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Integrated Amplifier for Gain Spectra Measurement of Bilayer Quantum Dot Laser Material

H.Shahid[1], D.T.D. Childs[1], M. A. Majid[1], K. Kennedy[1], R. Airey[1], R. A. Hogg[1], E. Clarke[2], P. Spencer[2], and R. Murray[2]

[1] Dept. of Electronic & Electrical Engineering, The University of Sheffield, Centre for Nanoscience & Technology, North Campus, Broad Lane, Sheffield, S3 7HQ, United Kingdom.
Phone: Tel: +44-(0)114-2225168 E-mail: H.Shahid@sheffield.ac.uk

[2]Physics Department, Imperial College, Blackett Laboratory, Prince Consort Road, London SW7 2AZ, UK

1. Introduction

Quantum dots (QD) devices are an area of ever increasing interest owing to their current commercial applications in biomedical imaging [1], mode-locking applications [2], and optical communications due to their low cost, and temperature insensitive threshold current density [3,4]. Key to semiconductor laser performance, device physics and engineering is an understanding of the spectral gain-current relationship. One of the most commonly used techniques for gain measurement is the segmented contact method [5]. Here unguided spontaneous emission is eliminated through the use of external spatial mode filters. A modification of this method was demonstrated by Xin *et al.* where the device's waveguide was used as a mode filter [6]. In this paper we report the use of the gain material as an integrated amplifier and demonstrate an enhancement to the measurement of the gain spectrum in terms of the spectral region which may be accurately measured, and also in the measurement of the gain spectrum at very low current densities where the active material is operating in loss, which is of importance for materials such as quantum dots.

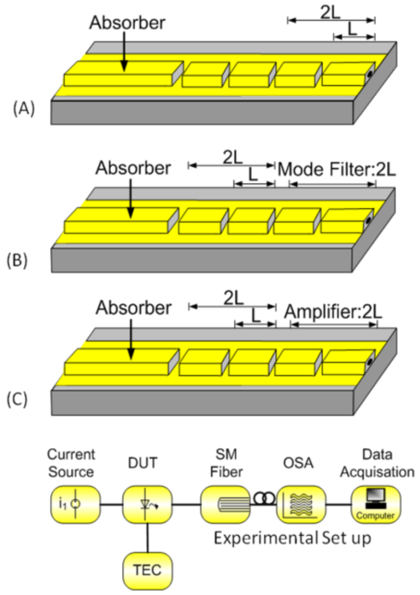

Figure 1. Schematic of the different device drive geometries and experimental setup.

2. Device Structure

A bilayer InAs/GaAs quantum dot laser material was used for the gain comparison [7].The two coupled (electronically and strain) QD layers in the case of a bilayer device allow the independent control of density (first "seed" layer), and emission wavelength (second QD layer). Each of the two QD layers may be grown under different conditions, with strain interaction from the smaller QDs in the seed layer fixing the QD density in the larger QDs of the second layer.

3. Experiment

A schematic of the device geometries we discuss is shown in Figure 1. In geometry A, driving sections of length L and 2L allow the gain spectrum to be derived [5]. Here, for simplicity we neglect the use of external mode filters, as shown in the schematic at the bottom of the Fig. 1. Configuration B shows the case where two un-pumped sections of the waveguide are used as an integrated mode-filter. By setting these sections to a suitably high current density where optical gain is achieved (1.42 $kAcm^{-2}$), the experiment may be repeated in geometry C with the integrated amplifier acting to both amplify the electroluminescence intensity and act as a mode filter. Figure 2 plots the spontaneous emission spectrum at 14 Acm^{-2} and the gain spectrum at 1.42 $kAcm^{-2}$ and highlights the advantages of using the amplifier section. The gain spectrum can only be determined at wavelengths over which there is spontaneous emission, with this region eroded in the case of the waveguide operating in loss. The use of the amplifier section acts to enhance the signal to noise at a given wavelength, and also to increase the spectral range over which the gain can be deduced. Comparison of the three measurement schemes is shown in Figure 3. To long wavelength all three techniques show essentially identical results for the shape and magnitude of the gain from the ensemble of quantum dot ground-states.

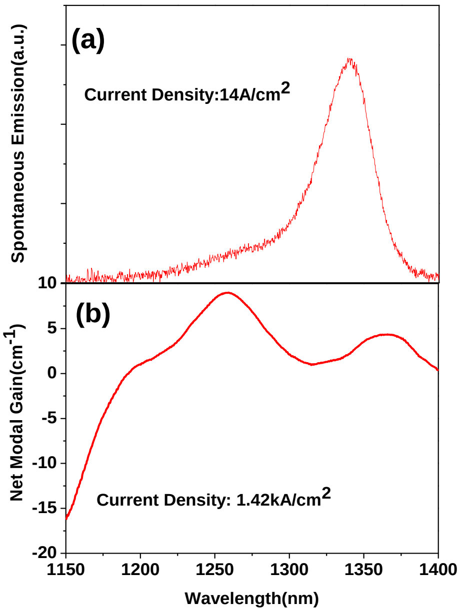

Figure 2. (a) Spontaneous emission spectrum at 14Acm^{-2} and (b) Gain spectrum at 1.42kAcm^{-2}.

To shorter wavelengths the schemes utilizing the integrated mode-filter and amplifier are co-incident suggesting that unguided spontaneous emission is present in scheme A. (We do not use any external mode filters). For the unpumped mode-filter reliable gain measurements are possible only over a limited spectral range.

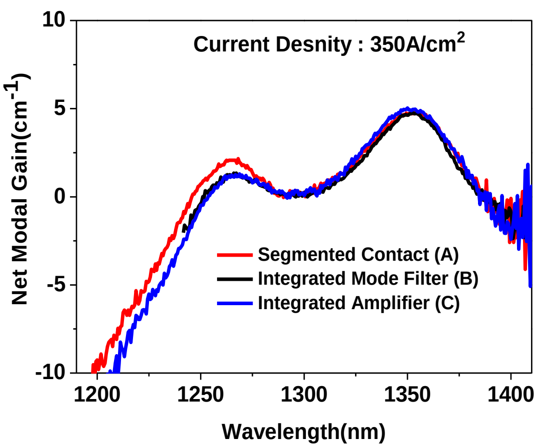

Figure 3. Gain spectra obtained utilizing schemes A, B, and C.

We find that using the integrated amplifier results in gain spectra measurements over wider spectral ranges and to lower current densities under identical acquisition conditions, making it a valuable tool in characterizing gain material such as quantum dots. Figure 4 shows the room temperature gain spectra as a function of current density obtained using this technique.

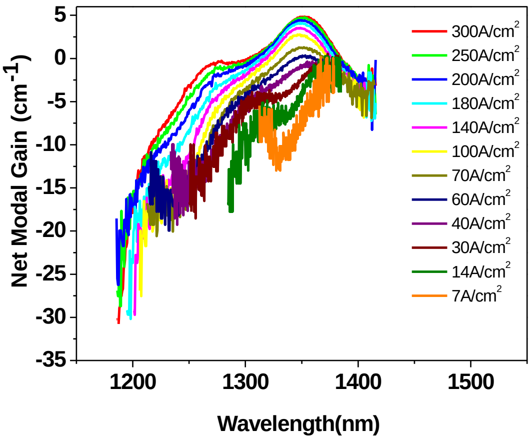

Figure 4. Gain spectra as a function of current utilizing the integrated amplifier.

4. Conclusion

A comparison of gain spectrum measurement techniques utilising segmented contact devices is made. The use of an amplifier is shown to provide integrated mode-filtering and also extends the spectral region over which the gain spectrum can be measured. This is particularly valuable for low current densities where the material is operating in loss.

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