Student Paper

Properties of InAs- and Silicon-Based Ballistic Spin Field-Effect Transistors Operated at Elevated Temperature

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A spin field-effect transistor (SpinFET) is composed of source and drain contacts which sandwich a semiconductor region [1]. Current modulation is achieved by electrically tuning the gate voltage dependent strength of the spin-orbit interaction in the semiconductor region.

We first investigate the properties of an InAs SpinFET. Figure 1 demonstrates the increase of the period of the tunneling magnetoresistance TMR = $(G_{\uparrow\uparrow} - G_{\uparrow\downarrow})/G_{\uparrow\downarrow}$ [2] oscillations, as the length L of the semiconductor channel decreases. In order to operate a SpinFET at room temperature by adjusting the value of the band mismatch δE_c, the TMR oscillations must have a period larger than k_BT = 25meV. Figure 2 shows that even a channel as short as 50nm does not provide a sufficiently long period of the TMR.

Following [2] and [3] we are taking into account delta-function barriers with a strength $z \equiv 2m_f U/\hbar^2 k_F$ with $k_F \equiv \sqrt{2m_f E_F/\hbar^2}$, where m_f is the effective mass in the contacts, $\hbar$ is the reduced Plank constant, U is the potential barrier height, E_F is the Fermi energy. As the barriers become stronger, the quantization of the energy in the semiconductor channel becomes more pronounced. The energy quantization is responsible for the appearance of the sharp peaks on the TMR dependence on δE_c clearly seen in Figure 3. An excellent feature following from Figure 3 is that the TMR value remains positive in a broad range of δE_c. The sign and the values of the TMR depend on the strength of the spin-orbit interaction. It then follows, that in the presence of the barriers between the contact and the channel, the values of the TMR must depend on the strength of the spin-orbit interaction controlled by the gate voltage at elevated temperatures as well.

Figure 4 displays the TMR dependence on the strength of the spin-orbit interaction at different temperatures. The TMR modulation is preserved at elevated temperatures thus opening a practical possibility to modulate the TMR by changing the value of the spin-orbit interaction even at room temperature.

Finally we study properties of a SpinFET built on a silicon fin. Following [4] the spin-orbit interaction is treated in the Dresselhaus form. A stronger dependence on the spin-orbit interaction parameter β for fins of [100] orientation is observed in Figure 5. Figure 6 shows that the TMR modulation is preserved in the SpinFET at higher temperatures. This may open the path towards constructing a silicon-based SpinFET operating at room temperature.

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References

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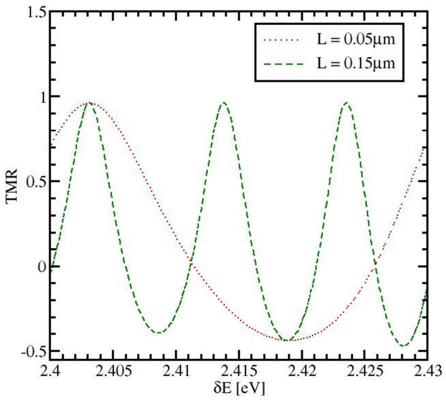

Fig. 1 TMR dependence on the value of δE_c for E_F = 2.47eV, z = 0.

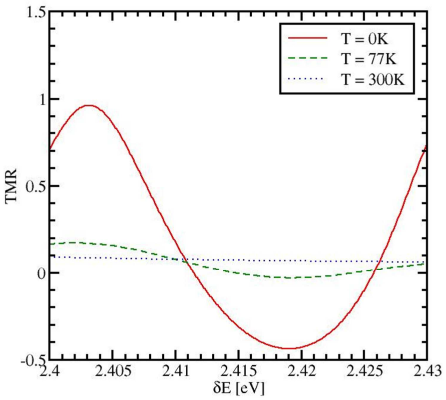

Fig. 2 Same as Fig. 1 for L = 0.05μm.

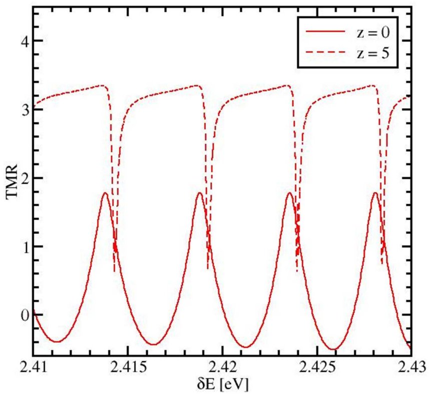

Fig. 3 Same as Fig. 1 for L = 0.3μm.

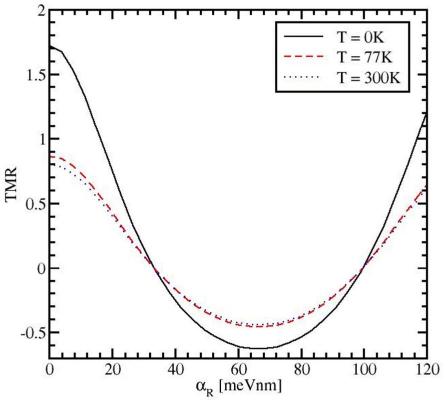

Fig. 4 TMR dependence on the value of the spin-orbit interaction for L = 0.05μm, δE_c = 2.42eV, z = 5.

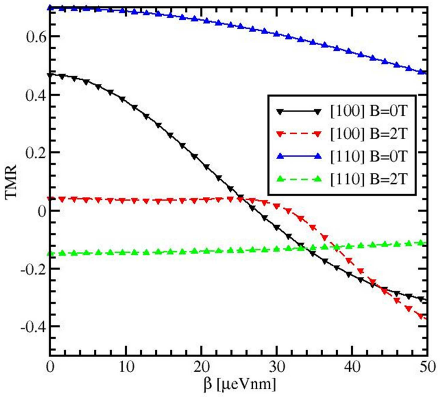

Fig. 5 TMR dependence in a Si-based SpinFET on the value of the Dresselhaus spin-orbit interaction for L = 5μm, z = 2.

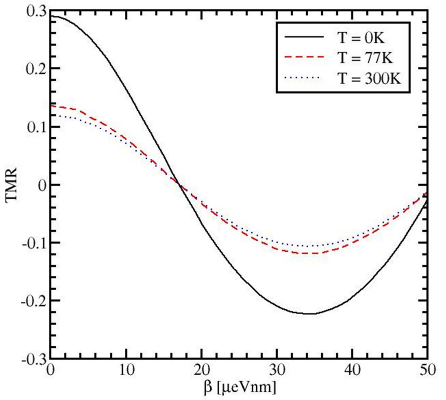

Fig. 6 TMR dependence in a Si-based SpinFET on the value of the Dresselhaus spin-orbit interaction for L = 8μm, z = 3, B = 0T.