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InP based 1.55 μm quantum dot materials and lasers for ultra-narrow linewidth applications

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A review will be given about the recent progress of quantum dot (QD) material for the 1.55 μm wavelength range and their potential application for complex light sources dedicated for future high-capacity coherent optical communication systems.

1. Introduction

In the last few years the modal gain in 1.3 and 1.55 μm QD laser material could be strongly improved [1-6]. With these improvement new record values in the digital modulation speed in 1.3 μm [3] and 1.55 μm [7, 8] could be obtained. Beside the direct modulation, which is mainly used in datacom or local area networks, a different type of light source is needed for ultra-high capacity optical networks based on coherent communication, which is used as a wavelength reference. A possible implementation is a narrow linewidth, widely tunable single mode laser.

QD material has a great potential to address several issues for such a high performance light source. For example, according to [9] the linewidth of a laser is given by

$$\Delta\nu = \frac{\Gamma R'_{sp}}{4\pi N_P}\left(1+\alpha^2\right) \qquad (1)$$

with Γ as confinement factor, R'_{sp} as spontaneous coupling factor, N_P as photon density and α as linewidth enhancement factor defined as

$$\alpha = -\frac{4\pi}{\lambda}\frac{dn/dN}{dg/dN} \qquad (2)$$

with λ as emission wavelength, n as static effective refractive index, g as modal gain and N as carrier density.

In QD laser, depending on the operation condition, the α-factor can be very low. As a consequence, ultra-narrow linewidths are expected, which is indicated by first results [10]. However, beside the narrow linewidth, also a wide wavelength tuning range has to be implemented, which can be very limited in conventional temperature tuned distributed feedback (DFB) lasers due to the large mismatch of the temperature dependence of the refractive index and the maximum gain. QD material can be designed to address this issue as well. This paper will give a review on the recent progress of 1.55 μm QD laser materials and their potential to realize high-performance local oscillators.

2. QD laser materials and characteristics

The laser materials reported here consist of 1 – 3 QD layers and are grown by solid source molecular beam epitaxy using As_2 growth mode [11]. The laser design is schematically shown in Fig. 1.

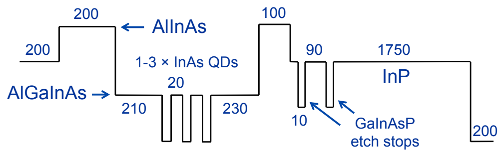

Fig. 1 Schematic of the layer design of QD lasers.

The photoluminescence spectrum of QD ensembles shows a rather low linewidth of < 25 meV, which indicates a low QD size fluctuation (see Fig. 2). The inset of Fig. 2 show a high density of circular shaped QDs with a QD density of about 6×10^{10} cm^{-2}.

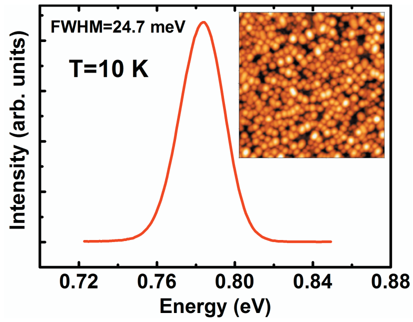

Fig. 2 PL spectrum of QD layers. The inset show an 1 x 1 μm^2 atomic force microscope image of a similar QD test sample [12].

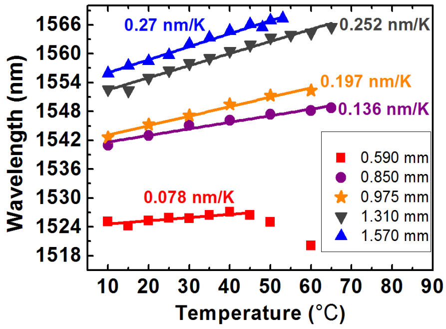

Fig. 3 Wavelength of broad area QD lasers with 2 QD layers as function of the heat sink temperature for different cavity lengths showing different temperature coefficients as indicated [12].

From those materials 100 μm wide broad area lasers were processed and evaluated with different cavity lengths. Record values of the modal gain could be evaluated with 15 – 17 cm^{-1} per QD layer [12]. By tailoring the dot geometry (dot density, dot size, size fluctuations) the balance between loss (e.g., given by mirror losses) and gain can be influenced and the wavelength shift with temperature can be widely changed from 0.55 nm/K (QW laser) down to nearly zero (see Fig. 3).

3. DFB laser fabrication and characteristics

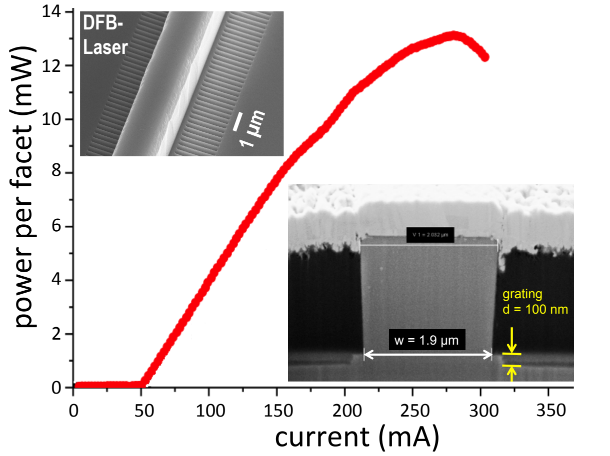

Fig. 4 Light output characteristic of a QD DFB laser. The insets show an SEM top view of the etched grating before planarization and a focused ion beam cross-cut.

From laser material with 3 QD layers DFB laser diodes are processed as shown in the insets of Fig. 4 based on 1[st] order lateral index gratings. More than 10 mW output power per facet can be obtained for mounted devices with a cavity length of about 1 mm. The emission wavelength can be tuned by temperature over a wide range. In Fig. 5, the spectra are shown for different injection currents, which demonstrates a stable wavelength tuning over 3.6 nm caused by internal heating.

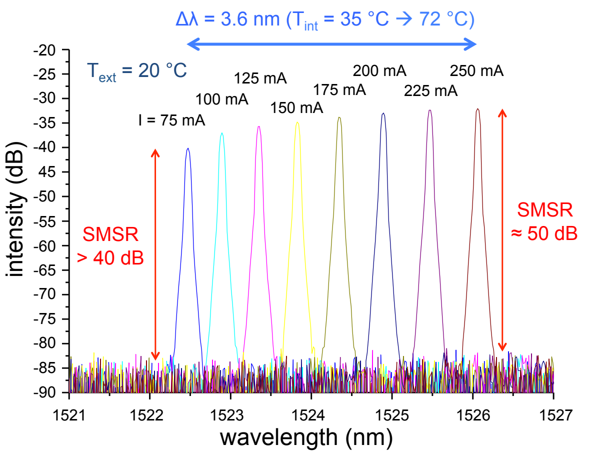

Fig. 5 Emission wavelength tuning of a QD laser by internal current heating. The total wavelength shift and corresponding temperature variation of the active zone are indicated above.

First linewidth measurements on such devices, using a delayed heterodyne interferometer with an electrical spectrum analyzer as illustrated in the inset of Fig. 6, indicates a significant linewidth reduction. In Fig. 6, the Lorentz part of the total linewidth, which are deduced by fitting a Voigt function, are plotted against the injection current. As expected from equation (1), the linewidth reduces with increasing photon density, although the $1/N_P$ dependence is not fully quantitatively reproduced.

4. Conclusions

High performance QD laser material was developed and DFB lasers processed, which show stable wavelength tuning properties and indicate narrow emission linewidths.

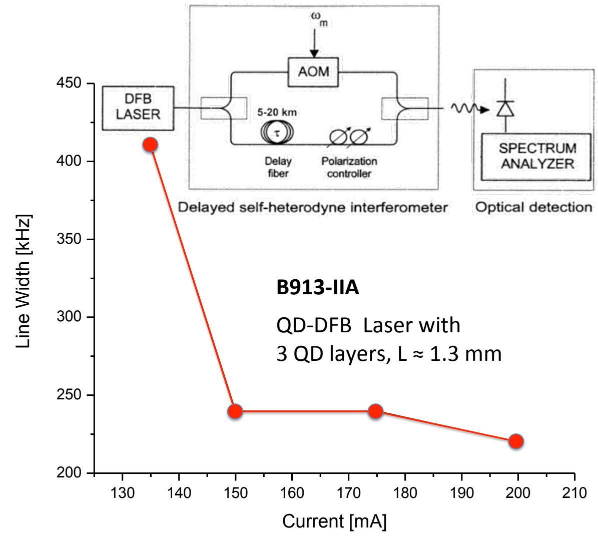

Fig. 6 Linewidth of QD laser measured by delayed heterodyne interferometer (see schematics above).

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