Resonant Tunneling Effect of InAs Quantum Dots Grown on InAlAs/InP

B. Zhang, W. G. Ning, F. M. Guo*

* Shanghai Key Laboratory of Multidimensional Information Processing, Key Laboratory of Polar Materials & Devices, School of Information Science Technology, East China Normal University, China

*Corresponding Author: fmguo@ee.ecnu.edu.cn

***Abstract*- InAs quantum dots grown on InAlAs/InP were discussed by Lumerical software in this paper. By discussing current-voltage characteristics curve (I-V) and capacity-voltage characteristics curve (C-V), we founded that resonant tunneling effect of InAs QDs and barrier of InP and InAlAs result in the asymmetry of I-V.**

I. Introduction

In recent years, the QDs (Quantum Dots) attract much attention in electronic device. Because the properties of QDs are more outstanding than QW in many aspects, for example QDs laser has lower threshold current and lower dark current [1, 2]. Thus, the characteristics of QDs are interesting for researchers and engineers to develop new devices. Most of the studies have focused on InAs/GaAs and InAs/InP QDs [3]. However, the current-voltage (I-V) characteristics curve in structure of InAs QDs on InAlAs/InP is rarely studied. In this paper, we has found the asymmetry of I-V and discussed by capacity-voltage characteristics curve (C-V) and current-voltage characteristics curve (I-V). We found that the resonant tunneling effect of InAs QDs and triangle barrier formed by InP result in the asymmetry of I-V.

II. Modeling

The model is based on InP substrate. They consisted of a 0.4μm thick $In_{0.52}Al_{0.48}As$ as buffer layer with Si doped at $3\times10^{16}/cm^2$, then 0.9 nm thick InAs followed by 0.2 um InAlAs with Si doped at $3\times10^{16}/cm^2$. On the top and bottom, the ohmic contact is made. Fig. 1 is the energy band diagram simulated at equilibrium. InAs QDs are embedded between triangle barriers formed by $In_{0.52}Al_{0.48}As$ and InAlAs.

III. Results and Disscussion

The I-V is obtained by setting the model a DC sweep bias at the range between -2V to 2V as shown in Fig. 2. The current increasing with voltage is in two directions. However, an asymmetry exists in I-V. We will discussion three reasons for this phenomenon by analyzing the I-V with different samples.

We name the model sample B. X in $In_xAl_{1-x}As$ represents the radio of components of Al. x_y is used for characterizing the height of barrier in two sides of InAs QDs. The smaller X, the higher of the barrier of $In_xAl_{1-x}As$. x_y of sample A, B, C, D, E, F, G is 0.52_0.52, 0.52_0.50, 0.52_0.48, 0.52_0.46, 0.52_0.42, 0.42_0.52, 0.42_0.52, 0.52_0.52, respectively. Sample G is with using $In_{0.52}Al_{0.48}As$ to replace InP. Sample H is with an asymmetry structure of $In_{0.52}Al_{0.48}As$.

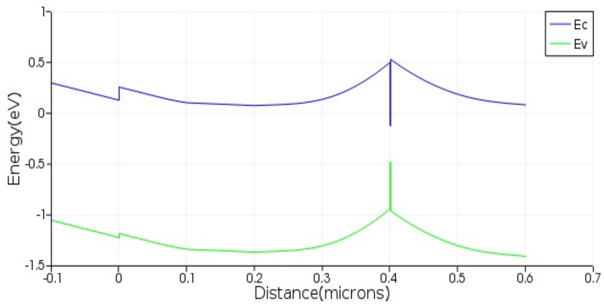

Fig. 1. Band diagram under equilibrium

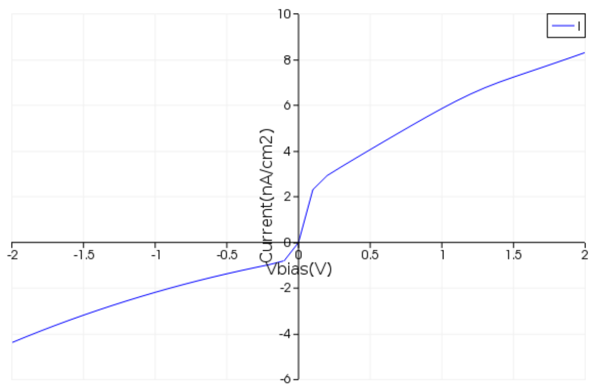

Fig. 2. I-V at different bias voltage, from -2 V to 2 V.

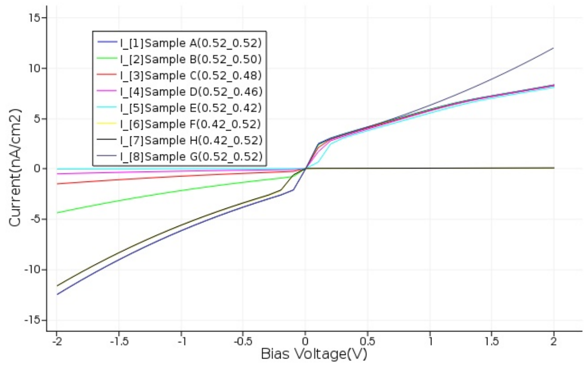

Fig. 3. I-V of all samples applied by voltage from -2V to 2V.

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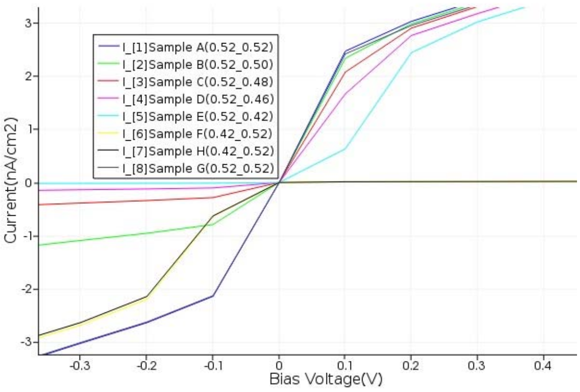

Fig.4 The enlarged view of Fig. 3.

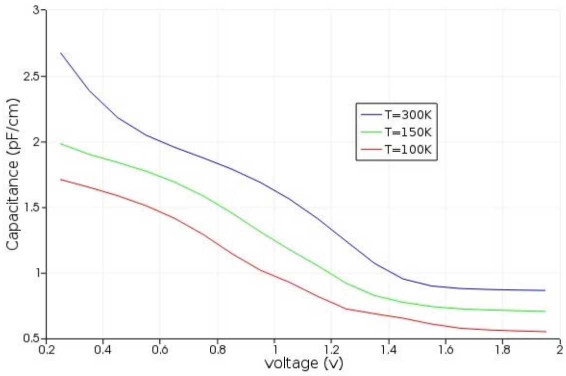

Fig. 5. C–V measurements performed at T = 300 K, 150 K, and 100K.

We measured the current-voltage characteristic of all samples applied by voltage from -2Vto 2V (electrode near InAlAs is ground potential) as shown in Fig. 3 and Fig. 4 is the enlarged view of Fig. 3. To confirm the existence of resonant tunneling, we measured its capacitance-voltage characteristics of InAs QDs, shown in Fig. 5.

Fig. 5 shows the C-V with the bias voltage in different temperature. A. J. Chiquito and Yu. A. Pusep. had made experiments for calculating the energy of ground and excite states. In InAs QDs, the energy states are about E_{e1}=(240±10) meV and E_{e2}=(180±10) meV, E_{e3}=(70±10) meV, repectively[4-5]. InAs QDs in the model has the same structure of energy states.

From Fig. 4, we can see three bias points in forward voltage, V≈0.1V, V≈0.2V, V≈0.3V, respectively. The three voltages are larger than the energy states may due to voltages of the other parts of the model except InAs QDs. In backward bias voltage, the three similar bias points are obvious observed in sample A and G due to the bigger current than other samples. The points is about in the energy states in InAs QDs and the structure of the model is similar to DBRTs (double barrier resonant tunneling structure) [6]. Thus we confirm the effect of resonant tunneling effect by comparing all samples.

To confirm the asymmetrical effect of InP by compare sample A and G in Fig. 3 and 4. Sample A has InP, sample G has not. By comparing the I-V of sample A and G, sample G has asymmetrical characteristics, sample A has not. The current of sample G is higher than A in the forward bias voltage due to the triangle barrier the InP.

To confirm the barrier effect of $In_xAl_{1-x}As$ by changing x, then we observe the change in I-V. By comparing sample A, B, C, D, E (x from 0.52 to 0.42), the obvious decline of current in backward bias voltage has been observed, In particular, the current of sample E becomes zero. Thus, it can be concluded that the barrier of $In_xAl_{1-x}As$ results in the asymmetry in I-V. By comparing sample E (x_y=0.52_0.42) and F (x_y=0.42_0.52), the zero current of sample F in forward bias voltage again confirm the conclusion.

IV. Conclusion

The InAs QD in InAlAs barrier model is built and simulated by Lumerical software. By measured the I-V of the model, the asymmetry of I-V is found. By measured the C-V, we confirm the existence of the energy states in InAs QDs. We found that the resonant tunneling effect of InAs QDs Grown on InAlAs/InP and the triangle barrier formed by InP and InAlAs , the barrier of InAlAs result in the asymmetry of I-V.

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