LO-phonon assisted injection observed in a THz Quantum Cascade Laser

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***Abstract*—We report on the observance of a GaAs/AlGaAs based Quantum Cascade Laser with no injector/extractor region which lases while utilizing LO-phonon assisted injection. With the magnetic field parallel to the grown axis, the voltage versus current and magnetic field both show a sharp change, corresponding to an energy of an LO-phonon, while still lasing. This shift of voltage above the normal lasing condition is attributed to the QCL transitioning from a resonant tunneling injection to an LO-phonon assisted injection regime.**

I. Introduction

Terahertz Quantum Cascade Lasers (QCLs) were first demonstrated in 2002 by Köhler et. al.[1] by utilizing a chirped superlattice active region. In 2003, Williams et. al.[2] demonstrated an injectorless THz QCL that utilizes LO-phonon scattering for the depopulation of the upper state. Up until now, QCL designs not based on a superlattice active region have only exploited resonant tunneling to inject carriers from the injector region into the upper state of the active region.

Although resonant tunneling is the most efficient means of injection, there are alternative processes, such as LO-phonon injection. LO-phonon assisted tunneling has already been shown to be an effective means of opening up additional channels for current flow[3]. In our presentation, we report the observance of lasing in an injectorless terahertz QCL utilizing LO-phonon injection in an external magnetic field.

II. Experimental

The samples are a GaAs/AlGaAs THz QCL design similar to that in reference 2, emitting at ∼3.1 THz (12.8 meV). The QCLs were measured in a DC magnet up to 18 T such that the magnetic field lines are perpendicular to the 2DEG and parallel to the direction of the current ($B//I\perp$2DEG). All measurements were performed at 6 K and in a burst current mode. The current burst width was 1 μs with a burst repetition of 120 μs containing 12 bursts and a burst repetition rate of 85 Hz. The light was monitored using a bolometer detector. The voltage versus magnetic field $V(B)$ (current $V(I)$) and light versus magnetic field $P(B)$ (current $P(I)$) were measured applying a constant current (magnetic field) and sweeping the magnetic field (current). The $V(B)$ and $P(B)$ dependence were measured at currents ranging from 0.27 to 1.14 times the laser current threshold (Ith). Spectra were taken with a Bruker 66 spectrometer.

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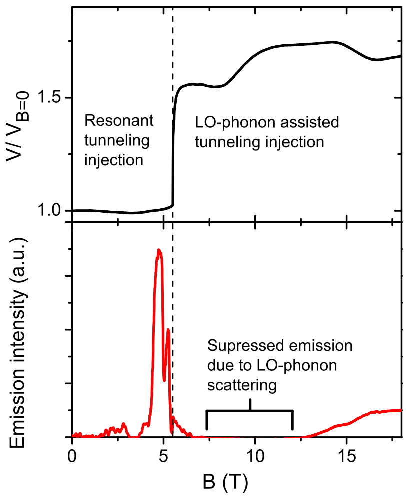

Fig. 1. Voltage and Light curves as a function of the magnetic field at 1.04*I_{th}.

III. Results and Discussion

As shown in Fig.1, the voltage curves shows a very sharp change at a particular field. The change in V divided by the number of periods in the QCL structure is ∼36 mV. This coincides with the LO-phonon energy for GaAs (36meV), thus indicating LO-phonon assisted injection. Although it is less efficient than resonant tunneling, it remains efficient enough to sustain lasing action. We note that the suppression of light (8-12 T) is attributed to a different mechanism, intersubband magneto-phonon resonance[4] (Fig. 1).

Both regimes can be evidenced in the $V(I)$ and $P(I)$ curves (Fig. 2). The sharp changes in the voltage bias at constant B-field corresponds to the different aligning of the energy levels. Point A indicates the normal operating condition of the QCL for resonant tunneling injection. At point B, the QCL is operating under LO-phonon assisted injection. Evidenced from the spectra, the QCL maintains the same lasing transition in both regions. The presence of light after point B further indicates that LO-phonon assisted injection can be utilized in the designs of future QCLs.

IV. Conclusion

These measurements evidence that one can probe both the injector and the active zone of the QCL. The observation of a shift in the voltage bias corresponding to that of an LO-phonon per active zone in both the $V(I)$ and $V(B)$ at fixed

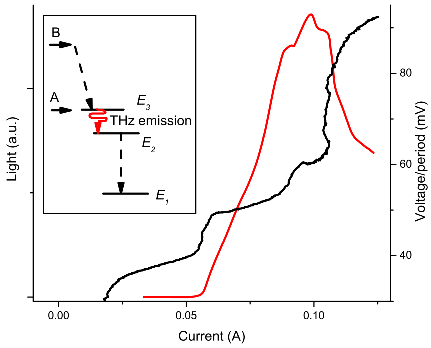

Fig. 2. The figure shows the $P(I)$, red, and $V(I)$, black, at 6 K and $B = 18$ T and the insert a simplified diagram of the QCLs active region. THz lasing occurs between E3 and E2, and the fast relaxation by an LO-phonon between E2 to E1 insures population inversion. Points A and B denote the resonant tunneling and LO-phonon assisted injection regimes, respectively.

magnetic fields and currents, respectively, proves the presence of LO-phonon assisted injection in the QCL. This also shows that it can be used as a means of injection in the engineering design of future lasers.

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