Delta-layer tunnel junctions in semiconductors for charge sensing

J.P. Mendez and D. Mamaluy
Cognitive & Emerging Computing, Sandia National Laboratories, Albuquerque, USA
e-mail: jpmende@sandia.gov

INTRODUCTION

At Sandia National Laboratories, a lot of effort has been dedicated to what we have denominated Atomic Precision Advanced Manufacturing (APAM) to explore new opportunities for Beyond Moore computing. APAM allows us to create 2D doped regions (δ-layers) in a semiconductor. Simultaneously, we have also explored other new opportunities that δ-layers might offer. In particular, the use of δ-layers in semiconductors for charge sensing. In this work, we will show that the presence of a single charge near the tunnel gap in a Si: P δ-layer tunnel junction is easily detected by electrical current measurements.

QUANTUM TRANSPORT FRAMEWORK

Our open-system quantum transport framework [1,2,3] relies on a self-consistent solution of Poisson-open system Schrödinger equation in the effective mass approximation and the Non-Equilibrium Green's Function (NEGF) formalism. To reduce the computational cost of these intensive calculations, we utilize the Contact Block Reduction (CBR) method [1,2,3], which is an efficient method to calculate the electronic transmission function of an arbitrarily shaped, multi-terminal open device and scales linearly with the size of the system.

DISCUSSION AND CONCLUSIONS

Our device (see Fig. 1) consists of two highly-conductive P δ-layers separated by an intrinsic gap embedded in Si, which corresponds to a lightly doped Si body and Si cap. The δ-layers are in contact with a source and drain respectively.

Fig. 2 shows the computed electrical current through the device for different positions of an electrical charge in the middle plane (y=W/2). As one can notice, the electrical current is not affected when the charge is located very far from the tunnel gap (the current without the charge is 1.4e-7 A). However, the electrical current increases considerably when the charge is around the tunnel gap. Indeed, the maximum current is reached when the charge is in the middle of the tunnel gap, which is approx. 18 times higher for just a single charge.

Fig. 3 shows the local density of states for Si: P δ-layer tunnel junctions. We postulate that the extreme sensitivity of the δ-layer tunnel junction to the presence of charges is due to the strong quantization of the conduction band (shown schematically as white dashed lines in the figure) for these highly-confined systems. As a result, the presence of a single charge near the tunnel gap can be translated into a strong effect on the current.

In conclusion, we have shown that a single charge near the intrinsic gap of a Si: P δ-layer tunnel junction can be easily detected by electric current measurements. Therefore, this results shed light on new opportunities for highly-confined systems in semiconductors to be used for sensing charges in many applications.

ACKNOWLEDGMENT

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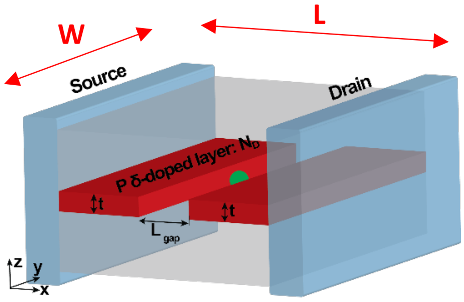

Fig. **1**. Si:P δ-layer tunnel junction (TJ). The electrical charge is represented as a green sphere in the figure.

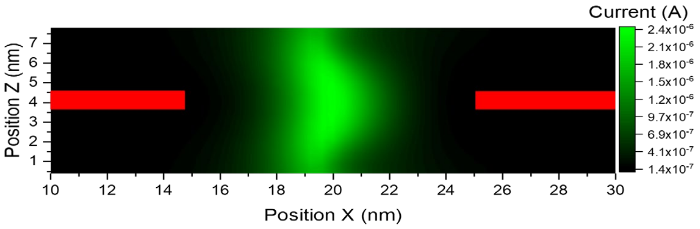

Fig. **2**. Computed electrical current for different position of the electrical charge in the middle plane (y=W/2). The applied voltage is 100mV. Note that the current without the charge is 1.4e-7 A

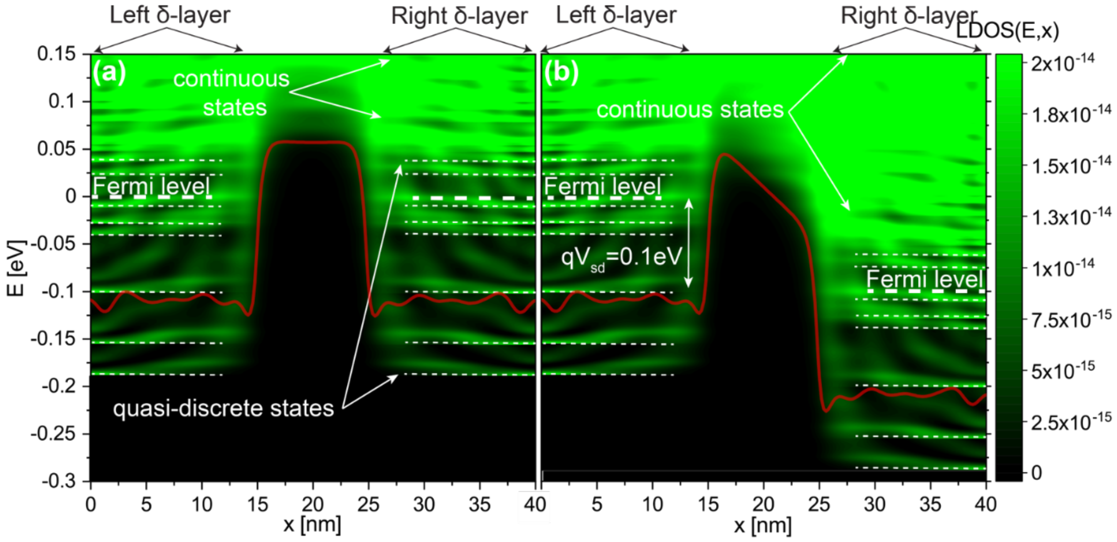

Fig. **3**. Local density of state (LDOS) for δ-layer tunnel junction device shown in Fig. 1: (a) for an applied of 1 mV; (b) for an applied of 100mV. The semi-quantized states in the conduction band are indicated with dashed lines.