THz-QCLs based on three-well active modules and injection barrier effects on device performance

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First demonstrated in 2002 [1], the performance of terahertz quantum cascade lasers (THz-QCLs) has greatly improved ever since [2-4]. Between the two common designs for THz-QCL, chirped superlattice and resonant-phonon, the latter has better temperature performance because of the relatively larger phonon energy (~36meV) compared to miniband width (~15meV). The resonant-phonon design commonly has four or more wells per active module. In this paper, we report a new design that employs only three wells per module. Each module consists of two tunnel-coupled wells for the two lasing states and another well for both resonant-phonon depopulation and carrier injection. This design is the simplest so far among the published various working devices. The design parameters are shown in Fig. 1. The 10K threshold current was around 800 A/cm^2. The device lased around 3.4 THz up to a maximum temperature of ~142 K under pulsed mode.

Because of its simplicity, the 3-well structure is well suited for systematic study of the effects of different design parameters on device performance, such as injector and collector barrier, doping concentration [5]. Here we report on an experimental investigation of the effects of varying injector barrier thickness. A special MBE growth technique was employed to obtain structures with various injector barrier thickness and otherwise identical layers. Six samples with injector barrier varying from 54 to 38 Å were processed. All six samples achieved lasing. The results are shown in Fig. 2. It is found that the threshold current density at 10 K increases monotonically from 445 A/ cm^2 to 1.29 kA/ cm^2 with reducing barrier thickness. On the other hand, an optimum injector barrier thickness of 44 Å is found to give rise to a maximum lasing temperature of ~141 K.

In summary, we report on the design and results of THz-QCL based on three-well active modules. The performance of the three-well THz-QCL is comparable to that of the common four-well design. We also report an experimental systematic investigation of the effects of injection barrier thickness. Our results show the importance of injection barrier optimization on device performance.

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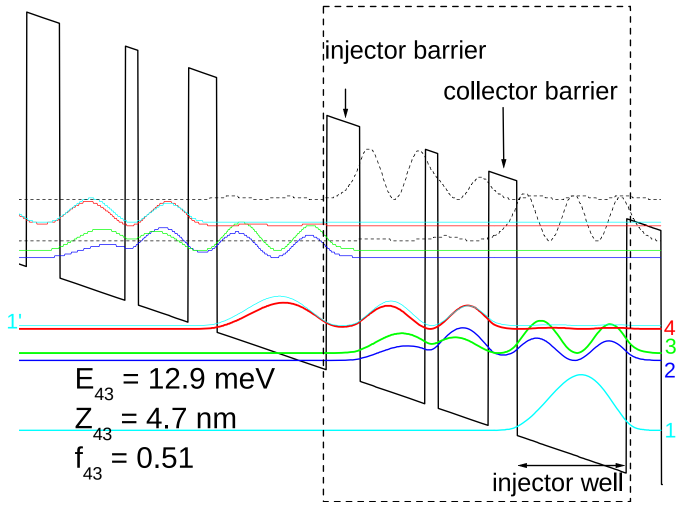

Fig. 1: Calculated conduction GaAs/$Al_{0.15}Ga_{0.85}As$ band diagram under alignment bias (12.5 kV/cm, 55 meV/module). The layer thicknesses are **44** /96 /**20** /74 /**42** /<u>161</u> Å, starting from the injector barrier with the barriers indicated in bold fonts. The center 36 Å of the 161 Å injector well is doped with Si to 1 x 10^{17} cm^{-3} to give a two-dimensional carrier concentration of 3.6 x 10^{10} cm^{-2} per module.

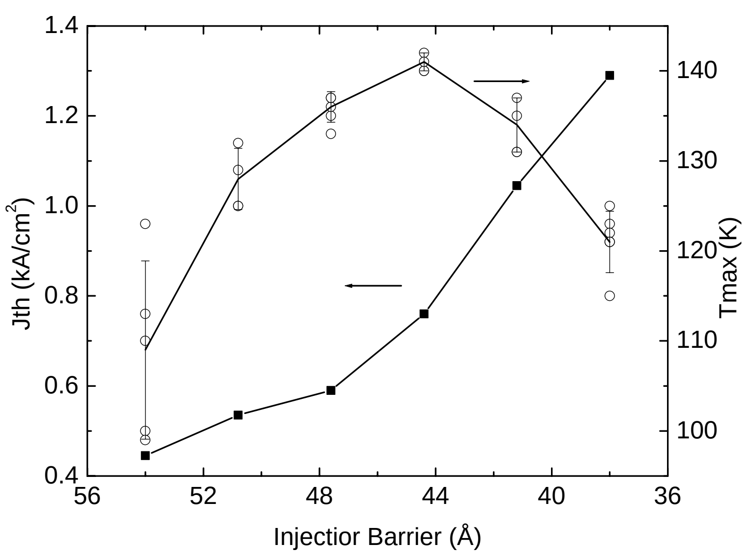

Fig. 2: Threshold current density at 10 K and maximum lasing temperature as a function of injector barrier thickness. At least four devices from each sample were tested for maximum lasing temperature. Each circle represents one device. The error bar is the standard deviation from statistical analysis.