THE EFFECT OF THE STRUCTURAL INTERFACE OF THE RESONANCE TUNNELING DIODE ON ITS PERFORMANCE

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ABSTRACT: *The effect of the interface roughness on performance of Resonance Tunneling Diode has been theoretically studied, especially the V-I characteristic curve, at which the Negative Differential Resistance present. The complicated structure of the interface is among the major factors of electron scattering; as a result it affects the I-V curves of the device. We propose a theoretical model to represent the interface structure. Here, we assume that, the interface morphology is purely random. It has been noticed that the third interface is the most influential among others. It also turns out that Fermi energy plays a role in minimizing the impact of the distortion of the interfaces, in which it enables one to select the optimum dimensions to get the best values for the maximum current density of the diode.*

Keywords: Resonant tunneling devices, Nanoelectronics, Quantum theory, Quantum wells, Semiconductor device modeling.

1. INTRODUCTION

Recent technological advances to minimize the chip size and increasing speed of ICs [1], is hindered by the quantum mechanical limit [2], at which the process began hitting the barrier separates classical and quantum regime once the size approaches the nanometer scale. Such an effect has been observed in many tunneling devices since a long time and an issue of intensive research [3, 4, 5]. Resonance Tunneling Diode (RTD) is such an example of the quantum devices. RTD structure is usually represented by a double barrier structure with flat interfaces [6], however such an ideal interface cannot be achieved. Moreover, theoretical modeling of such interfaces is not feasible [7, 8, 9].

It is a common practice to use a double barrier potential profile to determine the characteristics of the RTD. Fig (1) shows the IV characteristics of RTD, it explains the presence of the Negative Differential Resistance (NDR) as well [10]. The current depends on external potential applied to the device, if a small potential difference applied, the energy of the electrons on the junction would be less than the quantized energy levels of the quantum well, which result in a small current flowing as depicted in figure (1a). The current will reach its maximum value when the electron energy is equal to the energy levels of the quantized well (1b), then the electron energy becomes higher than the energy of the quantized levels at which the current will reach it highest value in the so called negative differential resistance (NDR) (1c), where the current drops as the potential difference increases [11].

The current density J through, the device can be calculated using the following equation [3]:

$$J = \frac{em^*kT}{2\pi^2\hbar^3}\int \frac{(T_u^* T_u) ln\left(1+e^{(\mathcal{E}_F-\mathcal{E}_l)kT}\right)}{1+e^{(\mathcal{E}_F-|e|V-\mathcal{E}_l)/kT}} d\mathcal{E}_l \qquad (1)$$

Where m^* is the band-edge effective mass, k is Boltzmann constant, T is the lattice absolute temperature, $\hbar$ is Plank constant divided by 2□, $T_u^*T_u$ gives the tunneling probability density of the outgoing electron, □$_F$ is Fermi energy level, □$_l$ is energy of the electron associated with longitudinal wave vector of the electron in the conduction band, V is the applied voltage.

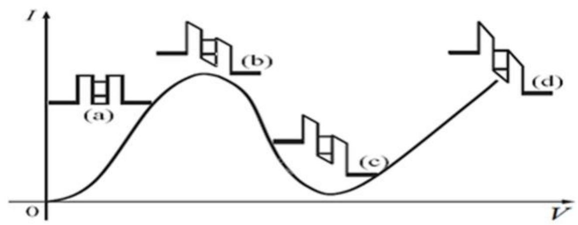

Fig. 1 The characteristics I-V curve of the Resonant Tunneling Diode (RTD) along with the biasing states of the device

2. THE PROPOSED MODEL

The proposed model presented in this study, simulates the interfacial structure of the junction between different layers as a random structure. The roughness are assumed to follow a Gaussian distribution. We try to identify the critical interfacial layer, i.e., which interface is the most influential on the properties of the RTD.The RTD is represented by a double barrier as shown in fig. 2.

Fig. 2 Double barrier structure, the numbers identify the interfaces

Fig. 3 shows the IV curve of RTD in the case of smooth interfaces. We then change the interface roughness, to see the effect of each interface as stated earlier.

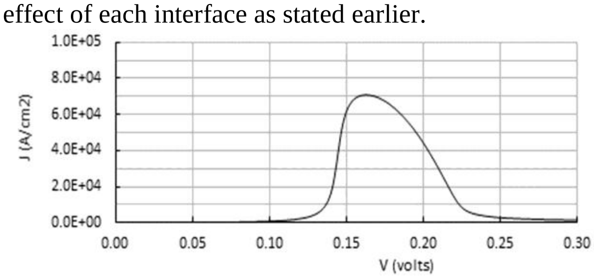

Fig. 3 the ideal RTD device current density versus the applied voltage

2.1 First interface

The roughness factor is changed in the range (0%, 0.4%, 4% and 10.0%). One can notice that, the current density changes as the roughness factor increases, i.e. the interface becomes rougher. Also the current density shows some sudden increments, as in fig. 4.

The sudden increments in the current density are probably due to charge carrier scattering at the interface where some of the off-resonance state changed on-resonance states. The other fact is that interface 1 is close to an accumulation region of charge.

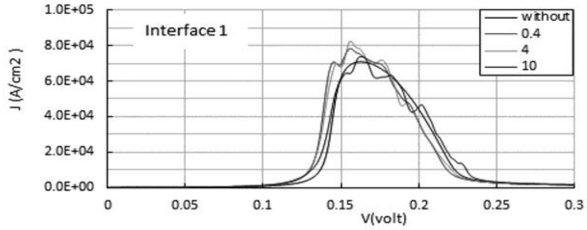

Fig. 4 Introducing interface 1 as a crispy and rough, while others junction are smooth and plain. A noticeable increment in the current density occurs as roughness increased

2.2 Second interface

In this case, interface 2 is the rough interface while other interfaces (1^{st}, 3^{rd} and 4^{th}) are abrupt. Roughness is varied in the same range as of the first interface (namely; 0%, 0.4%, 4%, and 10.0%). We notice that, the IV characteristics does not show a noticeable change in the roughness range (0.4%, 4%) an increase in the current density and the maximum shifts toward lower applied voltage, while as the roughness increases to 10%, the maximum current slightly dropped compared to the normal (smooth) junction, as in fig. 5.

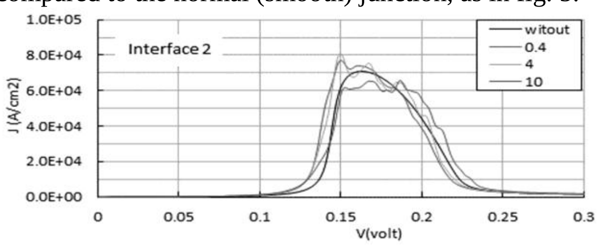

Fig. 5 Interface 2 as rough, while others interfaces kept smooth. A noticeable fluctuations in the current density occurs as the roughness changed

2.3 Third interface

In this case, the roughness of interface 3 is varied (0%, 0.4%, 4%, and 10.0%), while others (1^{st}, 2^{nd}, and 4^{th}) are kept abrupt. It is clear that, variations in this interface do lead to noticeable changes in the current density, as in fig. 6.

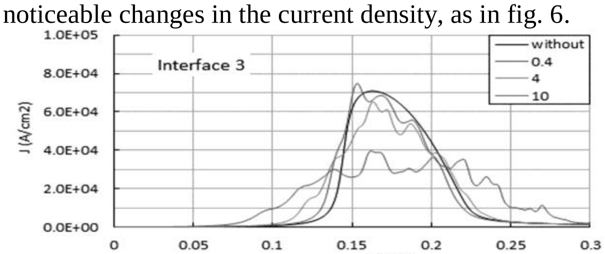

Fig. 6 Interface 3 is rough, while others junctions are smooth. A noticeable widening and deformation in the current density occurs as roughness increases

The 3^{rd} junction variations have a great influence on the current density of the RTD, even at lower roughness of 0.4%. It is evident that the maximum of the current density shows significant shift and becomes broader. Negative differential Region (NDR) disappears, especially at higher random roughness.

This can be owed to the fact that the 3^{rd} interface is adjacent to the quantum well which contain a quasi-quantized energy levels, at which some of the on-resonance will converted to off-resonance states.

2.4 Fourth interface

Fig. 7 shows the case where interface 4 is the rough interface, as in the previous cases. One can notice a change in the shape, while the current density shows a small change in the peak value.

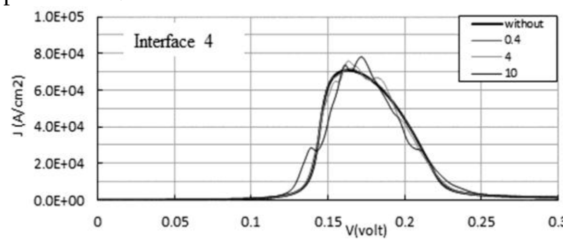

Fig. 7 Interface 4 is rough, while others junctions are smooth. A slight change took place when roughness factor increased and a noticeable change occurs at higher roughness factor

A slight change in the current density especially for the 0.4% and 4% roughness factor for this interface and a clear deformation in the current density can be seen when the roughness factor increased to higher values ~ 10%.

We believe that the reason behind this is, all the electrons reach this junction possess a high transmission factor.

3. REFERENCES

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