HIGH-MAGNETIC-FIELD SPECTROSCOPY OF InGaAs-AlAs/InP QUANTUM-CASCADE LASERS

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Introduction

Quantum-cascade lasers (QCLs) have attracted a great deal of attention because of their important applications in the mid-infrared and THz regions of the electromagnetic spectrum including high-sensitivity gas sensing, security monitoring, military countermeasures, and communications. The control of the upper-laser-state population is vital for the operation of a QCL, and is especially important for the engineering of the emission wavelength. Therefore, any experimental method that allows an investigation of the population inversion in the active region is of a great value. Early experiments with QCLs in high magnetic field have demonstrated a QCL emission enhancement and magneto-phonon-resonance effects, and led to a deeper insight into the physics of intersubband lasers.

Experimental

Within the present experiment we have compared two active regions in QCLs emitting at 3.8 μm through a high-resolution spectroscopy study of the laser emission in constant magnetic fields up to 33 T. The experimental method allows the identification of the particular Wannier-Stark (W-S) states responsible for the laser action in an operating QCL by comparing the calculated and measured spectral shifts of the laser emission as a function of magnetic field strength and as a function of the injection-barrier width. The size and direction of the shift is determined by both the band non-parabolicity and the Stark effect, both of which differ from one pair of W-S states to another. This experimental method can be applied to a wide variety of QCLs based on different materials and emitting at different wavelengths.

Results and Discussion

Applied to two QCL designs with different coupling of the injector miniband and the bound state, the data [1-3] indicate that the laser transition is not that with the highest oscillator strength in the active region, the bound state to extractor-miniband, but between the injector-miniband state and the extractor-miniband, which has a lower oscillator strength and a lower transition energy. New quantum-cascade laser sample, designed regarding the high-magnetic-field spectroscopy results mentioned above, indeed operates at shorter wavelength and demonstrates outstanding performance up to room temperature.

Conclusions

High-magnetic-field spectroscopy study was done on two QCLs with a different degree of coupling of the injector miniband to the bound state in a modified bound-to-continuum QCL design. Interestingly, our results show that in the weak coupling case, the laser transition does not occur within the pair of W-S states with the highest dipole matrix element, but, rather, takes place between the injector-miniband state and the extractor-miniband state. This result suggests that different approaches may be necessary to engineer the QCL operation wavelength to shorter values than pushing up the upper bound state energy. New quantum-cascade laser sample [2-3], designed regarding the high-magnetic-field spectroscopy results [1-3] mentioned above, indeed operates at shorter wavelength and demonstrates outstanding performance up to room temperature.

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