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Observation of the Infrared Emission from Simply Periodical GaAs/AlAs Superlattices

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I. INTRODUCTION

In the last few years, quantum cascade (QC) lasers [1], [2] have been attracting a lot of interest as novel light sources. In previous studies, findings such as continuous wave operation at the liquid nitrogen temperature [3] and high power pulse operation of 0.5 W at room temperature [4] have been demonstrated. Reported QC lasers have been shown to emit a long wavelength of about 3.4 μm [5] to 15.5 μm [6]. Such lasers can be useful for remote chemical sensing or pollution monitoring, and wireless communications in atmospheric transparency windows (3 μm < λ < 5 μm, 8 μm < λ < 13 μm) or fluoric optical fiber communications (3 μm < λ < 4 μm). In addition, QC lasers have been proposed as terahertz (1 THz < f < 10 THz, or 30 μm < λ < 300 μm) emitters [7], [8].

On the other hand, QC lasers contain very complicated superlattice (SL) structures enabling them to achieve population inversion in their quantum wells. In fact, they require more than five quantum wells as carrier injectors into higher subbands of the active layer for each period.

In type-I GaAs/AlAs SLs, the lowest energy states of electrons and holes are confined in the GaAs quantum wells. The AlAs layer, which is the barrier for the Γ state, is the quantum well for the X electron state. The X states in the AlAs barriers have a large density of states, and can be expected to be useful for carrier injection into a higher Γ-subband, because population inversion between the third excited Γ state (Γ4) and the second excited Γ state (Γ3) has been observed, which is caused by carrier injection from the first X state (X1) into the adjacent Γ4 state [9].

In this report, we present an observation of infrared electroluminescence (EL) from a simply periodical GaAs/AlAs SL.

II. EXPERIMENTAL

The studied sample is a GaAs/AlAs type-I SL embedded in an n^+-n^--n^+ diode grown on a (001) - oriented n^+- GaAs substrate by molecular beam epitaxy. The growth sequence of the sample is as follows: n^+- GaAs buffer layer (0.2 μm), n^+- $Al_{0.5}Ga_{0.5}As$ cladding layer (1 μm), 20 periods of an n^-- GaAs/AlAs SL layer sandwiched by i- $Al_{0.5}Ga_{0.5}As$ undoped layers (50 nm), n^+- $Al_{0.5}Ga_{0.5}As$ cladding layer (1 μm), and n^+ - GaAs cap layer (20 nm). The thicknesses of the GaAs and AlAs layers are 53 and 18 monolayers (ML), respectively. Si as an n-type dopant is doped into the centric 6 ML of the AlAs barrier layer at about 2×10^{18}. The band diagram of the SL and the calculated subband energies are shown in Fig. 1. The sample is structured into two types of devices. One device is structured into 400 μm square mesas. The alloyed electrodes on the cap layer have a window (diameter: 200 μm) to allow the observation of photoluminescence (PL) (sample-A). The other device is structured into the LD structure. It has a striped electrode on the cap layer (width: 100 μm, length: 300 μm) and two opposing cleaved mirrors (sample-B).

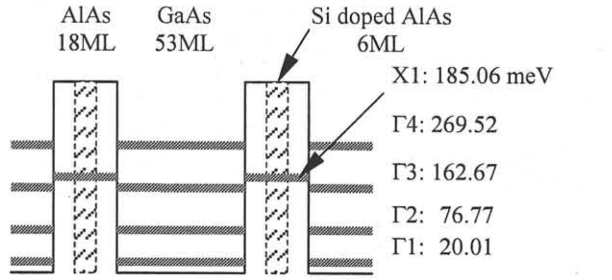

Fig. 1. Conduction band diagram of a superlattice and calculated subband energies.

III. RESULTS AND DISCUSSION

Figure 2 shows PL spectra of sample-A for a cw He-Ne laser intensity of 1 mW. The sample is cooled to 20 K. A Γ1-hh1 PL line exhibiting a red shift due to the quantum confined Stark effect at around 808 nm to 840 nm can be clearly observed. This wavelength agrees well with our calculation. Without laser irradiation, we can observe EL due to the interband carrier transition at 10 V at the same wavelength. However, the EL intensity is about 5×10^5 times lower than the PL intensity at the same voltage.

The EL of sample-B is measured using the lock-in technique. Figure 3 shows the EL intensities. The sample is cooled to 80 K. The pulse bias is applied at 1 kHz at 10 % duty. The thermal emission can be neglected because of the high frequency modulation. In order to cut off the EL emission caused by the interband carrier transition, a Si substrate polished on both-sides is used as a long-wave pass filter between the sample and HgCdTe (MCT) detector.

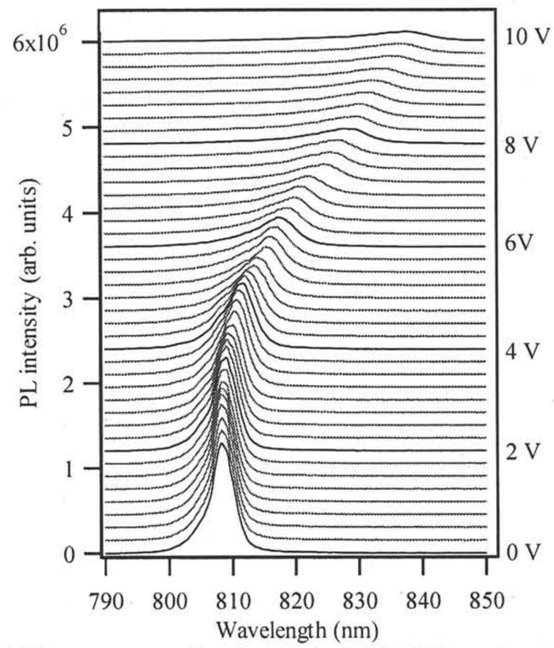

Fig. 2. PL spectra as a function of the applied bias voltage for a He-Ne laser intensity of 1mW.

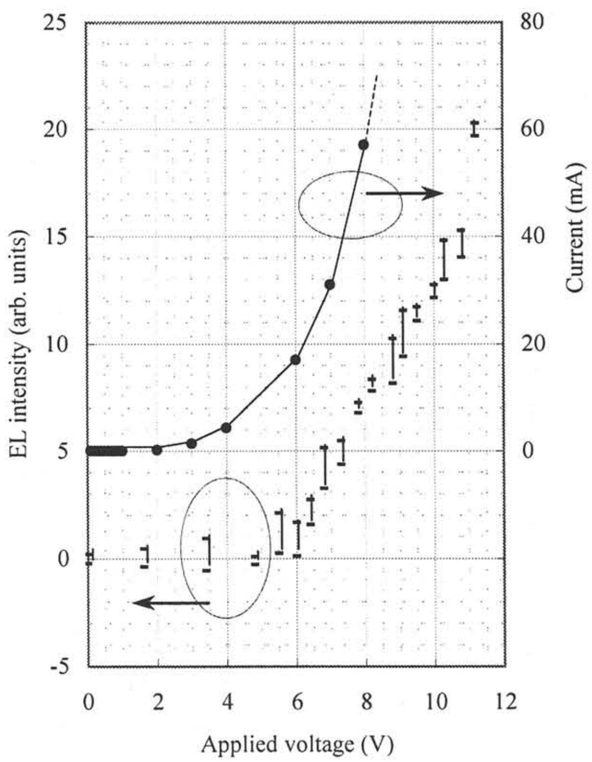

Fig. 3. EL intensity as a function of the applied bias and I-V curve (solid line). The EL is measured with a liquid nitrogen-cooled MCT detector.

According to our calculation, X1-Γ4 resonance occurs at 4 V (Fig. 4). In fig.3, higher than X1-Γ4 resonant voltage, the current increases rapidly [10], resulting in carrier injection into the Γ4 state [9]. The infrared EL intensity also increases as the current increases. Thus, one possible origin

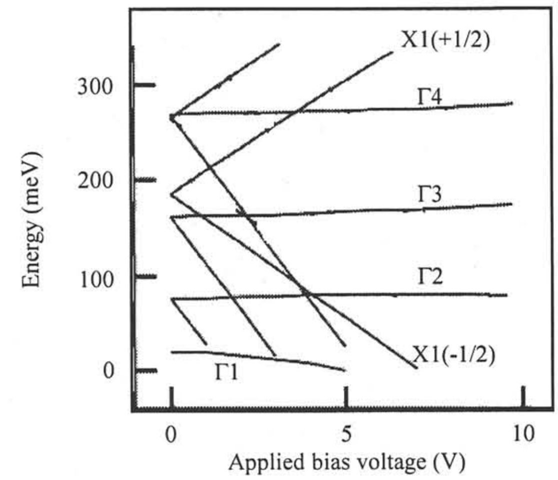

Fig. 4 Calculation of subband energies as a function of the applied bias voltage.

of the infrared emission is the intersubband carrier transition from the Γ4 state to the lower states.

IV. SUMMARY

We have observed infrared emission in simply periodical GaAs/AlAs superlattices. The origin of the infrared emission is not the interband carrier transition or the thermal emission. We therefore believe that the infrared emission is due to intersubband carrier transition and these results can be useful for achieving simple quantum cascade laser structures.

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