Modeling synchronization of spin torque oscillators through spin Hall magnetoresistance

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Spin torque oscillator [1] is a promising candidate for practical devices such as microwave generator and magnetic recording head. In particular, synchronization of the spin torque oscillators is an exciting topic in the field of spintronics to enhance the emission power and to extend the technology to new practical applications such as bio-inspired computing [2]. Several methods have been proposed and demonstrated experimentally to stabilize the synchronizations, based on spin wave propagation, dipole coupling, or electric current injection [3-5].

The spin torque oscillator based on the spin Hall effect has been developed recently. It has the advantage of easier fabrication and that it is unnecessary to apply electric current to the ferromagnet directly. The synchronization of the spin torque oscillators in the spin Hall geometry induced by the spin wave propagation was also demonstrated [6].

The spin Hall effect causes another interesting phenomenon related to magnetoresistance effect. It was recently found that the resistance of ferromagnetic/nonmagnetic bilayers depends on the magnetization direction in the ferromagnet, even when the ferromagnet is an insulator [7]. This new type of magnetoresistance effect, named as spin Hall magnetoresistance, originates from additional electric currents generated by the charge-spin conversion due to the direct and inverse spin Hall effects. The spin Hall magnetoresistance has been confirmed by measuring the longitudinal and transverse voltages.

In this study, we investigate the synchronization of the spin torque oscillators through the spin Hall magnetoresistance. Let us consider the system consisting of a ferromagnetic/nonmagnetic bilayer, as in the experiments of the spin Hall magnetoresistance, and imagine that another ferromagnet is placed onto the nonmagnetic heavy metal in the longitudinal or transverse direction. The electric current generated through the spin Hall magnetoresistance effect will be injected into this second ferromagnet as spin current by the spin Hall effect, and excite the spin torque on the magnetization, and vice versa. As a result, the coupled motions of the magnetizations in the ferromagnets are expected. This coupling is unavoidable whenever several ferromagnets are placed onto the same nonmagnet. We have confirmed a tangible synchronization of magnetizations having several different phases, depending on the material parameters, by numerically solving the Landau-Lifshitz-Gilbert (LLG) equation.

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