Terahertz Quantum Cascade Laser grown by low-pressure metalorganic vapor phase epitaxy

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***Abstract*—A Terahertz Quantum Cascade Laser structure has been grown by low-pressure MOVPE. The laser shows lasing emission at $\lambda = 90$ µm in a single-plasmon waveguide configuration with a threshold current density $J_{th} = 330$ A/cm^2 at 7 K.**

***Index Terms*—Quantum Cascade Lasers, Terahertz, MOVPE**

I. Introduction

Quantum cascade lasers (QCLs) are nowadays one of the most interesting laser source in the mid-infrared spectral range. Its performances have been increasing enormously in the last ten years thanks to the tremendous progress obtained in the epitaxyal growth techniques, achieving lasing emission in continuous wave operation well above room temperature [1-2]. Most of these results were obtained in InGaAs/AlInAs heterostructures grown by molecular beam epitaxy (MBE), a growth technique capable of very high interface quality even in QCL structures incorporating a large (40 or more) number of active periods, as well as state of the art material purity, especially in Al containing alloys.

The drawbacks of this technique are the relatively slow growth rate needed to keep excellent interface quality and surface morphology, and the long system down time due to the ultra high vacuum constraints.

In contrast, Metalorganic Vapour Phase Epitaxy (MOVPE) offers stable high growth rates compatible with a smooth growth front and surface morphology. MOVPE could therefore provide a valuable opportunity to extend the QCL fabrication on an industrial scale. Since the first demonstration of J. S. Roberts and coworkers in 2003 [3], MOVPE growth of mid-IR QCLs has made a tremendous progress achieving performances comparable to the best MBE-grown lasers [4].

However, we are not aware of any report on MOVPE-grown QCLs in the terahertz spectral range, probably because of further daunting challenges for epitaxial growth such as the very large number of active periods involved (over 100), and the demand for low residual background doping and highly accurate intentional doping level in the active region.

In this work we present the first terahertz ($\lambda = 90$ µm) QCL structure grown by low-pressure MOVPE. Its performances are compared with a parent structure grown by solid source MBE and based on the same active design. The vertical uniformity and the lasing characteristics of the QCL are comparable than those of our MBE-grown structure.

II. Results

The laser is designed in the GaAs/$Al_{0.15}Ga_{0.85}As$ material system. The active region is based on a bound-to-continuum design combined with a LO-phonon extraction mechanism, similar to the one published in [5]. The number of active periods is 100 for a total thickness of the grown layer of 13.8 µm.

Our laser was grown on a vicinal (100) GaAs wafer misoriented by 2° towards <110>. The epitaxy was carried out at 20 mb under nitrogen ambient in a commercial horizontal reactor. Trimethylgallium, trimethylaluminum, and arsine were used as the Ga, Al, and As precursors while disilane provided the Si source for n-doping. The growth rate was tuned between 0.139 and 0.556 nm/s. The growth temperature and the V/III ratio were chosen to ensure a low n-type background doping throughout the structure.

In Fig. 1 is shown a series of output light vs. injected current curves recorded at different temperatures, together with an I-V curve recorded at 7 K. These results are obtained from a ridge size 3 mm long and 200 µm wide.

The laser shows lasing action up to 93 K in pulsed regime, and the threshold current density is $J_{th} = 330$ A/cm^2 at 7 K. It is worth noting that the maximum operating temperature observed is 4 degrees higher than what observed in the MBE grown sample based on the same design and constituted of 120 active periods.

Manuscript received August 30, 2007.

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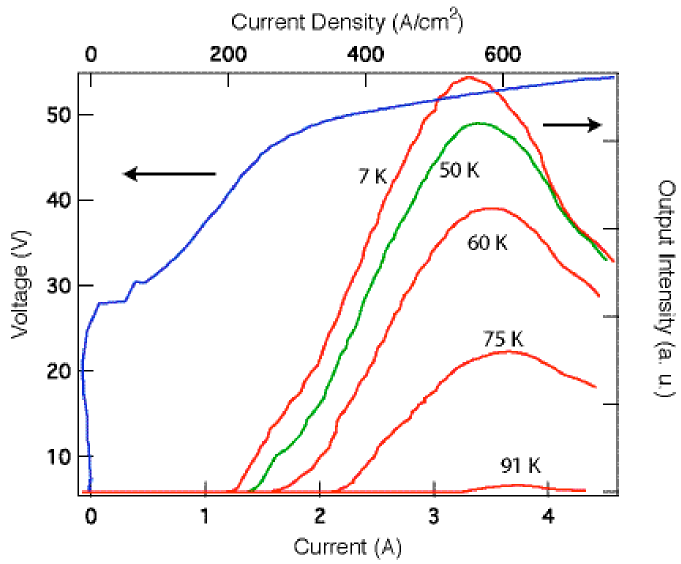

Fig. 1 Output light vs. injected current characteristics recorded at different temperatures, and current-voltage characteristics at 7K for a 3 mm long and 200 μm wide ridge waveguide.

The large operating voltage measured on this sample is probably due to a high top contact resistivity.

The lasing wavelength close to the lasing threshold is λ = 90 μm and a progressive spectral blue-shift is observed as a function of the applied bias due to a Stark shift induced by the slightly diagonal radiative transition (see Fig.2).

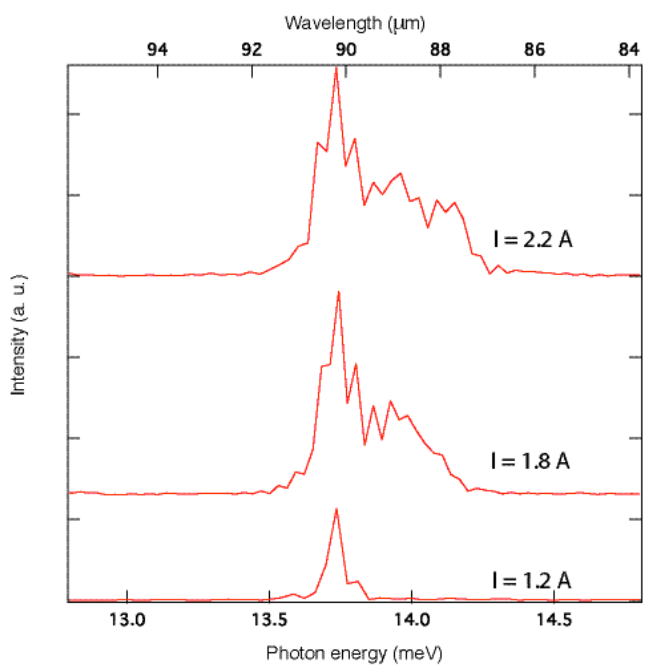

Fig. 2 Spectral evolution of the lasing emission for three bias levels.

The growth characterization, the spectral properties, the power measurements as well as results obtained from shorter cavities will be discussed more in detail.

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