Poster

A Localized Quantum Spin Reversal by Spin Injection in A Spin Quantum Dot: Effect of Spin Relaxation

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The single-atom memory is expected to be an ultimate microscopic element of the data storage device. Recently, towards development of such a memory, single quantum spin systems with bistable states have been studied extensively [1-3]. In particular, it has been experimentally reported that a single atomic spin (S=2) of an Fe atom on CuN surface has the uniaxial anisotropy energy, $-|D|S_z^2$, which shows the bistable potential between $Sz=-S$ and S, and $|D|$ is evaluated to be 1.55 ± 0.01 meV [1].

For the spin system with $-|D|S_z^2$, we consider the manipulation of spin states. As a method, we propose "a quantum spin reversal induced by spin injection in a spin quantum dot", where the transition from $S_z=-S$ to S is induced by the spin injection [2, 3]. It should be noted here that atomic vibration may give strong influence to the spin reversal, because the energy of the atomic vibration is usually in the range of 0.4 meV - 40 meV (100 GHz - 10 THz) which is close to the energy-level spacing of spin systems, and then the spin relaxation may be enhanced.

On the other hand, we expect that the other bistable spin systems such as S=1, 3/2, 5/2 will be synthesized in the future. An obvious difference of energy levels between the integer spins and half-integer ones, which is shown in Fig. 1, may make some sort of difference to the reversal.

In this paper, we study the spin reversal induced by the spin injection for electrode/spin quantum dot/electrode junctions, in which the dot has a localized spin $\boldsymbol{S}$ with S=1, 3/2, 2, 5/2 (see Fig. 1) [2, 3]. Furthermore, $\boldsymbol{S}$ shows $-|D|S_z^2$, and it is coupled to the vibration of the dot (VOD). Here, the spin relaxation time due to the $\boldsymbol{S}$-VOD interaction, τ, is introduced. For the initial state of $S_z=-S$, we consider a situation in which up-spin electrons exhibit the spin-flip tunnelling from the left electrode to the right one and then an exchange interaction acts between the electron spin and $\boldsymbol{S}$. Using the master equation and the Fermi golden rule, we investigate the time t dependences of the expectation value of the localized spin $\langle S_z \rangle$, the current, and the expectation value of the number operator of the VOD for any τ's.

As a result, we find that spin systems of S=3/2, 5/2 tend to exhibit the spin reversal compared to systems of S=1 and 2. In Fig. 2, we show t dependence of $\langle S_z \rangle$ of S=1, 3/2, 2, 5/2, at temperature T=10 K, where $|D|$ is 1 meV, and the voltage between the electrodes is 5 meV. The systems of S=3/2, 5/2 give rise to the spin reversal irrespective of τ, while the systems of S=1, 2 do not exhibit the reversal for τ=0.1 ns and 0.01 ns.

This behavior can be explained by taking into account the transition rates from $S_z=-S$ to S, where the transition rate due to "the conduction electron spin-$\boldsymbol{S}$" interaction (due to the $\boldsymbol{S}$-VOD interaction) is represented by $W^{\text{el-}\boldsymbol{S}}$ ($W^{\boldsymbol{S}\text{-VOD}}$), with $W^{\boldsymbol{S}\text{-VOD}}$ being a function of τ. Roughly speaking, $W^{\text{el-}\boldsymbol{S}}$ contributes to the spin reversal, while $W^{\boldsymbol{S}\text{-VOD}}$ tends to suppress the reversal. The magnitude of the ratio of transition rates $|W^{\boldsymbol{S}\text{-VOD}}/W^{\text{el-}\boldsymbol{S}}|$ of S=3/2, 5/2 is much smaller than that of S=1, 2, because the transition due to the $\boldsymbol{S}$-VOD interaction between $S_z=-1/2$ and 1/2 is forbidden. Therefore, the systems of S=3/2, 5/2 are apt to exhibit the spin reversal compared to S=1, 2.

References:

[1] C. F. Hirjibehedin *et al.*, Science **317** (2007) 1199.

[2] S. Kokado *et al.*, preprint.

[3] As a related literature, see S. Kokado *et al.*, Phys. Rev. B **76** (2007) 054451.

Figures:

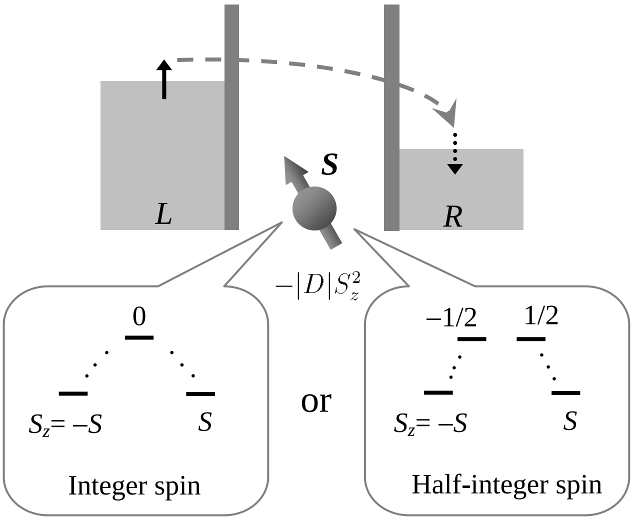

Fig. 1 Schematic illustration of electrode/spin quantum dot/electrode junctions. The quantum spin ***S*** has the uniaxial anisotropy energy, $-|D|S_z^2$, where energy levels for the integer spin (the half-integer spin) are shown in left frame (right frame). The spin ***S*** is connected to the left electrode (*L*) and the right one (*R*), where the *L* has conduction electrons with up spin, while the *R* has those with down spin. Furthermore, ***S*** is coupled to the vibration of the dot.

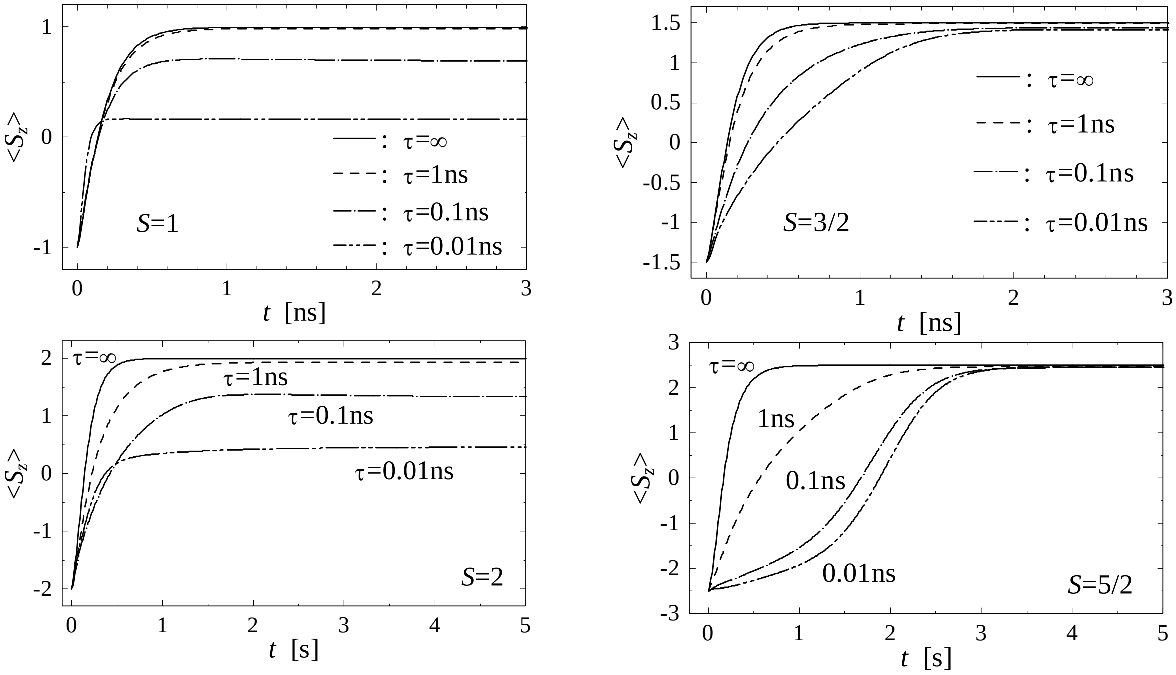

Fig. 2 Time t dependence of the expectation value of the z-component of the spin $<S_z>$ for each S.