Short wavelength InAs-based QC Lasers

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***Abstract*—We report on recent progress in the development of InAs/AlSb QCLs. The large conduction band offset of this material system allowed the fabrication of the first QCLs emitting below λ=3 µm. Devices operating at high temperature in the whole wavelength range from 3 to 5 µm are presented.**

***Index Terms*—Quantum cascade laser, mid-infrared, InAs, AlSb**

I. Introduction

INP-based QCL is today a dominant technology for mid-IR semiconductor lasers. However, intrinsic material properties — namely, insufficient conduction band offset and lateral valleys position — makes difficult the realization of efficient lasers below λ~4 µm.

For eight years, the shortest wavelength QCL emission was about 3.5 µm [1]. The year 2006 has seen remarkable breakthroughs with three different technologies approaching the wavelength mark of 3 µm: InGaAs/AlAsSb lattice matched on InP at University of Sheffield [2]; strained (Ga)InAs/Al(In)As heterostructures grown on InP at Humboldt University of Berlin [3]; and InAs/AlSb on InAs substrate at University of Montpellier [4]. Here, we present InAs/AlSb devices which push back the short wavelength frontier of QCLs well below 3 µm. We also demonstrate a new generation of InAs/AlSb QCLs operating in the spectral range of 3 to 5 µm with considerably improved performances.

II. Record short wavelength QCL

We reported recently the first QCL below the wavelength of 3 µm [5], with an emission peak of 2.95 µm at cryogenic temperature.

The InAs/AlSb heterostructures were grown on InAs substrates by solid source molecular beam epitaxy. The QCL employed a plasmon enhanced waveguide consisting in heavily doped InAs cladding layers separated from the active zone by short period InAs/AlSb superlattices. The active zone of the devices was based on a vertical transition in three active quantum wells (Fig.1).

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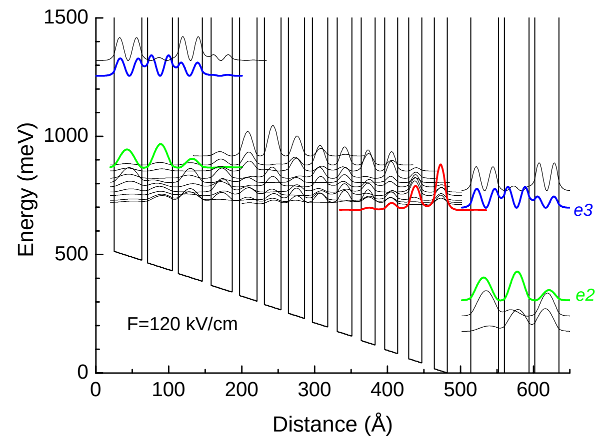

Fig. 1. Typical active region of the short wavelength InAs/AlSb QCLs, designed for an emission at 3.1 µm.

Using a similar design with a suitable scaling of InAs layer thicknesses we obtained room temperature QCL emission below λ=3 µm and a new record laser emission at a wavelength of 2.75 µm at low temperature (Fig.2).

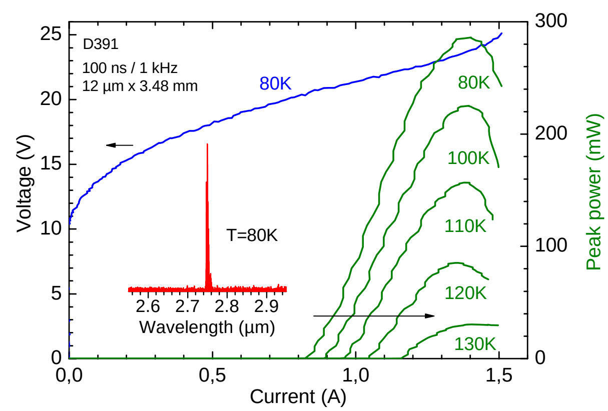

Fig. 2. Voltage-current and light-current characteristics of a InAs/AlSb QCL emitting at a wavelength of 2.75 µm.

III. High temperature operation of short wavelength QCLs

Up to now, InAs/AlSb QCLs [4][6] did not exhibit performances at the level expected from the attractive intrinsic properties of theses materials which are: a high conduction band offset of 2.1 eV, a large Γ-L separation of >0.73 eV and a small electron effective mass of 0.023 m_0 in InAs. Further than a much lower short wavelength limit, this should lead to high intrinsic optical gain and efficient operation at high temperature.

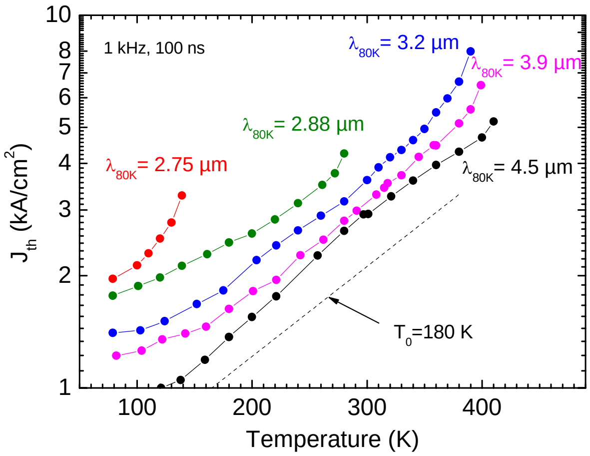

Fig. 3. Typical threshold current densities of improved InAs/AlSb QCLs emitting at different wavelength, as a function of temperature. High temperature operation with high T_0 is obtained in the whole range from 3 to 5 µm.

With the increasing maturity of this technology and using improved active region design, we fabricated a new generation of short wavelength InAs/AlSb QCLs. The devices operate in the range 3.2 – 4.5 µm, up to temperatures exceeding 400 K (130°C), with weak temperature dependence of the threshold current (T_0~180 K) above room temperature (Fig.3). Typical threshold current densities in the range 2 – 3 kA/cm^2 and peak optical powers of the order of 500 mW per facet are measured at room temperature.

The modal gain of our best devices, measured from the study of the cavity length dependence of laser properties, reaches 8 cm/kA at room temperature, which is better than the values achieved in state of the art InP QCLs [7].

IV. Conclusion

The present results demonstrate the potential of InAs/AlSb QCLs for short wavelength operation. Furthermore, these recent and continuous improvements indicate that there is still much room for significant progress.

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