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Crucial Role of Extremely Thin AlSb Barrier Layers in InAs/AlSb/GaSb/AlSb/InAs Resonant Interband Tunneling Diodes

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1. Introduction

Ultrahigh-speed operation of circuits with resonant tunneling diodes (RTDs) requires a high peak current density (I_p) for the RTDs. To obtain a high I_p, it is essential to make the barrier layers thin. Since a high peak-to-valley current ratio (*P/V*) is expected in double-barrier resonant interband tunneling (DBRIT) diodes made of the InAs/AlSb/GaSb material system, owing to the band-gap blocking of a GaSb well [1, 2], the AlSb barrier layers can be made extremely thin without degenerating the *P/V* [3]. In this study we have investigated effects of extremely thin AlSb barrier layers on the resonant interband tunneling current in InAs/AlSb/GaSb/AlSb/InAs DBRIT diodes. No negative differential resistance (NDR) was observed when the diode had no AlSb barrier layers, but NDR was observed when the diode had even 0.5-ML-thick AlSb barrier layers inserted at InAs-GaSb heterointerfaces. Our result demonstrates the crucial role of the extremely thin AlSb barrier layers characteristic in type II band structures.

2. Experiments

We prepared five different samples with the thickness of the AlSb barrier layers (L_b) ranging from 0 to 5 monolayers (ML). In order to obtain good uniformity in thickness for the AlSb layers, the rotation period of samples during molecular beam epitaxy (MBE) was adjusted so that the samples made one rotation per every 0.5-ML increase in AlSb layer thickness. A band-edge diagram of a DBRIT diode is shown in Fig. 1. The thickness of GaSb wells (L_w) was fixed at 17 ML (= 10.4 nm).

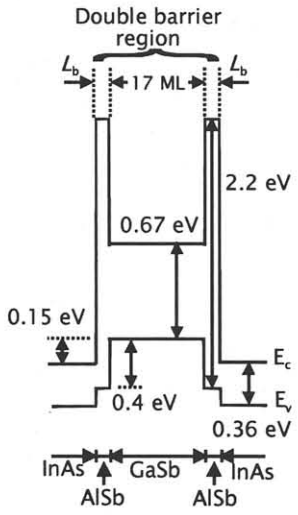

Fig. 1. Schematic band-edge diagram of an InAs/AlSb/GaSb/AlSb/InAs double-barrier resonant interband tunneling (DBRIT) diode. The conduction-band edge and the valence-band edge are indicated by E_c and E_v. The thicknesses of AlSb barrier layers (L_b) were 0, 0.5, 1, 2, and 5 ML.

3. Results and Discussion

No NDR was observed for the sample without the AlSb layers. This agrees well with the previous report [4] and can be explained by the calculation result which shows that the value of L_w (= 17 ML) is too small to place the resonance level above the InAs conduction-band edge. NDR was observed, however, when the sample had only 0.5-ML-thick AlSb barrier layers as well as thicker barrier layers (Fig. 2). This observation of NDR means that the resonance level is formed in the GaSb well which is located above the InAs conduction-band edge. The crucial role of the extremely thin AlSb barrier layers for the resonance level formation is thus demonstrated.

The resonant interband tunneling current density, I_{RIT}, which is defined as the difference between I_p and the valley current density, for the diode with L_b = 5 ML in addition to those in Fig. 2 is shown in Fig. 3. I_{RIT} exhibits different dependence on L_b in two regions. When the AlSb barrier layers are more than 2 ML thick, I_{RIT} decreases with an increase in L_b. This decrease in I_{RIT} is the same as in

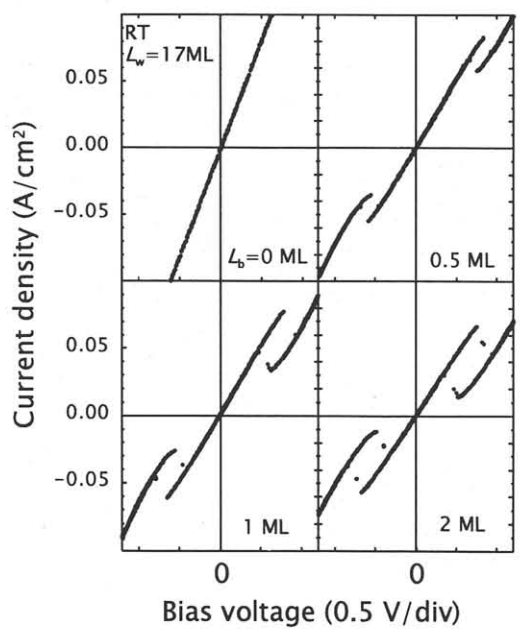

Fig. 2. Current-voltage (I-V) characteristics measured at room temperature for DBRIT diodes with GaSb well widths (L_w) of 17ML and with various barrier-layer thicknesses. The bottom electrode (collector) is grounded. The emitter area was 10×10μm².

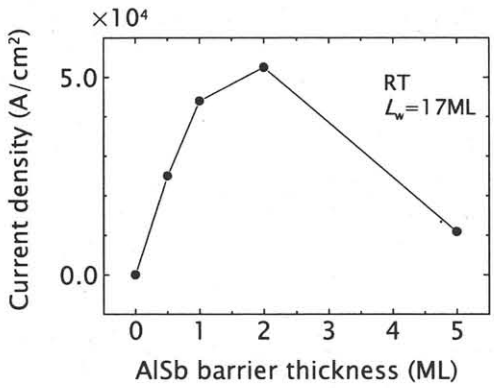

Fig. 3. Resonant interband tunneling current density (I_{RIT}) for the diode with L_b = 5 ML in addition to those in Fig. 2. I_{RIT} is defined as the difference between the peak current density (I_p) and the valley current density (I_v). The emitter area was 10×10 μm².

conventional type-I RTDs and can be explained by the variation in the resonance level width. In contrast, when the AlSb barrier layers are thin ($L_b \leq 2$ ML), I_{RIT} increases with an increase in L_b. This can not be explained in this manner.

By assuming that the resonance level in the GaSb well is moved up toward the edge of the GaSb valence band with an increase in L_b, the increase in I_{RIT} for L_b less than 2 ML can be interpreted as follows. For L_b = 0 ML the resonance level is below the InAs conduction-band edge as described above (Fig. 4-a). When 0.5-ML-thick AlSb barrier layers are inserted, the resonance level is moved up above the edge of the InAs conduction band and thus NDR is observed. But for values of L_b less than 2 ML, the whole resonance level, which is broadened due to the extremely thin AlSb barrier layers, is not completely above the InAs conduction-band edge. Then the resonant interband tunneling (RIT) is limited by the edge rather than the AlSb barrier layers (Fig. 4-b). In this case, as the resonance level is moved up and eventually leaves the edge with an increase in L_b from 0.5 to 2 ML, the limitation of the RIT by the edge becomes weak (Fig. 4-c). This means that RIT current increases with an increase in L_b. This dependence of the RIT current is in good agreement with our observed result that I_{RIT} increases with an increase in L_b from 0.5 to 2 ML.

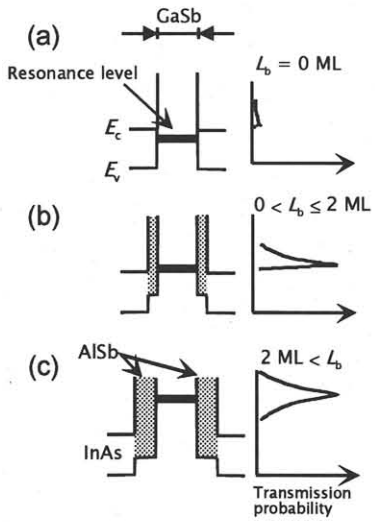

Fig. 4 Schematic showing band-edge diagrams and transmission probabilities for DBRIT diodes with different AlSb barrier thickness.

In type-II band structures there is coupling between InAs conduction-band states and GaSb valence-band states. Electron effective masses in both states are quite different. One possible mechanism that moves up the resonance level with an increase in L_b is due to reduction of the coupling between the conduction-band states and the valence-band states. The reduction can increase the effective mass for the GaSb well from an InAs-like state to a GaSb-like one and the resonance level is moved up toward the edge of the GaSb valence band.

4. Conclusion

We investigated the effect of the extremely thin AlSb barrier layers on I_{RIT} of InAs/AlSb/GaSb/AlSb/InAs DBRIT diodes. No NDR was observed for the diode without AlSb barrier layers, but NDR was observed when the diode had even 0.5-ML-thick AlSb barrier layers inserted at InAs-GaSb hetero interfaces. Our result demonstrates the crucial role of the extremely thin AlSb barrier layers that are responsible for the resonance level formation in the GaSb well.

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