Student Paper

Influence of a Space Charge Region on Spin Transport in Semiconductor

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Novel microelectronic devices have to be smaller and faster than the traditional ones and be more efficient to reduce power consumption of future integrated electronic circuits. Spin-based electronics (spintronics) is a promising alternative which takes the spin degree of freedom into account. Silicon is the basic element of modern charge-based microelectronics and at the same time it possesses several properties attractive for spin-driven applications [1], especially the long spin lifetime and well established processes and technology. Understanding the details of the spin propagation in silicon structures is therefore a key for novel spin-based device application. Efficient spin injection in silicon [1] is a must for success of spin-driven applications. An evidence that an inclusion of the space charge effects at the interface boosts the spin injection by an order of magnitude was recently presented [2].

In this paper we study the electron spin and charge transport in an n-doped silicon bar with spin-dependent conductivity. As a sanity check we first reproduce the analytical solution of the spin density (Fig. 1) under any arbitrary external electric field when the charge is neutral at the boundaries and hence no space charge effects are present [3]. We can vary the spin polarization factor (SP) at the left boundary by maintaining the charge neutrality (CN) conditions. If the charge current is set to zero, the spin current reaches its maximum when SP is 1.

Additionally we carry out simulations considering the charge accumulation and depletion at the boundaries. Injection (release) of charge causes a non-zero charge current in the device. For the simulations, we assume an electron mobility of 1400 $cm^2V^{-1}s^{-1}$, a doping concentration $N_D=10^{16}$ cm^{-3}, a silicon intrinsic spin diffusion length of 1 μm and a bar length 3 μm. A significant spin and charge accumulation (depletion) can thereby also be introduced and the spin current can diffuse out of this region. This spin current can be tuned by varying the charge accumulation and the external electric field. The charge current variation with the charge chemical potential (μ_{Chem}) at the interfaces is shown in Fig. 2. The nonlinear dependence of the charge current on μ_{Chem}, when the device moves to depletion from accumulation (Fig. 2), is caused by charge screening. The voltage is therefore further tuned to sustain a fixed charge current (zero or non-zero). We observe a significant decrease of the spin current (Fig. 3), spin density (Fig. 4), and the carrier density (Fig. 5) during the depletion. Under accumulation, the spin current shows an upper threshold [4] (Fig. 3) and strong charge screening within the Debye length (λ_D) from the interface is noticed. It is also noticed that, when SP is 1, the spin current at λ_D from the interface for charge accumulation is the same as for charge neutrality at the interface (Fig. 6).

The presence of charge accumulation as well as depletion thus significantly and distinguishably influence the spin transport property both at interface and the bulk. These new effects are providing additional means for designing efficient spintronics devices.

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References

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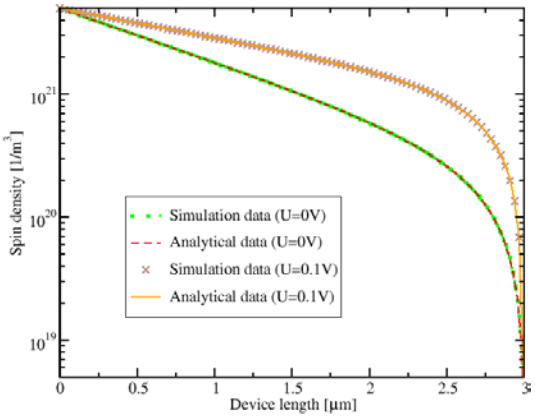

Fig 1: A comparison of simulated and analytical data for spin density, showing closeness (SP=0.5, U: applied voltage).

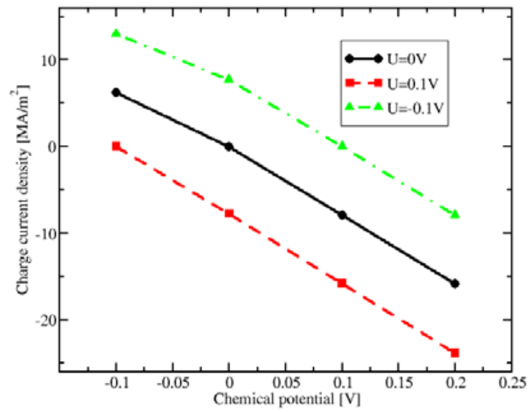

Fig 2: Variation of the charge current density with the chemical potential with an external voltage (U) is as parameter.

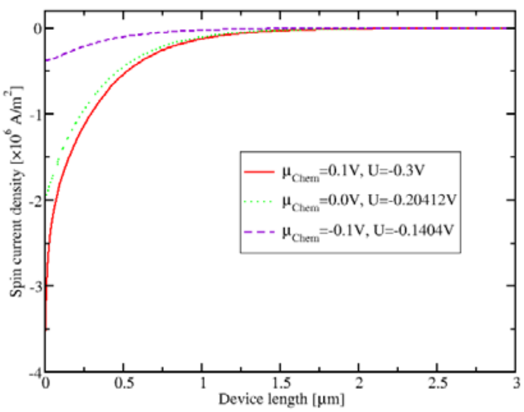

Fig 3: Spin current under charge accumulation (depletion) at the left boundary. The charge current is kept fixed (15.8MA/m^2) by tuning the voltage.

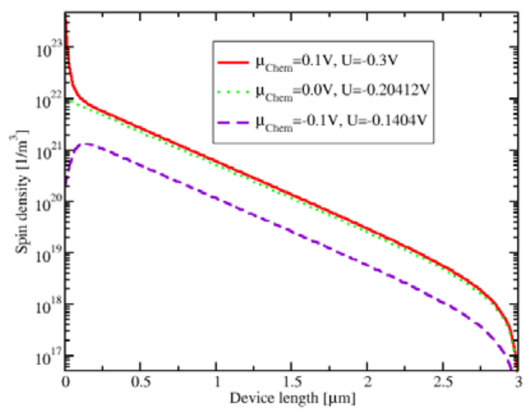

Fig 4: Variation of spin density under Fig. 3 condition, signifying a large drop of spin concentration (both at interface and the bulk).

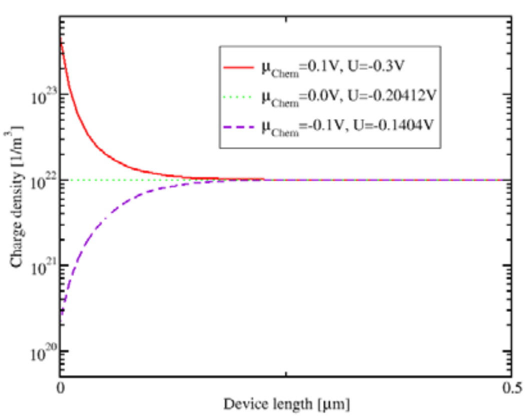

Fig 5: Electron concentration under Fig. 3 condition, implying a drop of carrier near the left boundary under the charge depletion.

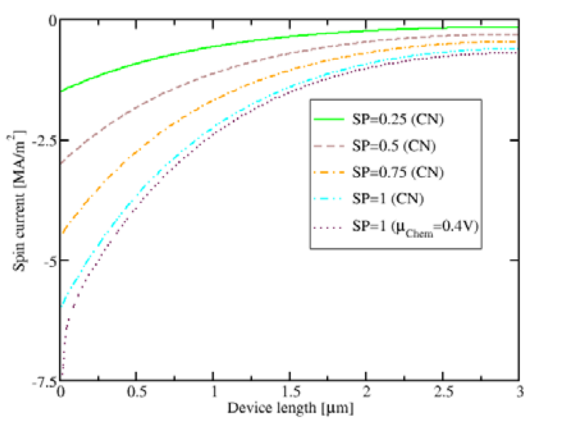

Fig 6: Spin current with SP (under CN). One plot is also shown considering high charge accumulation (μ_{Chem}=0.4V) (zero charge current).