Scattering-Dependence of Bias-Dependent-Magnetization-Switching in Ferromagnetic Resonant Tunneling Diodes

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It has been predicted on the basis of ballistic quantum transport theory and simulation that the Curie temperature (T_C) of a ferromagnetic resonant tunneling diode (FRTD) – i.e. an RTD with a dilute ferromagnetic semiconductor (DFS) well – will switch with increasing bias voltage (V) from its equilibrium value to nearly zero in two steps [1]. Here we study the effect of scattering on the magnetization switching in this system. Quantum transport in the Keldysh formalism, including the phenomenological Buttiker probe scattering model, is simulated self-consistently with the Poisson equation for electrostatics; together with the mean-field description of ferromagnetism in DFS materials, this yields the T_C – V characteristics of an FRTD.

The scattering strength is varied and its effect on the T_C – V and I – V characteristics shown in Fig. 1 and Fig. 2 respectively. Transport in an RTD can be classified into three regimes by scattering strength [2]. The first is the 'coherent transport' regime where the broadening of the transmission peak due to the left and right barriers, shown in Fig. 3, is much greater than the broadening due to scattering. This corresponds to the least scattering and the sharpest T_C – V profile. When the broadening due to scattering is greater than the 'coherent broadening', we have the 'sequential transport' regime. We see that, in this case, the steps are smoothed out but discernible. At still stronger scattering, one enters the regime where the resonance in the well is completely destroyed, as evidenced by the disappearance of the negative differential resistance (NDR) region in the I – V curve and the steps in the T_C – V. It is seen from Fig. 1 that the first step in the T_C – V is almost completely washed out somewhere between the second and third regimes – the relative robustness of the second transition can be explained on the basis of the asymmetry in the barriers at non-zero bias. The decrease in the equilibrium T_C with scattering is seen to be specific to our choice of device parameters; the broadening of the density of states (DOS) moves more of it outside the range of filled states, and decreases the contribution to the spin susceptibility, as seen from Fig. 4.

Finally, by correlating the scattering time to a bulk mobility, we see that it would require much larger than typical [3] scattering for the device to enter the sequential regime. This augurs well for the experimental observability of the magnetization switching effect.

[1] Swaroop Ganguly, L.F. Register, S. Banerjee and A.H. MacDonald, *Phys. Rev. B* **71**, 245306 (2005).

[2] S. Datta, *Electronic Transport in Mesoscopic Systems* (Cambridge University Press, 1995); Chapter 6.

[3] B.D. McCombe, X.Liu *et al.*, http://mccombe.physics.buffalo.edu/miscdoc/GaAs-Mn_Transport.pdf, (2004). A typical measured mobility is $2700 cm^2 V^{-1} s^{-1}$, with the measured effective mass having the heavy hole mass value.

ISBN 3-901578-16-1

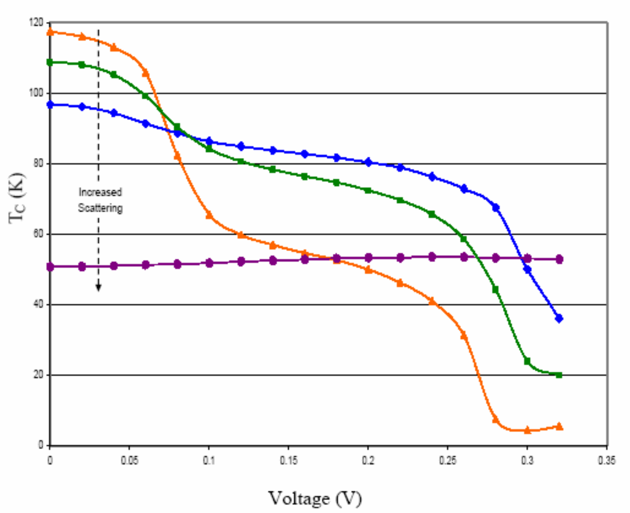

Fig. 1. T_C-V curve for ferromagnetic RTD in the presence of scattering. Scattering is modeled with Buttiker probes with associated lifetime $\tau = \infty$ (orange triangles) - coherent, 41fs (green squares) - sequential, 16.4fs (blue diamonds), and 2.5fs (violet discs) – no resonance. Note that the first step in the T_C-V is much more broadened out than the second.

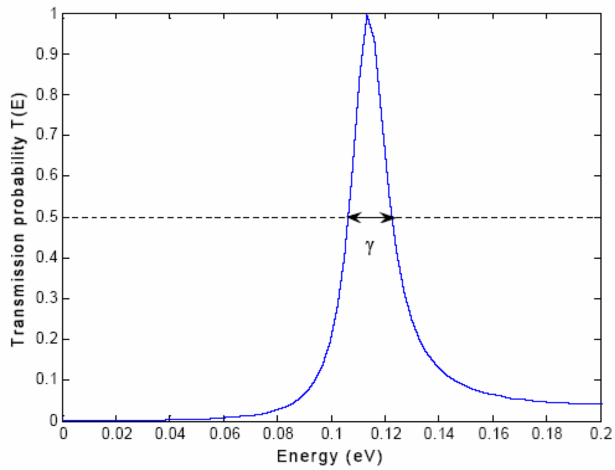

Fig. 2. Transmission probability vs. energy for the RTD in equilibrium in the absence of scattering. This is used to calculate the 'coherent broadening' γ – that due to the barriers – as shown.

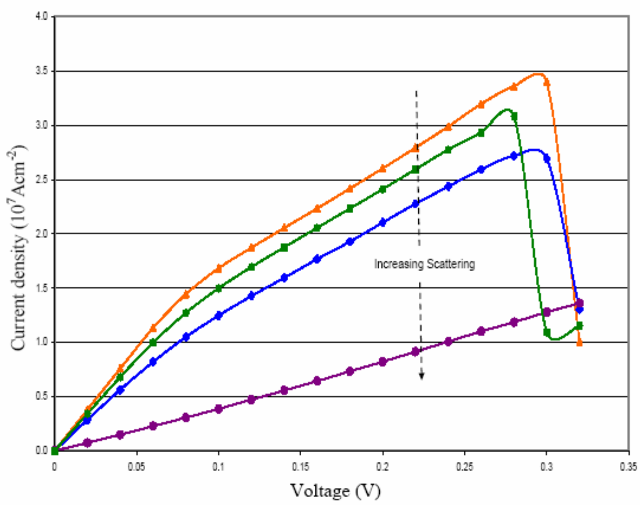

Fig. 3. I-V curve for ferromagnetic RTD in the paramagnetic regime in the presence of scattering. Scattering is modeled with Buttiker probes with associated lifetime $\tau = \infty$ (orange triangles), 41fs (green squares), 16.4fs (blue diamonds), and 2.5fs (violet discs).

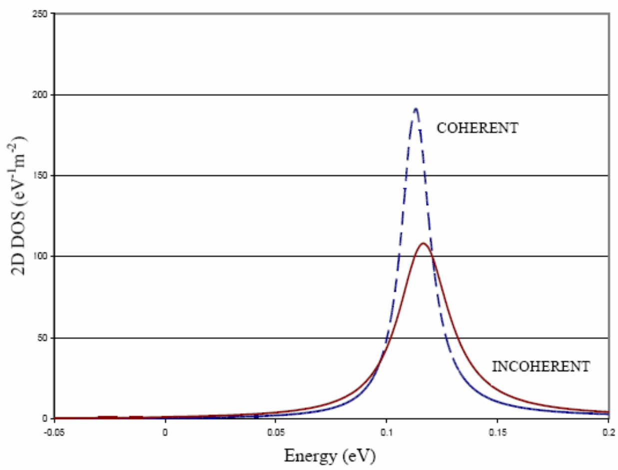

Fig. 4. Equilibrium 2D DOS vs. energy in the well region of the RTD with and without scattering. A large fraction of the DOS in the coherent case (broken blue) is seen to be within the chemical potential μ=0.15eV than in the incoherent or sequential case (solid red). This gives a larger spin density, and hence T_C in equilibrium for the coherent case.