Failure of the current modulation driven linewidth broadening factor for analyzing the optical linewidth behavior of quantum dot lasers

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Narrow linewidth lasers can be engineered with self-assembled quantum dots (QD) as gain media. Owing to the tight carrier confinement and the low inversion factor, optical linewidths of a few hundreds of kHz can be obtained [1]. The optical linewidths of semiconductor lasers are often in the megahertz range and strongly increased above the Schawlow–Townes limit because of the linewidth broadening factor (α_H-factor) [2]. For quantum well lasers the α_H-factors measured below- and above-threshold are relatively uniform. However, in the particular case of QD lasers, which exhibit a strong coupling between the energy levels, the dispersion is wider. Near-zero α_H-factors are classically measured below-threshold (amplified spontaneous emission i.e. ASE) while above, values up to 60 are encountered (modulation technique i.e. FM/AM) [3]. In this work, we show that QD lasers can simultaneously exhibit a narrow optical linewidth (low α_H-factor from the optical linewidth), while producing a much larger frequency chirp (high current α_H-factor from the FM/AM). In other words, as far as the phase noise characterization is concerned, the well-established FM/AM method does not apply anymore for QD lasers.

The studied device is an InAs/InP QD distributed feedback (DFB) laser. The QD active region grown by CBE on a n-type InP(100) substrate consisted of 5 InAs dot layers with 1.15Q InGaAsP barriers and cladding for a total core thickness of 350 nm. The dots are about 1.6 nm in height and 50 nm in lateral extension, with an areal density of approximately 4×10^{10} cm^{-2} per layer. Fig. 1(a) shows an atomic force microscopic image of one dot layer. The cavity of the QD DFB laser is 1 mm with a 3-μm wide ridge waveguide, and the facets are AR/HR coated. Fig. 1(b) depicts the light-current characteristics of the laser at 298K, the threshold current is at I_{th} ~ 46 mA; the inset shows the optical spectra measured at $2 \times I_{th}$ (black marker), the ground state (GS) lasing wavelength is at 1520 nm. In Fig. 2(a), red markers indicate the α_H-factor measured from the FM/AM. Large values from ~7 to 8 are unveiled when normalized biased current is varied from 1.3 × to $2.8 \times I_{th}$. As opposed to that, the α_H-factor measured from the ASE (green marker) reveals a small value close to 1. Fig. 2(b) now depicts the optical linewidth measured with a self-heterodyne interferometer and retrieved from a Voigt profile [4]. At $1.9 \times I_{th}$, the QD laser exhibits an ultra-low optical linewidth of 160 kHz. Taking an inversion factor close to the unity leads to a α_H-factor below 1 [2], which is closer to the ASE value. The FM/AM method reflects most likely a current modulation driven α_H-factor, since the carrier fluctuations are perturbed by the current modulation while other methods show that QD lasers perturbed by the optical noise exhibits a smaller α_H-factor. This conclusion is valid for QD lasers in which the α_H-factor is strongly dependent on the energy separation between the resonant GS and off-resonant states [5]. To sum, the FM/AM method overestimates the α_H-factor and its application is limited when characterization of the phase noise is required such as in coherent communication systems.

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Figures

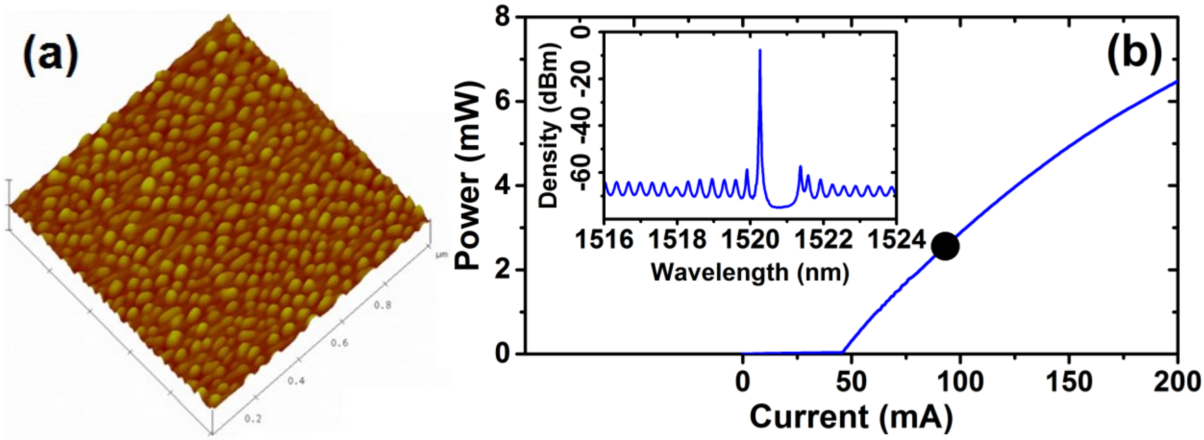

Fig. 1. (a) atomic-force microscopy image of one QD layer (1 µm × 1 µm); (b) light-current characteristic of the QD DFB laser, the inset presents the optical spectrum at 2 × I_{th} (black marker).

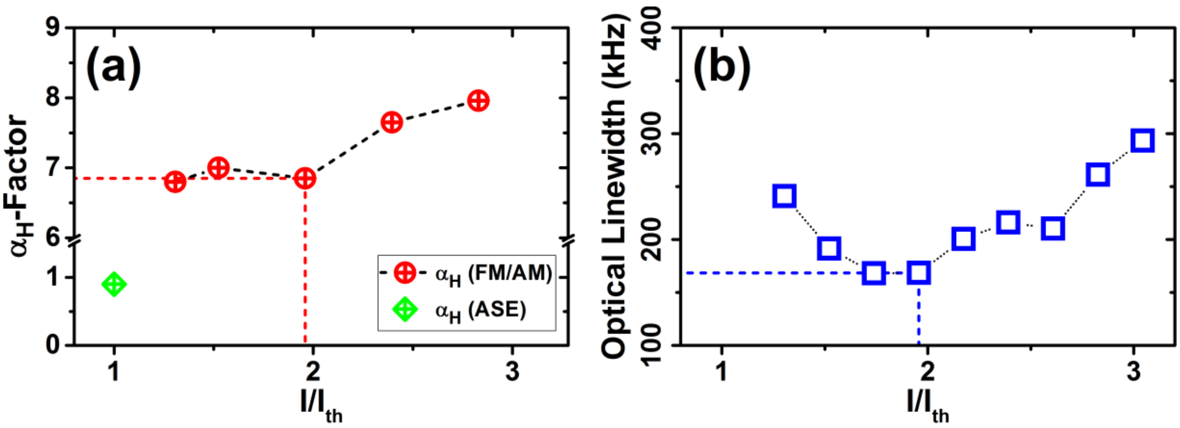

Fig. 2. (a) The measured α_H-factor and optical linewidth of the QD DFB laser as a function of the bias current, red markers: by FM/AM method; green markers: by ASE method. (b) Optical linewidth fitted with a Voigt profile. Around 1.9 × I_{th}, the α_H-factor is measured at 6.8 (red dashed lines in (a)) while a linewidth of 160 kHz has been measured (blue dashed lines in (b)).