Spin Dependent Injection Model for Monte Carlo Device Simulation

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Nowadays, there is great interest in the study and development of semiconductor devices based on the manipulation and control of the electron spin (Spintronics [1]). These devices must have an efficient spin-polarized electron injection at room temperature so that they can be used in practical applications. Ferromagnetic-metal/semiconductor structures are a possibility to achieve this goal [2]. On the other hand, the Monte Carlo method for the study of electronic transport in semiconductor devices is a widely used technique [3]. In this work we present a spin dependent injection model suitable for use with Monte Carlo (MC) simulators.

The electrical spin injection from ferromagnetic contacts can be thought of in terms of a spin-dependent contact resistance [4]. Physically, this is typically achieved by means of a tunnel barrier between the contact and the semiconductor. In our model, two spin states are considered ($\uparrow$ and $\downarrow$) and they are injected in a previously chosen proportion $F = n_\uparrow/n_\downarrow$. A two terminal ballistic device is simulated (see Fig. 1), in which electrons are injected from both terminals (c = source s or drain d) and tunneling probabilities are defined ($P_c^\uparrow$ and $P_c^\downarrow$). The injection rates are calculated following the work of Oriols *et al.* [5]. When an electron is to be injected, a random number r uniformly distributed between zero and one is generated and if $r < P$ the carrier is successfully injected. A similar procedure is done when a carrier reaches a contact from the device region. Simulations were done using an ensemble Monte Carlo code coupled to a 3D Poisson solver, where carriers move ballistically inside the device according to the semiclassical equations of motion.

As expected, the current grows with the value of P (Fig. 2), indicating a decrease of the contact resistance. In order to evaluate the accuracy of the algorithm used, resistances were calculated by a linear fit to the I-V curves, finding good agreement with the expected [6] $(1 - P)/P$ behavior (Fig. 3). The method presented here reproduces the fundamental physics of a spin dependent resistance and can easily be adapted to standard Monte Carlo codes.

References

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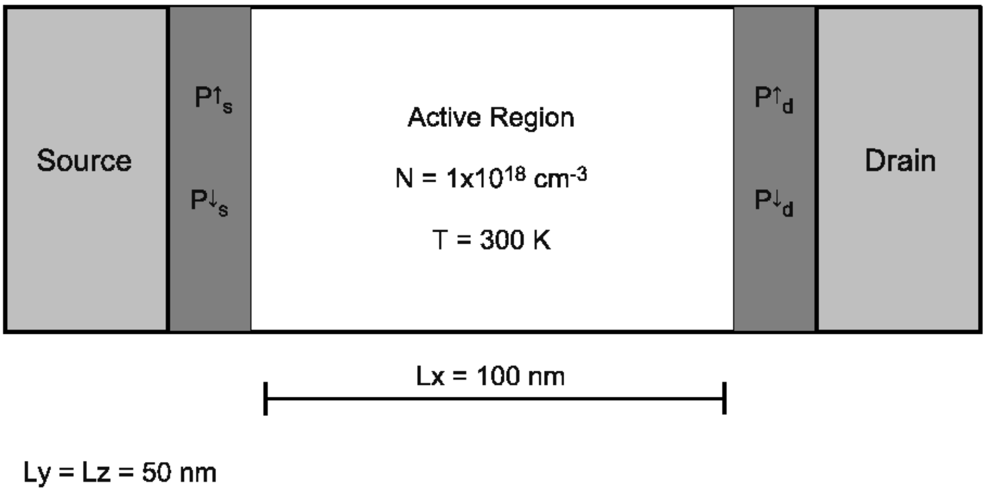

Figure 1: Schematic representation of the device structure under investigation

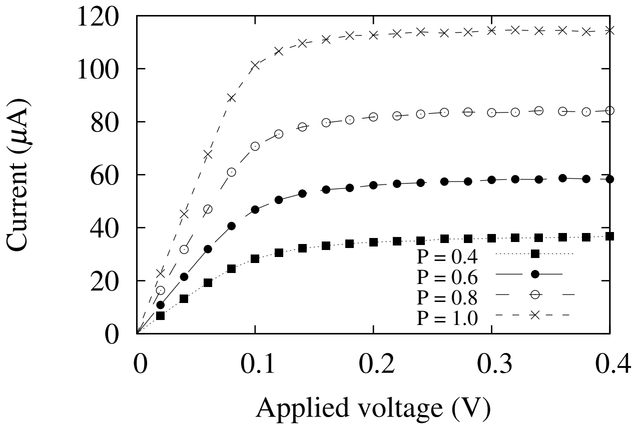

Figure 2: I-V curves for different values of Tunnel Probabilities (P) using $F = 1$

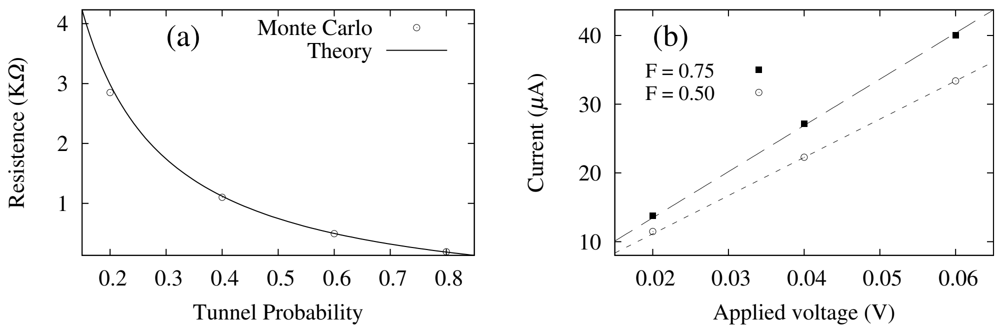

Figure 3: (a) Resistance Values as a function of the Tunnel Probability using $F = 1$. Points=This Work. Line= 746 (1-P)/P Ω. (b) I-V curves for two different fractions F of spin injected compared to $I = V[F/(R_i + 2R_\uparrow) + (1 - F)/(R_i + 2R_\downarrow)]$ where R_i is the resistence for $P = 1$ and $R_{\uparrow/\downarrow}$ the resistence of the channel for the state up or down.