Poster

LOCALIZED SPIN REVERSAL BY SPIN INJECTION IN A SPIN QUANTUM DOT: A MODEL CALCULATION

Satoshi Kokado, Kazumasa Ueda, Kikuo Harigaya, and Akimasa Sakuma
Shizuoka University, Hamamatsu 432-8561, Japan
AIST, Tsukuba 305-8568, Japan
Tohoku University, Sendai 980-8579, Japan

tskokad@ipc.shizuoka.ac.jpT

Magnetization reversal by spin injection, in which the magnetization of a ferromagnet (FM) is reversed by injecting a spin-polarized current into the FM, is one of the most interesting topics in spin-electronics. Recently, such phenomena have been experimentally observed in FM/non-magnetic film/FM junctions [1], and those have been analyzed by using theoretical models, where the magnetization of the FM is described by classical spins [2]. On the other hand, theoretical studies for quantum spin reversal by spin injection have scarcely been reported so far.

In this paper, we theoretically studied the quantum spin reversal by spin injection in a dot having a quantum spin (a spin quantum dot). Consequently, we derived the spin reversal time of the quantum spin and the transmission rate of the conduction spin.

As shown in Fig. 1(a), we consider a model, in which the quantum spin *S* with a uniaxial anisotropy energy showing a bistable potential is contacted by two electrodes with antiparallel spin-polarization. Many conduction spins flow from the left electrode (L) to the right electrode (R) one by one [3]. Here, the L has an energy level of up spin, while the R has *N* energy levels of down spin. Note that *N* levels of R are set by considering inelastic processes of conduction spins giving and taking energies with the quantum spin (the localized spin).

The interaction Hamiltonian obtained from the second order perturbation is written by,

$$V=|J|\sum_{R}\left(c^{+}_{R\downarrow}c_{L\uparrow}S_{+}+c^{+}_{L\uparrow}c_{R\downarrow}S_{-}\right),$$

where $c^{+}_{i\sigma}$ ($c_{i\sigma}$) is the creation (annihilation) operator of an electron with σ-spin (↑ or ↓) at the *i*th electrode (L or R), and $S_{\pm}=S_x \pm i S_y$. Furthermore, *J* represents the exchange interaction between the conduction spin and the localized spin. This interaction acts while each conduction spin runs through the dot. Also, it is assumed that the localized spin canted by the conduction spin is not rapidly relaxed, and it interacts with the subsequently injected conduction spin.

On condition that the initial state of the localized spin is $S_z=-S$, we solve a time dependent Schrödinger equation. From the time dependence of the probability density, the spin reversal time t_{SR} is obtained as $t_{SR}=\sum_{Sz=-S}^{S-1}\Delta t_{Sz}$,

$$\Delta t_{Sz}=\frac{h}{4|J|\sqrt{N(S-S_z)(S+S_z+1)}},$$

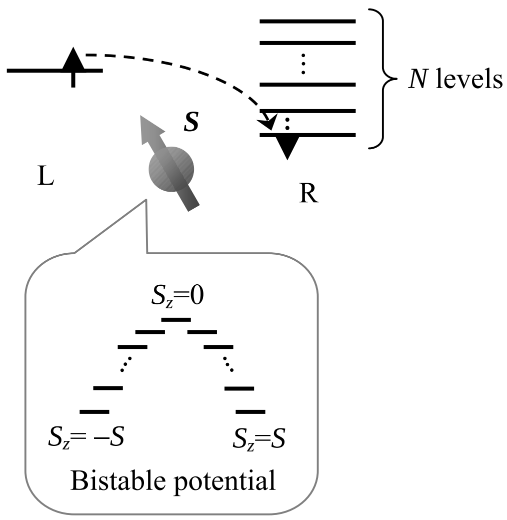
with *h* being the Planck constant, where Δt_{Sz} denotes time to transform the localized spin from S_z to S_z+1 , and also it is the transmission time of one conduction spin. Figure 1(b) shows *S* dependence of $t_{SR}\times\sqrt{N}|J|/h$. With increasing *S*, $t_{SR}\times\sqrt{N}|J|/h$ monotonically increases and comes close to $\pi/4$, which is obtained in the classical spin limit. We believe that the spin reversal is realized when a relaxation time of the localized spin τ_{spin} satisfies the relation of $\tau_{spin} > t_{SR}$.

In addition, we investigate the transmission rate of the conduction spin $1/\Delta t_{Sz}$ for *S*=10, 20, 30 in the case of *N* =100. In Fig. 1(c), $1/\Delta t_{Sz}$ is plotted for the elapsed time $t_{Sz}\left(=\sum_{i=-S}^{Sz}\Delta t_i\right)$, where t_{Sz} means the total time to transform the localized spin from $-S$ to S_z+1. The transmission rate $(1/\Delta t_{Sz})\times h/|J|$ for each *S* exhibits a single peak. At each $t_{Sz}\times|J|/h$, $(1/\Delta t_{Sz})\times h/|J|$ becomes large with increasing *S*.

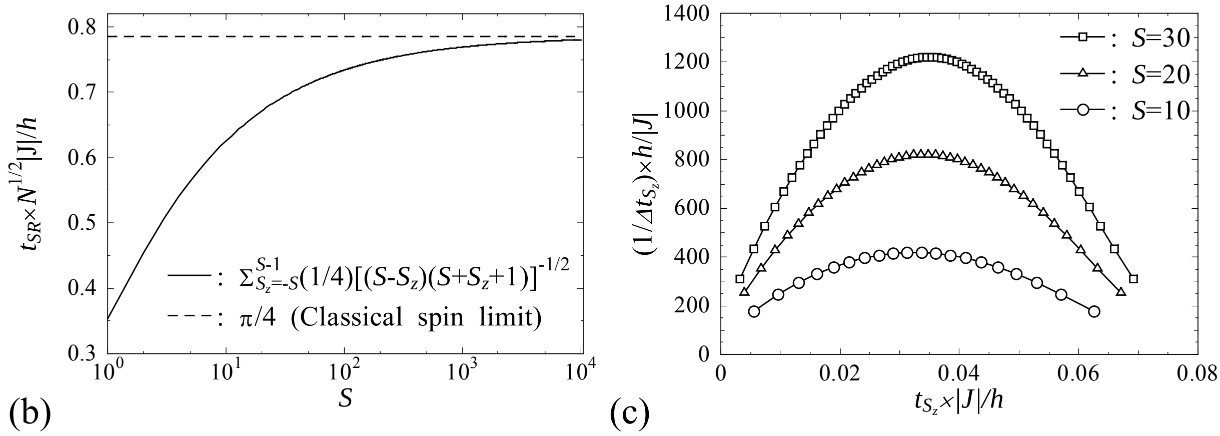
References:

[1] E. B. Myers, D. C. Ralph, J. A. Katine, R. N. Louie, and R. A. Buhrman, Science **285** (1999) 867.
[2] For example, see C. Heide, P. E. Zilberman, and R. J. Elliott, Phys. Rev. B **63** (2001) 64424.
[3] For example, see M. Eto, T. Ashiwa, and M. Murata, J. Phys. Soc. Jpn. **73** (2004) 307.

Figures:



(a)



(b) (c)

Figure 1 (a) A model of the spin quantum dot. (b) Spin *S* dependence of the spin reversal time t_{SR} [for convenience, $t_{SR}\times\sqrt{N}|J|/h$ vs *S*]. (c) The elapsed time t_{Sz} dependence of the transmission rate $1/\Delta t_{Sz}$ [for convenience, $(1/\Delta t_{Sz})\times h/|J|$ vs $t_{Sz}\times|J|/h$] for *S*=10, 20, 30 in the case of *N* =100.