Simulation Study on a Quasi Fermi Energy Movement in the Floating Body Region of FITET (Field-induced Inter-band Tunneling Effect Transistor)

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Abstract

Negative-differential conductance (NDC) characteristics as well as negative-differential trans-conductance (NDT) characteristics have been observed in the room temperature I-V characteristics of Field-induced Inter-band Tunneling Effect Transistors (FITETs). These characteristics have been explained with inter-band tunneling physics, from which, inter-band tunneling current flows when the energy bands of degenerately doped regions align, and it does not flow when they don't. FITET is an SOI device and the body region is not directly connected to the external terminal. Therefore, Fermi energy in the body region is determined by electrical coupling among four regions - gate, source, drain and substrate. So, a quasi Fermi energy of the majority carriers in the floating body region can be changed by external voltages, and this causes the energy band movements in the body region, which determine whether the energy bands between degenerately doped junctions aligns or not. This is a key point for an explanation of NDT and NDC characteristics.

In this paper, a quasi Fermi energy movement in the floating body region of FITET was investigated by a device simulation. This result was applied for the description of relation between quasi Fermi energy in the body region and external gate bias voltage.

Keyword: FITET, floating body, inter-band tunneling, negative-differential conductance, negative-differential trans-conductance

I. Introduction

FITET is a three terminal quantum tunneling device, which uses inter-band tunneling effects as a core operation principle, and it has a structure compatible with SOI-MOSFET except for degenerate body region and the intentional omission of lightly doped drain (LDD) region.

This device shows negative-differential conductance (NDC) as well as negative–differential transconductance (NDT) characteristics at room temperature, and these characteristics can be explained by inter-band tunneling between degenerately doped body and source/drain region, assuming that the energy band in the body region move according to the external bias voltages [1,2].

In this paper, the quasi-Fermi energy movements in the floating body region of FITET have been investigated by device simulation [3], which is applied to the analytical SPICE model equation of FITET [4].

II. Device Structure and Experimental Result

Fig.1 shows a cross-sectional schematic of p-FITET, which has n$^+$-doped body and p$^+$-doped source/drain, and on the other hand, n-FITET has p$^+$-doped body and n$^+$-doped source/drain region. It shows NDT and NDC characteristics of

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FITET in room temperature. In these experimental results, peak and valley characteristics depend on whether the energy bands between degenerately doped junctions align or not. Fig. 2 (a), (b) show the typical energy band diagrams for peak and valley characteristics, respectively.

The details of fabrication process sequence and electrical measurement results have been described in [1-2].

III. Simulation Result and Its Model Application

The body region of FITET is not directly connected to the external terminal. Therefore, quasi-Fermi energy in the body region is determined by external terminal voltages. The electron quasi-Fermi energy of p-FITET and the hole quasi-Fermi energy of n-FITET are investigated with surface inversion charge concentrations in Fig. 3. As the magnitude of gate-source bias voltage increases, the quasi-Fermi energy varies in the heavily doped body region. Fig. 4, 5 show the energy band diagram from p^+-source to n^+-body region and from n^+-body to p^+-drain region according to the various external bias voltages by device simulations, which show that quasi-Fermi energy of majority carriers in each junction are changed clearly. From these considerations, quasi-Fermi energy in the body region is related as Eq. (1)

$$E_{F,B} \sim (|V_{GS}| - |V_{IBT}|) / m_C \qquad (1)$$

where V_{IBT} is the turn on voltage of inter-band tunneling, and m_C is the body-effect coefficient related to the electrical coupling of the body region with external bias, and device dimension. Fig. 6, 7 show the electron quasi-Fermi energy movements according to the substrate voltage and the device dimension, which affect the body-effect coefficient. Fig. 8 shows that SPICE simulation results of the analytical model obtained by considering Eq. (1), which show inter-band tunneling current components. Complete analytical model was shown in [4].

IV. Summary

The quasi-Fermi energy movements in the floating body region of FITET have been verified by a device simulation, which is applied to the analytical SPICE model equation.

References

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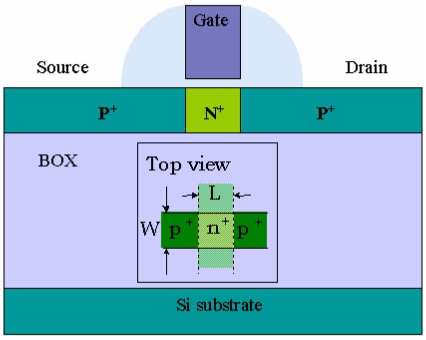
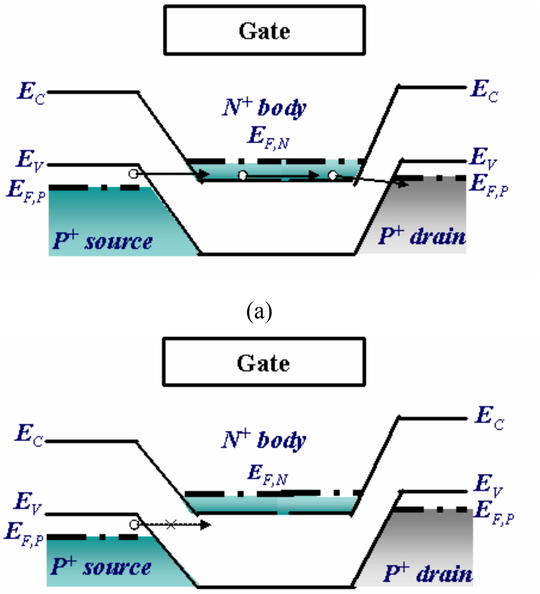


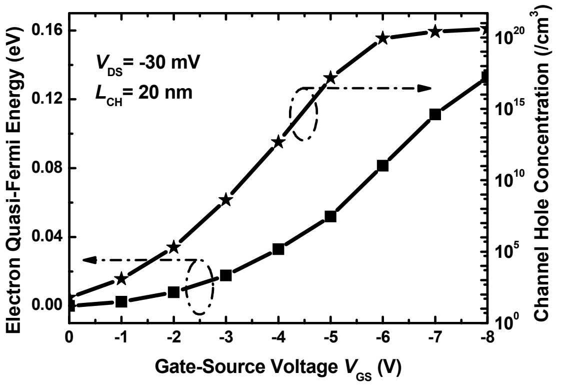
Fig 1. Cross sectional schematic of p-FITET which has a degenerately doped body region



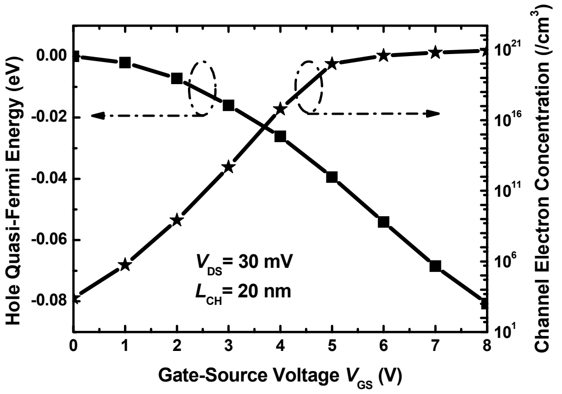
(a)

(b)

Fig. 2. Typical energy band diagrams for (a) peak and (b) valley characteristics.

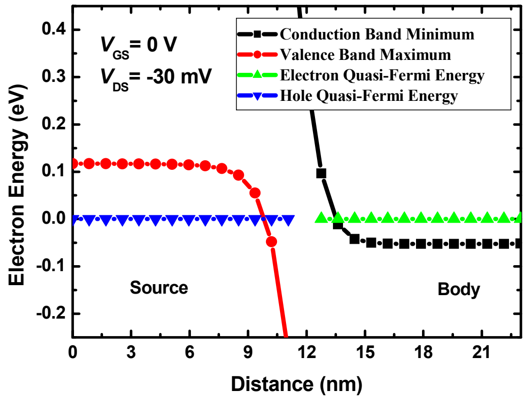


(a)

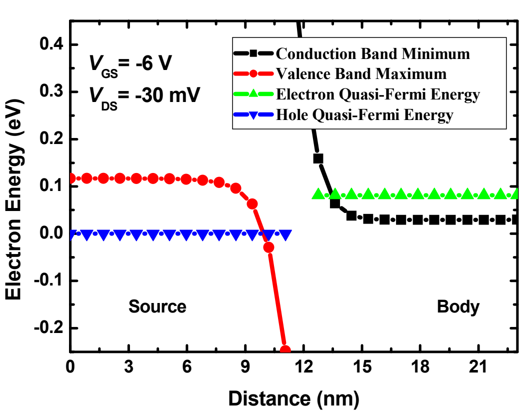


(b)

Fig. 3. Electron quasi-Fermi energy of p-FITET and the hole quasi-Fermi energy of n-FITET in the body region with surface inversion charge concentrations



(a)



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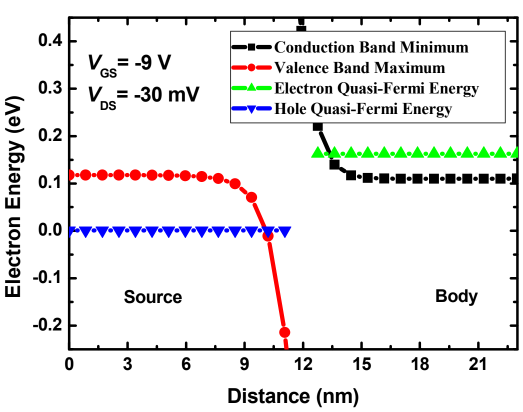
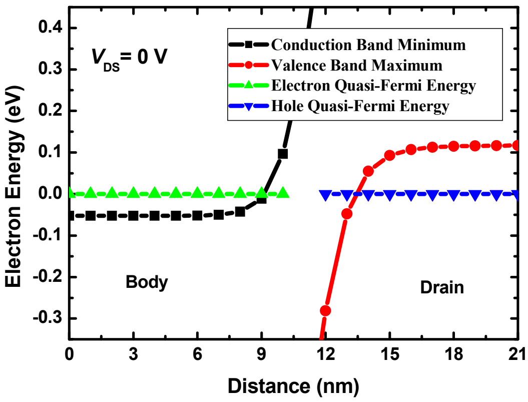
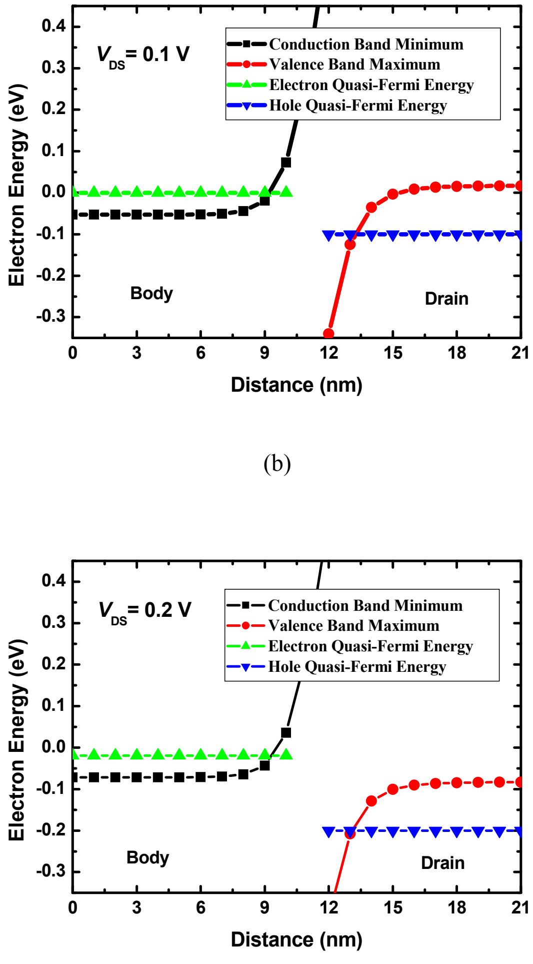


(c)

Fig. 4. Energy band diagrams from p$^+$-source to n$^+$-body region when V_{GS}= (a) 0 V (b) -6 V (*peak*) (c) -9 V (*valley*).



(a)



(b)

(c)

Fig. 5. Energy band diagrams from n^+-body to p^+-drain region when V_{DS}= (a) 0 V, (b) 0.1 V (*peak*) (c) 0.2 V (*valley*).

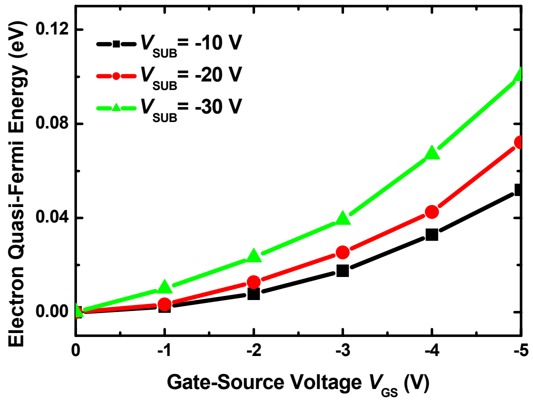


Fig. 6. Dependency of the electron quasi-Fermi energy movement on the substrate voltage

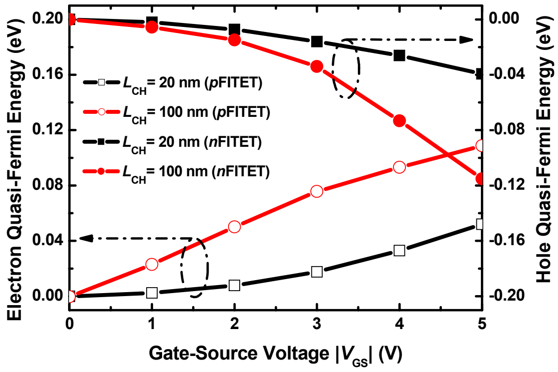
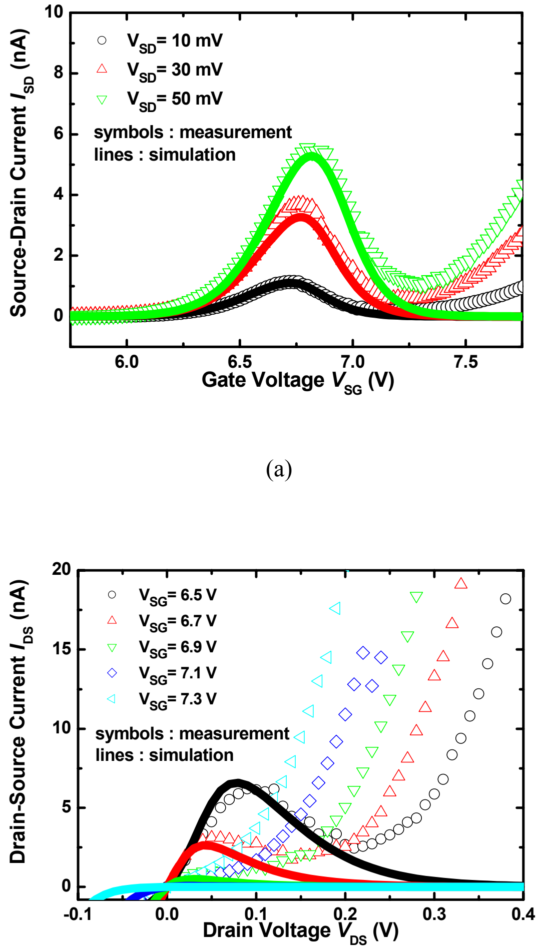


Fig. 7. Dependency of the electron quasi-Fermi energy movement on the device dimension



(a)

(b)

Fig. 8. SPICE simulation result of the analytical model about inter-band tunneling current component in (a) I_D-V_G characteristics and (b) I_D-V_D characteristics