Extended Abstracts of the 1996 International Conference on Solid State Devices and Materials, Yokohama, 1996, pp. 752-754 **A-7-2**

A Novel Bistable Double-Barrier Resonant Tunnel Diode by Charging Effect of InAs Dots

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We report a novel bistable current voltage characteristics of GaAs/AlGaAs double-barrier resonant tunnel diodes(DBRTDs) with self-assembled InAs dots formed on the cathode side of the barrier at room temperature. The memory effect is likely to be caused by the charging and discharging of InAs dots and the trapped electrons discharge through tunneling via resonance states in the adjacent double quantum well.

1. INTRODUCTION

As far as device applications of quantum dots go, there have been a few reports on lateral transport devices such as HEMTs [1] and MOSFETs[2][3], so far. However, the applications to vertical transport devices have been, so far, limited to semiconductor LASER diodes[4]. Here, we report a new type of DBRTD with bistable characteristics caused by charging effect of InAs dots operated at room temperature.

2. STRUCTURE AND FABRICATION

The MBE grown heterostructure of the DBRTD consist of 6,000Å n^+-GaAs, 40Å of GaAs, 40Å of AlGaAs barrier, 40Å of GaAs well, 40Å of AlGaAs barrier, 20Å of GaAs, effectively 2.5ML of InAs, 20Å of GaAs and 1,445Å of n^+-GaAs/n^+-InGaAs/n^+-InAs graded layer as shown in Figure 1. Two different formation schemes of InAs dot growth were selected in order to verify the effect of average dot size and size distribution on I-V characteristics of RTD. The lateral size of the measured devices are 2μm and 5μm. The device fabrication process is almost the same as standard GaAs FET process except the non-alloyed ohmic contact for the top terminal (cathode) by depositing Pt/Au on InAs top layer grown by graded composition scheme in order to avoid the alloy diffusion to the double quantum well. The average areal density of the dots in 5μm device were 1,400 dots and 16,000 dots per device, respectively. AFM micrograph of InAs dots (large dot sample) is shown in Figure 2. Smaller dots were 200Å in lateral

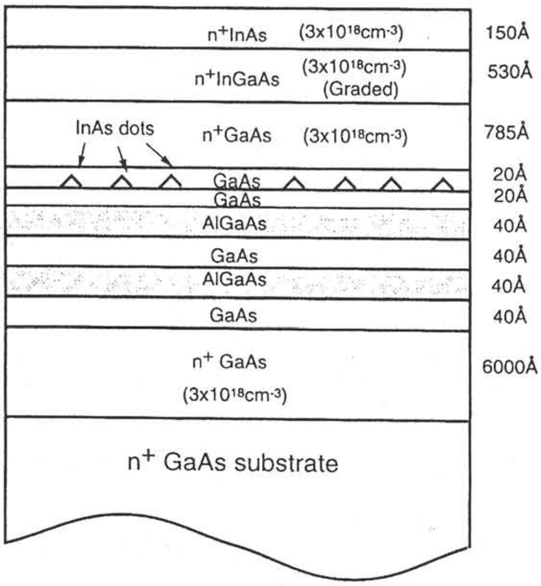
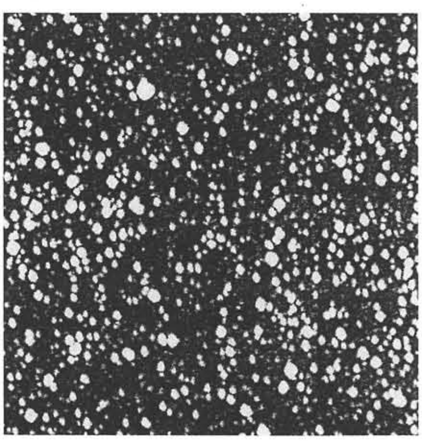


Figure 1. Heterostructure of the DBRTD with InAs dots.



5μm × 5μm

Figure 2. AFM micrograph of InAs dots (large dot sample) grown on top of the RTD top barrier.

size, 20 Å in height and 6.3 x 10^{10} cm^{-2} in average density. Larger dots were 800 Å in lateral size, 80 Å in height and 5.7 x 10^{9} cm^{-2} in average density. The distributions of dot size and calculated quantized energy level distribution of the large dots are illustrated in Figure 3. In the structure with large dots, the size distribution of the dots were made so random that the electron distribution becomes continuous from the bottom of the bulk conduction band minima, so that the current voltage characteristics in forward bias show blurred negative resistance in the forward bias condition as will be shown in the next section.

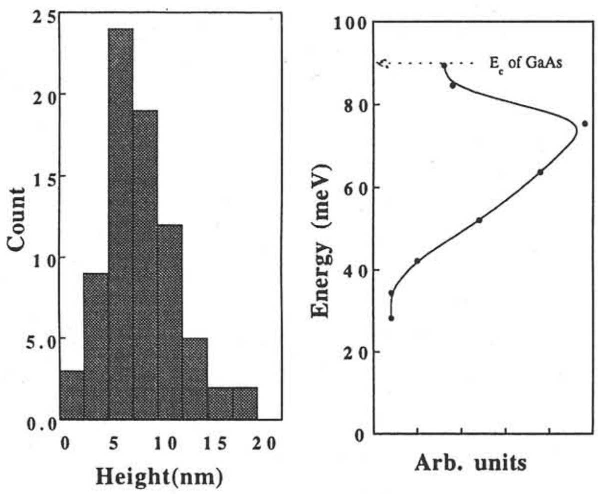


Figure 3. Dot height distribution and quantized level distribution (in z-direction) of larger dot sample measured from the bottom of conduction band of InAs.

3. RESULTS AND DISCUSSIONS

The I-V characteristics of the RTD with InAs dots are shown in Figures 4 and 5. As can be seen, RTD with *large* dots (sample L) exhibits hysterisis characteristics while RTD with *small* and uniform dots (sample S) exhibits almost no hysterisis. It is clearly seen that the I-V characteristics of sample S appears normal except small positive peak current and blurred resonance characteristics in the positive bias, while sample L exhibits pronounced hysterisis characteristics and unnoticably weak negative resistance in the positive bias. However, the dips in the differential current curve of sample L suggests resonance position in the positive bias as marked by arrows in Figure 5, which is close to the resonance position in the control sample without dots. It is presumably caused by the smearing of the

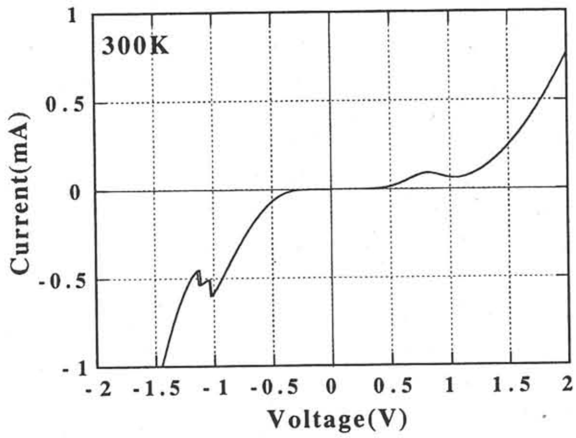


Figure 4. Current-voltage characteristics of "sample S" measured at room temperature. Reduced peak current and blurred resonance peak in the forward bias is noticed.

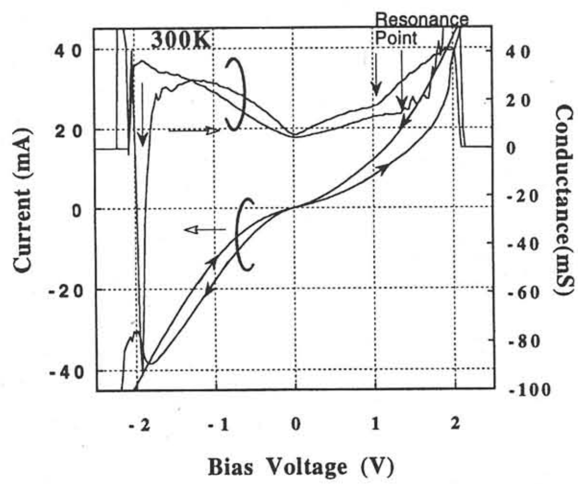


Figure 5. Current-voltage characteristics of "sample L" measured at room temperature. Typical hysterisis characteristics is observed. Shifted resonance level is observed in its differential curve in the positive bias.

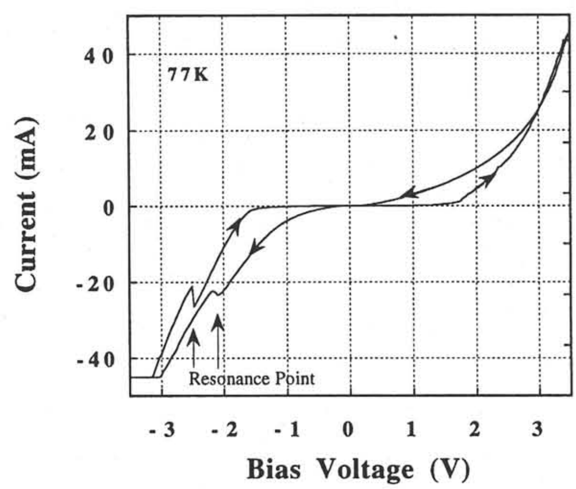


Figure 6. Current-voltage characteristics of "sample L" measured at 77K. Resonance level shift in the negative bias is clearly observed.

density of states near the bottom of the conduction band. Resonance voltage shifts in Figure 5 (300K) and Figure 6 (77K) suggests that charging effects causes the hysterisis. Let us closely look at the characteristics of RTDs with large dots(sample L). When the voltage scan is below resonance condition, the hysterisis is weak and when the scanned voltage exceeds resonant tunneling condition in both polarities, typical hysterisis curve is obtained. When the voltage is scanned from zero bias, no hysterisis is observed in the positive side up to resonance condition, however, hysterisis were observed slightly in the negative side as seen in Figure 7. Physical model for the RTD with large sized dots is the following. When the device is negatively biased, InAs dots starts to be filled with electrons. On the other hand, the discharging of the InAs dots are initiated when the positive bias exceeds resonance condition (between 0D and 2D states) as schemstically depicted in Figure 8. The switching between off-state (charged) and on-state (discharged) is clearly seen and their two-terminal resistance at zero bias were 3.4k Ω and 150 Ω, respectively, at room temperature. Depending on the charging condition of the dots, not only the hysterisis characteristics, but also the resonance position shifts slightly run by run. Due to the present method of self-organized InAs dot formation, the larger sized dots are nonuniform in its size distribution. Therefore, separation of non-uniformity and largeness of the dots is to be clarified from now on in order to verify the physical origin of the pronounced hysterisis in the RTD structures with larger sized dots.

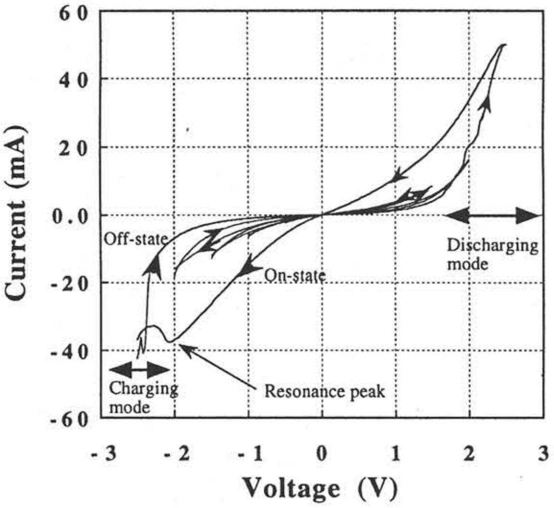


Figure 7. Current-voltage characteristics of "sample L" with voltage scan from zero volt. Pronounced hysterisis seems to occur when the bias exceeds peak voltage.

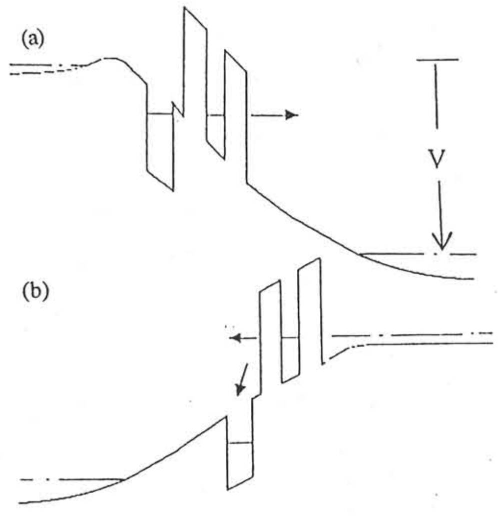


Figure 8. Schematic energyband diagram of the RTD with dots in discharging mode through resonance level (a) and charging mode (b).

4. CONCLUSION

We report a novel bistable current voltage characteristics of GaAs/AlGaAs DBRTDs with self-assembled InAs dots formed on the cathode side of the barrier at room temperature. The memory effect is observed only in the devices with large (800Å in lateral size and 80Å in its height) and is likely to be caused by the charging of hot electrons into InAs dots and discharging of the trapped electrons through tunnling via resonance states in the adjacent double quantum well. The present result may open up a possible novel application of Coulomb blockade phenomena to vertical transport devices such as RTD, LED, APD and LASERs.

Acknowledgements

The authors are grateful to S.Shiina for technical help for measurements. This work was partially supported by Grant-in-Aid for Scientific Research from The Ministry of Education, Science and Culture.

References

1) N.Horiguchi, T.Futatsugi, Y.Nakata, and N.Yokoyama, Tech.Dig. IEEE IEDM (1995) 371-374

2) K.Yano, T.Ishii, T.Hashimoto, T.Kobayashi, F.Murai, and K.Seki, Appl.Phys.Lett., 67 (1995) 828

3) S.Tiwari, F.Rana, K.Chan, H.Hanafi, W.Chan, D.Buchanan, Tech.Dig. IEEE IEDM (1995) 521-524

4) J. Temmyo, E Kuramochi, M.Sugo, T.Nishiya, R.Nötzel, T.Tamamura, Mat.Sci.Eng., B35 (1995) 7-11