Linewidth enhancement factor of a type-II quantum-cascade laser

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Abstract: We measured directly the optical gain, refractive index change, and the linewidth enhancement factor of a type-II quantum-cascade laser. We obtained very low linewidth enhancement factor of 0.8 near threshold.
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Mid-Infrared (IR) semiconductor laser covering the wavelength range of 3-4 μm attracts many applications for both military and civilian purpose such as IR countermeasures, chemical sensing, and free space communication [1]. Currently, type-II quantum-cascade (QC) laser has been demonstrated to operate up to 325 K in pulse mode and 200 K in continuous wave mode [2]. The linewidth enhancement factor (α_e) plays an important role in determining the spectral linewidth of semiconductor lasers. To date, α_e is only determined for a W-shape type-II superlattice structure using differential transmission and Kramers-Kronig transformation method [3]. In this paper we report a direct measurement of the α_e factor of a type-II QC laser by measuring the gain and refractive index change from the amplified spontaneous emission spectrum (ASE) of a type-II QC laser.

The structure of the laser is similar to the one described in Ref. 2. During the experiment, the QC laser sample with a cavity length of 1 mm is operated in a liquid nitrogen cryostat (78K) in continuous wave mode. The radiation from the laser is collimated by an AMTIR-1 lens and directed into the emission port of a BOMEM DA 8 Fourier transform infrared spectrometer. Finally, the beam is focused to a liquid-nitrogen-cooled InSb photodetector. The ASE spectra of the laser are taken with the current varied from 8.6 to 9.6 mA in 0.2 mA step interval, some of which are shown in Fig. 1(a). The net modal gain spectra are then extracted from the ASE data based on the Hakki-Paoli method [4] and the mirror loss as shown in Fig. 1(b). The mirror loss (α_m) of the type-II QC laser is estimated using the group index (~3.273) to be 12.62 cm^{-1} which is closed to the α_m of 11.22 cm^{-1} scaled by the cavity length from Ref. 5 (α_m = 22 cm^{-1} for a cavity length of 0.51 mm).

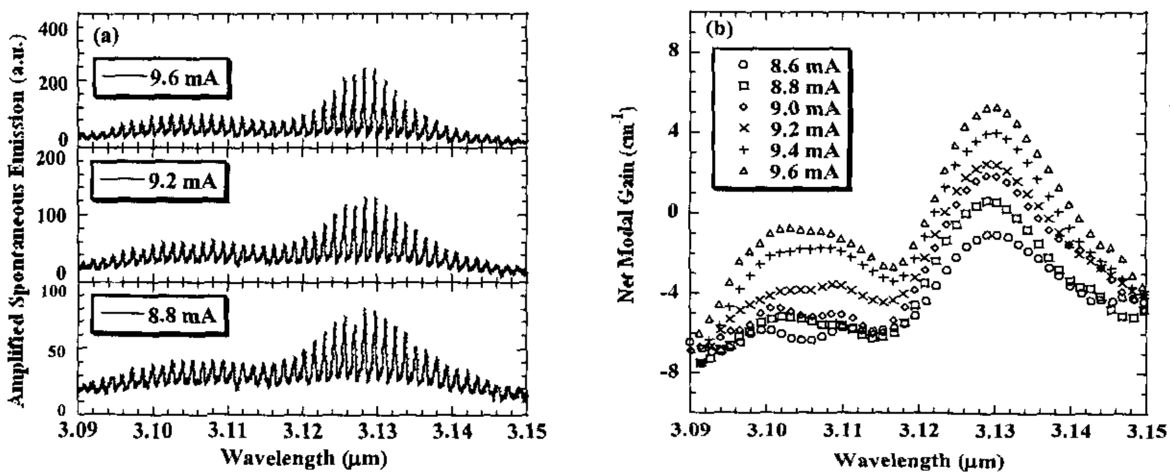

Fig. 1. (a) The amplified spontaneous emission spectrum of a type-II QC laser for different injection currents. (b) The optical gain spectrum extracted from the Hakki-Paoli method.

The differential gain for the 0.2 mA current interval is plotted in Fig 2(a). The differential index with respect to the change in current is obtained from the peak wavelength shift with respect to the increase of the injected current and is found to be approximately -3×10^{-5} as shown in Fig. 2(b). The differential gain and refractive index are then used to extract the linewidth enhancement factor. In Fig. 2(c) the linewidth enhancement factor for a 0.2 mA current interval is plotted as a function of wavelength, where a low value of 0.8 is achieved at the lasing wavelength of 3.13 μm.

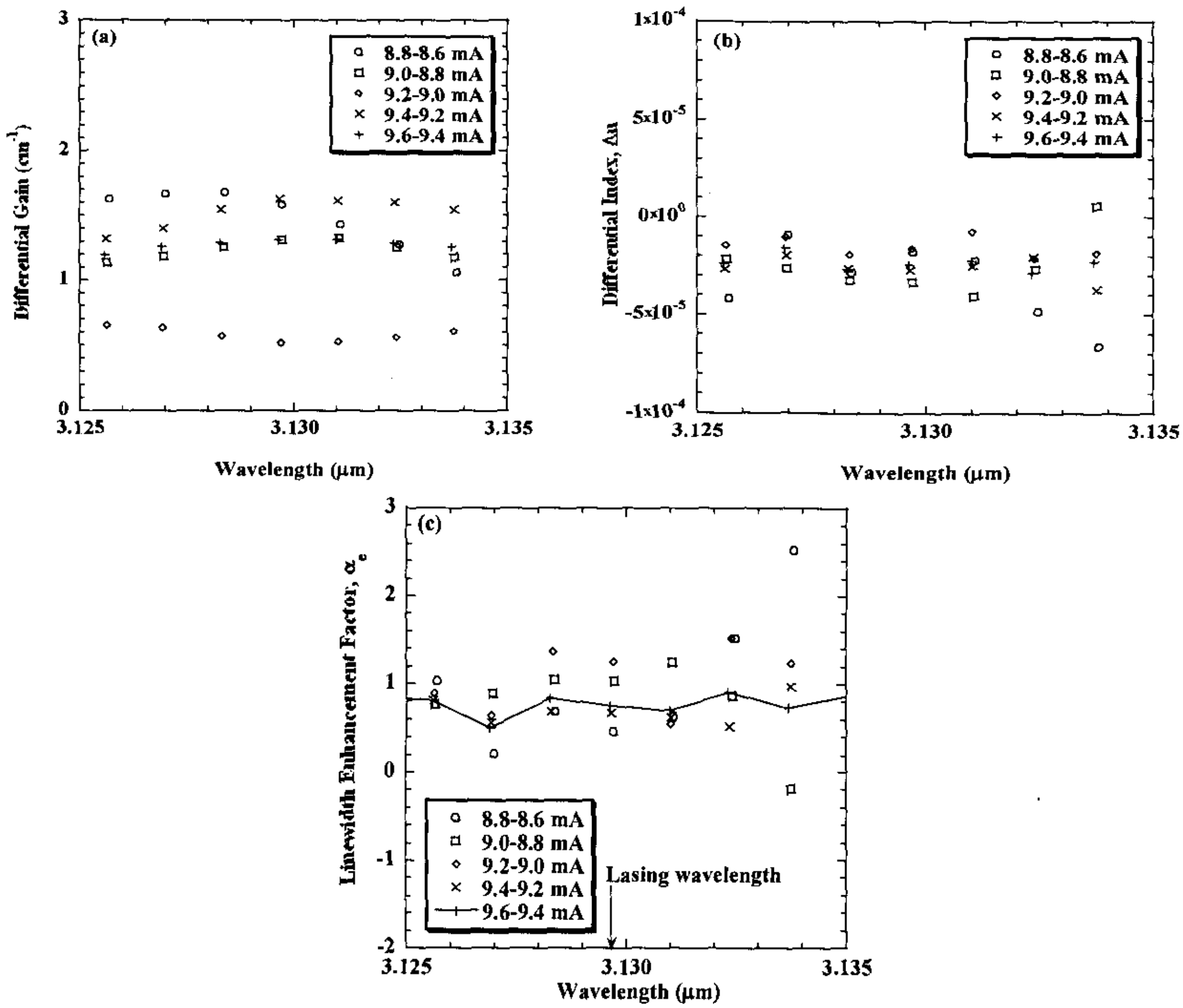

Fig. 2. (a) The differential gain spectra of the 0.2 mA current interval at different current level. (b) The differential index change with a current interval of 0.2 mA extracted from the wavelength shift and the Fabry-Perot spacing. (c) The linwidth enhancement factor (α_e) is calculated from the measured differential index change and the differential gain with a current interval of 0.2 mA at various currents. From the plot, the value of alpha is approximately 0.8 at the lasing wavelength of 3.13 near threshold.

We will also compare the results of type-II QC lasers with those of a type-I QC laser [6] which shows a red wavelength shift resulting in positive refractive index change, therefore, a negative linewidth enhancement factor as opposed to positive linewidth enhancement factor observed in type-II QC laser.

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