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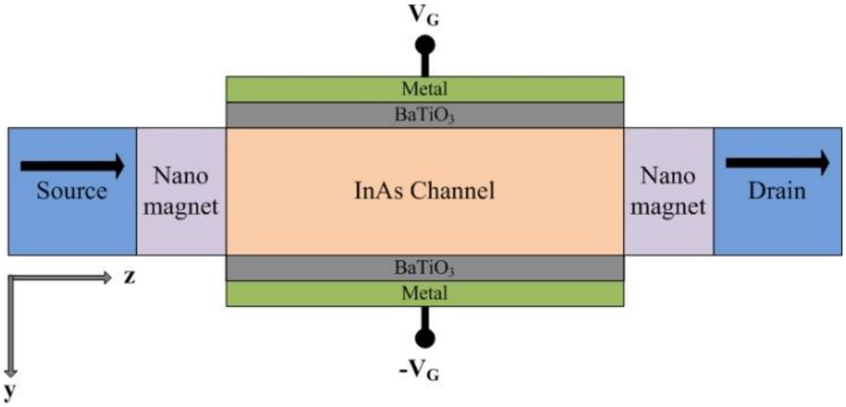
Student Paper

Novel SPINFET: By simultaneous utilization of *Rashba Effect, Zeeman Effect & Negative Capacitance.*

Nadim Chowdhury [a] , Imtiaz Ahmed [a] and Quazi D.M. Khosru [a]

[a] *Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh,* nadim.chow@gmail.com

Miniaturization of device according to the empirical “Moore’s Law” is leading the semiconductor industry towards a looming catastrophe by 2025 when the density of power dissipation on a chip will be ~2MW/cm^2. ITRS termed this impending disaster as “Red Brick Wall” [1]. One way of penetrating this wall is to use the spin degree of freedom of an electron to change the channel conductance of a FET [2] like structure depending upon the applied gate voltage. The use of electron’s spin rather than charge significantly reduces on chip heat dissipation. So it goes without saying that spintronics is the platform of next generation advanced technology. In this work we propose, a novel quantum wire SPINFET by simultaneous utilization of three physical phenomena namely *Rashba-Dresselhaus effect* for flipping the spin of electrons in the channel, *Zeeman effect* for increasing the spin injection efficiency and *Landau–Ginzburg–Devonshire’s (LGD) phenomenological theory* for lowering the threshold voltage.



. Fig.1: Proposed SpinFET Device structure

To simplify the theoretical modeling of the device a number of assumptions have been made which are as follows

1. Spin injection & detection efficiency is 100%.

$$\eta_s = \eta_v = \frac{I_{maj}-I_{min}}{I_{maj}+I_{min}} \tag{1}$$

2. Ferro magnet contacts on the source and drain point do not cause any magnetic field in the channel. To ensure to spin mixing.
3. Random spin relaxation in the channel is assumed to be zero.

By careful application of *Landau–Ginzburg–Devonshire’s (LGD) phenomenological theory* [3] it can be shown that for ferroelectric gate oxide the relation between the charge and the applied gate voltage is given by the following equation.

$$V_g = \alpha_0 Q + \beta_0 Q^3 + \gamma_0 Q^5 + \rho_0 \frac{dQ}{dt} \tag{2}$$

From this the relation between the surface potential Ψ_s and the gate voltage V$_{g.}$

$$V_g = (1+a_1)\Psi_s + a_2 {\Psi_s}^3 + a_3 {\Psi_s}^5 \tag{3}$$

$$\frac{dV_g}{d\Psi_s} \approx (1+a_1) \tag{4}$$

Where, $a_1 = 2\alpha C_s t_{ins}$

$$\Psi_s = \frac{V_g}{(1+a_1)} \tag{5}$$

So, it is evident from the aforementioned equation that if a_1 is negative and $|a_1|<1$ then the Ferroelectric oxide would work as a transformer amplifying the surface potential in the channel. This amplified surface potential will significantly increase the spin orbit interaction of the electron with the gate voltage. So the Ferroelectric Oxide acts as a negative capacitance in this case.

The nano-magnets at the source and drain contact are meant to increase the spin injection and detection efficiency by further splitting the energy of up spin and down spin electrons by means of Zeeman Effect depending upon the direction of the applied magnetic field by nano-magnets.

The zeeman effect splits the energy of upspin & downspin by

$$\Delta E = z\hbar\omega_0 \tag{6}$$

Where, $\omega_0 = \frac{|e|B_0}{2m_e}$ called Larmor frequency.

Now that we have discussed the theoretical framework of the proposed device, we can go for developing the model for useful device parameters like threshold voltage.

According to the Larmor formula [4]-[5] angular spin frequency of an electron is given by

$$\Omega = \frac{d\Phi}{dt} = \frac{g\mu_B\vec{B}_{Rashba}}{\hbar^2} E_y V_z = \frac{2m^* a_{46}}{\hbar^2} E_y V_z \tag{7}$$

So,

$$\frac{d\Phi}{dz} = \frac{\frac{d\Phi}{dt}}{\frac{dz}{dt}} = \frac{2m^* a_{46}}{\hbar^2} E_y \tag{8}$$

Therefore spatial rate of spin precession

$$\frac{d\Phi}{dz} = \frac{2m^* a_{46}}{\hbar^2} E_y \tag{9}$$

So, spin precession for travelling through the channel

$$\Phi = \frac{2m^* a_{46}}{\hbar^2} E_y L \tag{10}$$

For a spin FET the threshold voltage is defined as the gate voltage that would cause a spin precession of 180^0 while travelling through the channel.

Now electric field E_y for the proposed device

$$E_y = \frac{2V_g}{(1+a_1)t_s} \tag{11}$$

For threshold voltage

$$\Phi = \pi \tag{12}$$

$$\pi = \frac{2m^* a_{46}}{\hbar^2} L \frac{2V_g}{(1+a_1)t_s} \tag{13}$$

$$V_{th} = \frac{\pi\hbar^2(1+a_1)t_s}{4m^* a_{46} L} \tag{14}$$

Here, $(1+a_1) < 1$

$$V_{th} \approx \frac{\pi\hbar^2 t_s}{4m^* a_{46} L\beta} \tag{15}$$

where $\beta = \frac{1}{(1+a_1)}$ (16)

So, introduction of Fe-oxide reduces the threshold voltage. On the basis of aforementioned theoretical demonstration of the proposed device, it can be said that the proposed device can outperform the conventional spinfet.

References

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