Voltage tunability of quantum cascade lasers

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Abstract: The voltage tunability of three types of quantum cascade laser designs is investigated. The tuning coefficients and tuning ranges of electroluminescence and laser emission from all designs are measured and compared with the calculated results. A reduced tunability was observed in all lasers above threshold. This is attributed to the decrease of resistance across the laser active region as the photon density increases. A resumed tunability high above threshold occurs in the lasers with anti-crossed injector ground and upper laser states. Lasers based on the anti-crossed diagonal design are tunable above threshold, with a tuning range of about 30 cm^{-1} (~3% of the laser emission wavenumber), i.e. a tuning rate of 750 cm^{-1} per volt per period of active region and injector.

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1. Introduction

Quantum Cascade (QC) lasers are ideal candidates for infrared spectroscopy because their emission wavelength can be designed in the mid-to-far-infrared range from 2.7 μm to 24 μm [1, 2]. A broad wavelength tuning range is required for lasers in many applications. In the detection of multiple trace-gases or chemical species with interfering absorption features, for example, it is necessary to tune the laser wavelength over a wide range. External cavity QC lasers have wide tuning ranges (100 cm^{-1}-200 cm^{-1}) [2]; yet, they are bulky and usually have a low tuning speed. Distributed feedback (DFB) QC lasers are compact, however, they have very small tuning ranges (less than 4 cm^{-1} for current tuning and no more than 0.1 cm^{-1}/K for temperature tuning) [3].

Voltage tuning of QC lasers based on a strong linear Stark effect [4] in quantum wells is expected to function at a much higher tuning speed than temperature tuning or mechanical tuning. Faist et al. [5] demonstrated a broad tuning range of the intersubband electroluminescence (EL) (over 220cm^{-1}) in a structure based on phonon-assisted tunneling. However, above threshold, the lasers are not tunable. In this paper, we investigated the voltage tunability of the prevailing QC laser designs based on anti-crossed vertical and diagonal transitions, which have the best performance in room temperature continuous wave (CW) operation. We also compare these designs with a sample based on a photon-assisted diagonal transition active region.

2. Experimental results and discussion

The samples studied in this paper are based on three different types of QC laser designs: the anti-crossed vertical design (sample AVQ), the anti-crossed diagonal designs (sample ADQ) and the "super" diagonal design (sample SDQ, based on the photon-assisted tunneling active region). All three samples were processed into 200-μm-diameter circular mesas; for each sample, ridge lasers were also processed for different threshold current densities by changing the widths and lengths of their cavities. All lasers are based on a Fabry-Perot (FP) cavity with as-cleaved facets. The intersubband EL from the mesas was measured at low temperature (80 K) in pulsed mode (100 ns pulse width, 80 kHz) using a Fourier-transform infrared spectrometer (FTIR) with a cooled HgCdTe (MCT) detector. The EL of lasers below threshold as well as laser spectra above threshold were also measured at the same condition.

The peak wavenumbers of EL from all samples are shown in Fig. 1 as functions of the voltage per period of active region and injector as well as the corresponding average electrical field. The tuning range for the 'super' diagonal, anti-crossed diagonal and anti-crossed vertical designs are 190 cm^{-1}, 90 cm^{-1} and 40cm^{-1}, i.e. 12.5%, 9%, and 2% of their EL peak wavenumbers, respectively. The comparison of measured and calculated tuning coefficients shows a large overestimation for designs based on resonant tunneling. This is because the scattering in the quantum wells results in more localized electron probability distributions than calculated from the simple Schrödinger picture.

The lasers are tunable below threshold. However, their tunability is reduced above threshold. For the anti-crossed vertical design, the wavenumbers decrease first and then start to increase again after a certain voltage (0.35V for sample AVQ). For lasers based on the anti-crossed diagonal design, the wavenumbers are almost constant just above threshold, but the tunability approaches that of the EL after the voltage over one period is higher than 0.28V. Lasers based on the "super" diagonal design have almost no tuning above threshold. The reason is that the dramatic increase of light intensity above threshold makes the resistance of the active region decrease. Therefore, the electrical field over the active region does not increase as much as that over the injectors.

A resumed tunability has been observed in the anti-crossed designs. Lasers based on the anti-crossed diagonal transition have a tuning range of about 30 cm^{-1} (3% of the laser emission wavenumber) above threshold, i.e. a tuning coefficient of 750 cm^{-1} per volt per period of active region and injector. We attribute this to the anti-crossing of the ground state in the injector with the upper laser state.

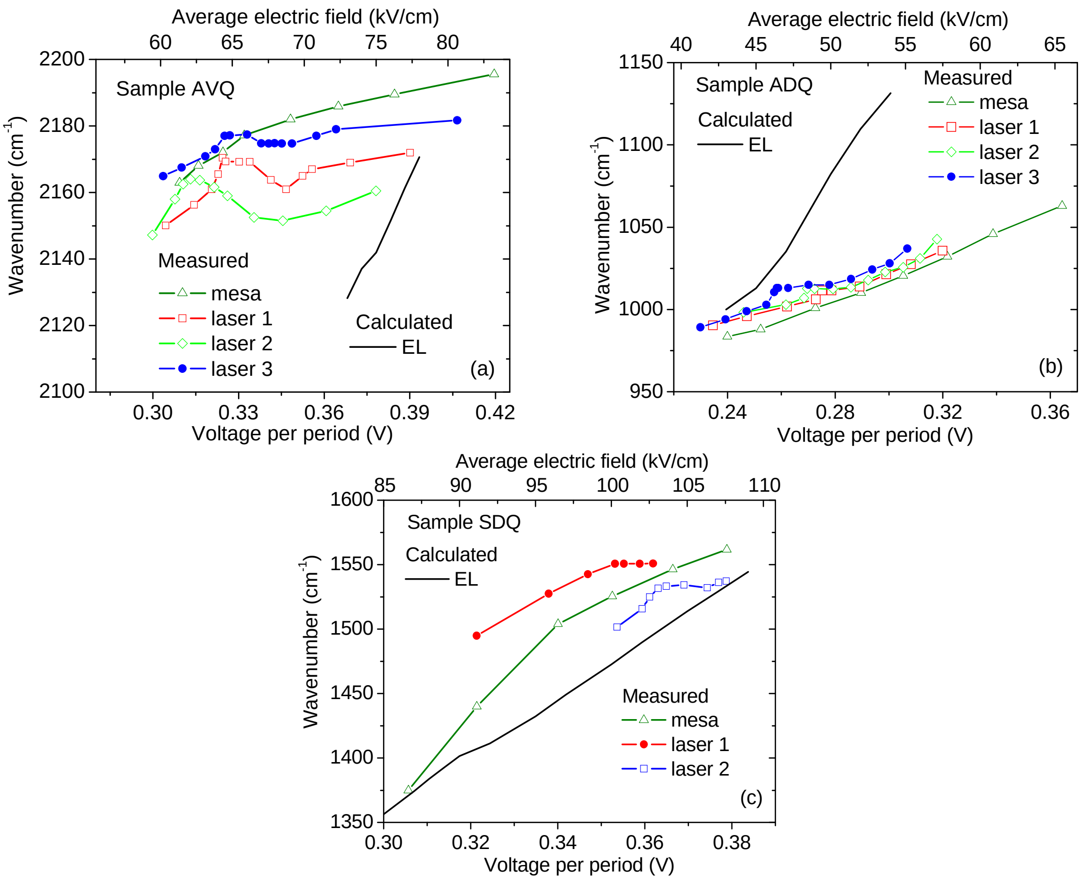

Fig. 1. (a) Anti-crossed vertical design (sample AVQ). (b) Anti-crossed diagonal design (sample ADQ). (c) “Super” diagonal design (sample SDQ). Solid lines: calculated peak EL wavenumbers as a function of the applied electric field. Symbols: measured peak EL and laser emission wavenumbers as functions of the voltage per period of active region and injector (bottom axis), and the average electric field (top axis). All data are measured at 80 K in pulsed mode.

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