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 os-
cillators 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 fer-
romagnet 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 magnetiz-
tations having several different phases, depending on the material parameters, by numerically
solving the Landau-Lifshitz-Gilbert (LLG) equation.

6. A. A. Awad et al., Nat. Phys. (advanced online publication).