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Development Software of Al-SiO_2-Si MOS IV Characterization in Accumulation Case

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Abstract

In this research we develop a software for calculating IV characteristics of Al-SiO_2-Si MOS in Accumulation case. The software can be used as a electrical characterization tool of MOS structures in order to analyze electrical properties of Al-SiO_2-Si –based MOS in Accumulation case. Simulation results show that tunneling current increase exponentially with increase in oxide voltage.

Keywords: software, IV characterization, Al-SiO_2-Si MOS, accumulation case

1. Introduction

Device size is getting smaller nowadays, which make it a limiting factor for the device's performance. There are several carrier transport models, but the most popular model is drift-diffusion transport model. Quantum effects has become more important and need to be calculated when device's size gets smaller. Several models, that taking account of quantum effects, have put boundaries in order to simplify calculation so that it makes inaccurate modeling (Vexler M. I, et al., 2001, Ranuarez J C, et al., 2006).

Most analytical formulation of tunneling current in Metal-Oxide-Semiconductor (MOS) structure assumes that longitudinal and transversal components of electron movement are uncoupled. Electron transport becomes ballistic when device's size gets smaller. Coupling effects between longitudinal and transversal components of electron movement cannot be ignored when electron velocity is higher than thermal injection velocity (Mao, 2007). Besides, semiconductor is considered as an isotropic (Clerc R, et al., 2002, Mao, 2007). Silicon semiconductor is indirect bandgap material, so has to be treated as anisotropic material (Rahman A, 2005).

When positive or negative bias is applied to ideal MOS capacitor, basically there are three possible cases of what happed to the surface of the semiconductor, accumulation, depletion, and inversion [Sze S.M et al., 2007]. In this research, we calculated tunneling current for accumulation case.

2. Method

Figure 1 shows ideal potential profile of MOS structure in accumulation case. This condition happens when negative voltage (V < 0) is applied to metal side of the MOS. We assumed the semiconductor is highly doped so that bending can be ignored. In accumulation case, majority carrier (hole) will be accumulated near semiconductor and will push electrons to tunnel from metal through oxide into semiconductor. Potential profile is given by the following equation:

$$V(z) = \begin{cases} qV & (metal) \\ \Phi - qV & (oxide) \\ 0 & (semiconductor) \end{cases} \quad (1)$$

For accumulation case, Schrödinger equation is (Mao, 2007)

$$\left[-\frac{\hbar^2}{2m_{ox}^*}\frac{\partial^2}{\partial z^2}+\left(V(z)-\frac{\hbar^2 k_r^2}{2m_{\perp-Al}^*}\left(1-\frac{m_{\perp-Al}^*}{m_{ox}^*}\right)\right)\right]\varphi(z)=E_z^{Al}\varphi(z) \tag{2}$$

where m_{ox}^* is effective electron mass of oxide, $m_{\perp-Al}^*$ is transversal effective electron mass in Al metal region, $\vec{k}_r$ is transversal wave vector of electron in plane parallel to Al/SiO_2 interface, and E_z^{Al} is longitudinal energy of tunneling electron in metal Al. Solution to equation 4 above will be used to obtain transmittance value.

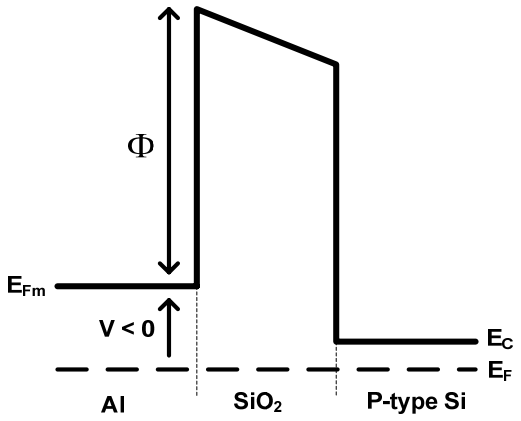

Figure 1. Energy band gap diagram for ideal MOS Al/SiO_2/Si capacitor in accumulation case

The obtained transmittance value will then be used to calculate the density of tunneling current J using this equation [Khairurrijal, et al., 2000],

$$J=\int_0^{\infty}\frac{em_z}{2\pi^2\hbar^3}T(E_z)\left(\int_{E_z}^{\infty}f_R(E)-f_L(E)dE\right)dE_z \tag{3}$$

where fR(E) and fL(E) is Fermi distribution function in the region to the right and left and T(Ez) is transmission coefficient obtained by solving above Schrödinger equation.

3. Results

The software is developed using Mathematica package and utilizing internal functions and libraries available to perform specific calculation of transmittance value and tunneling current characterization. We use Mathematica version 8.0 environment to develop the software. Figure 2 shows the flowchart of the software.

Because of the software used Mathematica's internal library that executed directly by Mathematica's kernel, the developed software cannot run standalone as an executable file (.exe), but need to run from inside Mathematica environment itself.

The software is then used to calculate the probability of electron that can get through depletion region and simulate the graph of tunneling current characteristics to forward bias voltage in Al-SiO_2-Si junction.

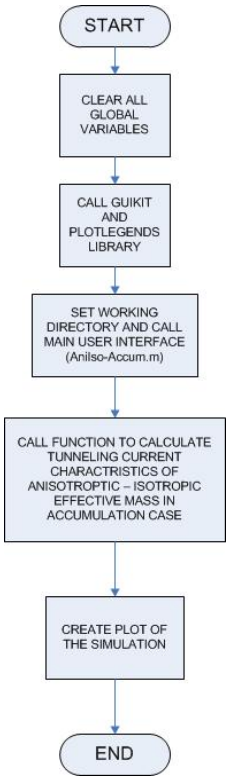

Figure 2. Software flowchart

4. Discussion

The calculation result is shown as a plot between V (oxide voltage) and I (tunneling current), which is shown in the lower area of the software interface. The software interface is shown in Figure 3.

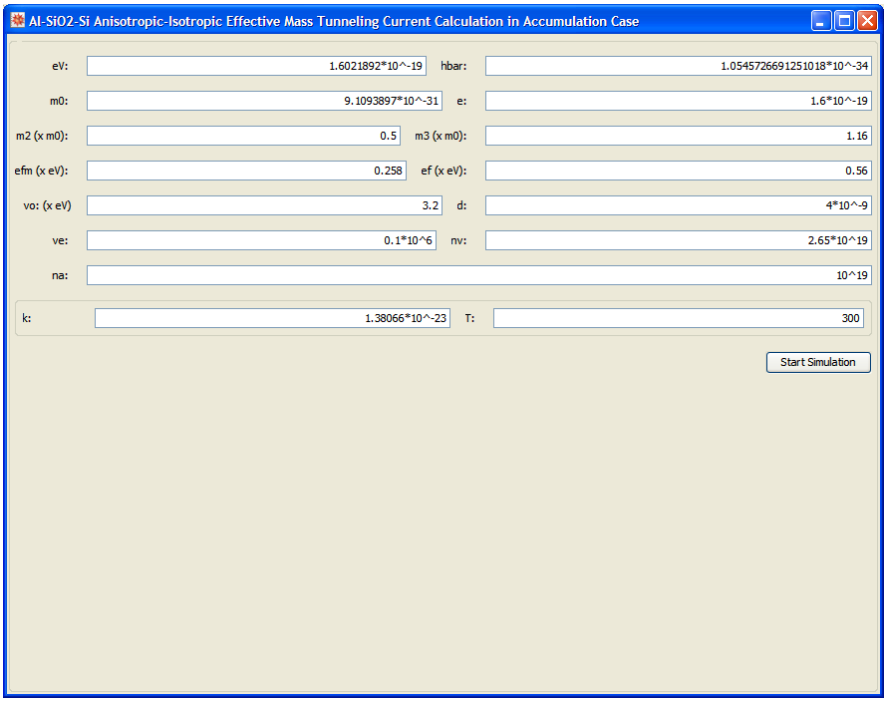

Figure 3. Software user interface.

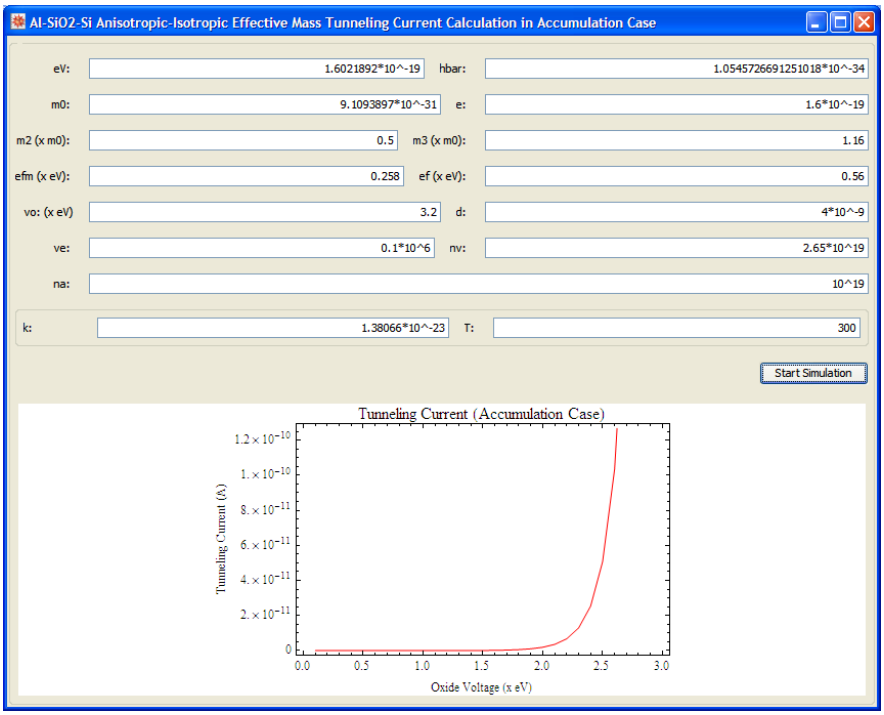

Figure 4. Graph between tunneling current and oxide voltage

The calculation result done by the software is shown in Figure 4. In the accumulation case, electrons move from metal through oxide to semiconductor. Metal and oxide are isotropic materials so they provide the same value of electron effective mass in both calculation models. The same value of electron effective mass in Al and SiO_2 from both calculations leads to the same behavior of the current. From the graph it can be seen that the density of the tunneling current increase exponentially with the increase in oxide voltage.

We have developed the software to simulate the IV characteristics of Al-SiO_2-Si MOS in Accumulation case. The developed software can be used as a learning tool to analyze electrical properties of Al-SiO_2-Si-based MOS in Accumulation case. The result of the simulation has shown that the tunneling current increase exponentially by increase in oxide voltage.

Acknowledgments

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