of dot sizes. In addition, the ground state is saturable at low currents, and by introducing a variation in emission wavelength (i.e. “chirp”) in different dot layers, a strong overlap of the GS and excited state can be achieved.² However, for single contact QD superluminescent diodes (SLEDs) the simultaneous realization of high power and a single, smooth Gaussian emission has not yet been reported.

In this paper we present a novel multi-contact superluminescent diode utilising chirped QD structures where the power and bandwidth may be tuned independently. From the power spectrum of the device the modulus of the interferogram and the system’s point spread function is calculated providing insight into the suitability of the device for OCT imaging.

II. SAMPLE DESIGN & PREPARATION

Figure 1(a) shows photoluminescence (PL) spectra from test samples where the position, d , of InAs QDs was varied within a 5nm GaAs QW, with $\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$ barriers. The inset schematically shows the structure. A $\sim 30\text{nm}$ shift in the emission peak is observed, indicating that growth of structures where this dimension is varied for each QD layer is a useful technique for tailoring emission wavelengths.

The two samples studied were grown on a Si doped (100) GaAs substrate in a molecular beam epitaxy reactor. The structure consists of a $1.5\ \mu\text{m}$ $\text{Al}_{0.4}\text{Ga}_{0.6}\text{As}$ n -cladding layer, a $475\ \text{nm}$ $\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$ optical waveguide, a $1.5\ \mu\text{m}$ $\text{Al}_{0.4}\text{Ga}_{0.6}\text{As}$ p -cladding layer, and a $300\ \text{nm}$ GaAs p -doped contact layer. Two different layer schemes were employed for the active region. The “unchirped” sample consisted of 3 QD layers with $d=2.5\text{nm}$. The “chirped” sample has 4

QD layers where the layers are alternated between $d=1\text{nm}$ and $d=4\text{nm}$. For both samples the QWs are separated by 7nm of $\text{Al}_{0.15}\text{Ga}_{0.85}\text{As}$. Fig 1(b) shows the absorption spectra for the samples.³ The unchirped sample has clearly resolved ground and excited state absorption peaks while the chirped sample has strongly overlapping ground and excited states, producing a single broad peak at $1050\ \text{nm}$. The inset to Fig. 2 shows schematically the active region layer structure for the two samples.

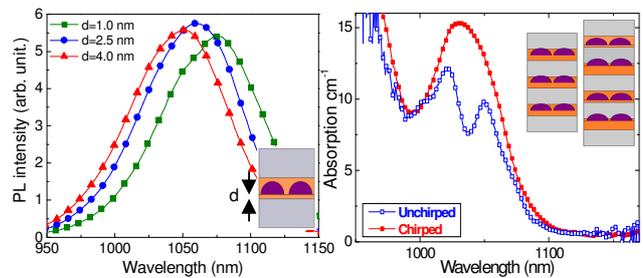


Figure 1 (a) PL as a function of position of InAs QDs within a GaAs QW, (b) absorption spectrum for unchirped and chirped samples measured using the multi-contact devices. Inset shows QD positions within QW.

The multi-contact SLED is $\sim 10\ \text{mm}$ long with electrically isolated $1\ \text{mm}$ sections and features a large tapered absorber with tilted, deep v -etched facet towards the back. The output facet is either normal to the cleave plane or at a 6° tilt due to a curved section of waveguide, shown as an inset to Fig 2.

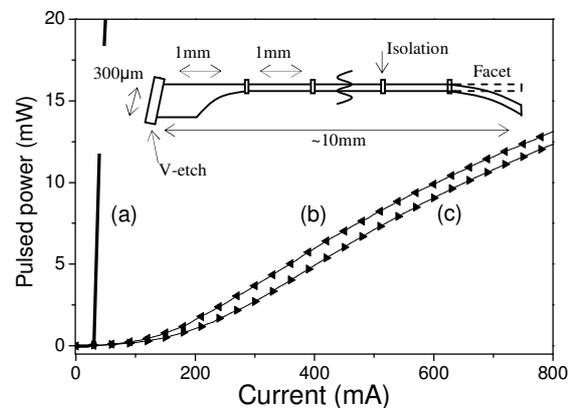


Figure 2. LI characteristics of (a) laser (b) straight facet SLED and (c) tilted facet SLED. Inset shows the device design schematically.

III. RESULTS AND DISCUSSION

Light-current characterization in Fig. 2 indicates that the combination of tapered absorber section and v-groove back facet effectively inhibit lasing at all applied currents. Furthermore, the curved front section and angled facet results in good single mode emission at all currents (not shown here), whereas for the straight waveguide an increase in far-field is observed at high currents.

The electro-luminescence (EL) spectra of the chirped sample, pumped uniformly across the front three sections with currents from 0 to 100 mA per section, are shown in Fig. 3 as solid lines. The balance of the ground and excited states occurs at a CW drive current of ~ 40 mA with low power output (~ 0.2 mW ex-facet) though at higher drive currents higher powers are obtained at the expense of bandwidth and with the peak now centred on the excited state emission. This demonstrates the problem with achieving simultaneous high powers and high bandwidth in a single contact device. Also plotted in Fig 3 are a series of emission spectra at various combinations of drive geometry, depicted schematically. By adding more ground state emission and optimising the drive current in each section, the balance of the ground and excited state was achieved at more than twice the output power of the single contact device. Also, the peak of the emission, which had shifted towards 1000 nm, was brought back to almost exactly 1050 nm, the required operating wavelength. The spectral shape obtained was a single Gaussian, with an integrated CW output power of ~ 1.2 mW.

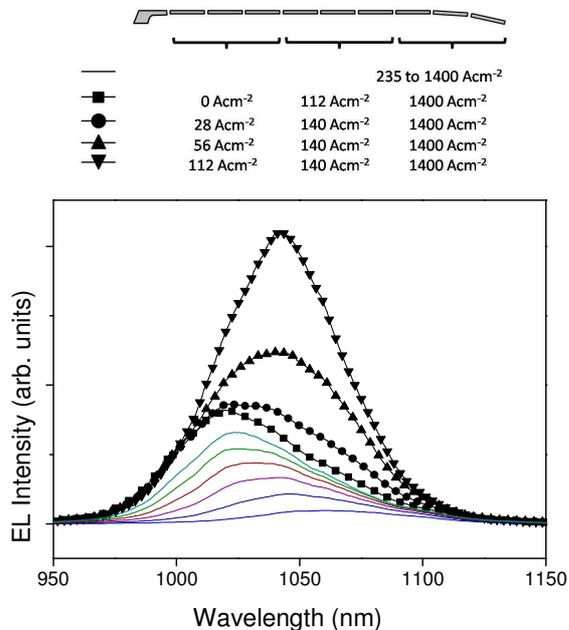


Figure 3. CW EL spectra for the chirped device. Schematic above shows the multi-contact device drive geometry.

Broad bandwidth SLEDs improve the axial resolution in OCT by narrowing the point spread function (PSF) which

is the Fourier Transform of the emission spectrum¹. Smooth PSFs with low side lobes will generate cleaner images. The PSF calculated from the emission spectrum is plotted in the inset of Fig. 4. The side-lobes for the unchirped single contact device are 6dB higher than for the chirped multi-section device. Both PSFs are smooth and noise free with FWHM of 15 μ m and 11 μ m for the chirped and unchirped devices respectively. The FWHM is related to the axial resolution of the OCT system. If the spectra were assumed to be Gaussian, the axial resolution would be half the FWHM. The additional output power (6 fold increase), centred on the at 1050 nm, and reduced PSF side-lobes with similar resolution demonstrates that the multi-section SLEDs incorporating chirped QDs have an output spectral shape which may be tailored to optimise the PSF and hence OCT image quality.

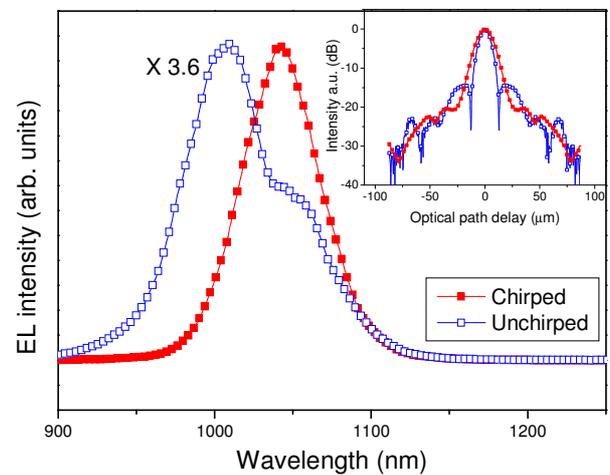


Figure 4. (a) Normalised CW EL spectra for unchirped and multi-contact chirped devices at current densities described in the text. (b) Calculated PSF of the best EL emission spectra recorded for unchirped and multi-contact chirped.

IV. CONCLUSIONS

A novel multi-section SLED utilising chirped QDs has been described. The emission power and spectral shape of this device have been shown to be tuned independently allowing the optimisation of expected OCT system performance.

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