Modeling synchronization of spin-torque oscillators consisting of perpendicularly magnetized free layer and in-plane magnetized pinned layer

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Synchronization of spin-torque oscillators is an exciting topic in the field of spintronics. This is because it has a possibility enhancing emission power of practical devices based on spin-torque oscillators, such as microwave generator and magnetic sensors, and applicability to new devices such as brain-inspired computing[1]. Several mechanisms of synchronization have been proposed theoretically and/or demonstrated experimentally[2], such as spin wave propagation, electric current injection, microwave field, stochastic noise in current, and dipole interaction.

An attractive structure of spin-torque oscillator for practical applications is that consisting of a perpendicularly magnetized free layer and an in-plane magnetized pinned layer because this type of spin-torque oscillator results in high emission power, narrow linewidth, and wide frequency tunability simultaneously[3]. The oscillation properties of this type of spin-torque oscillators, such as the relation between the injected current and the oscillation frequency, as a single oscillator have been investigated experimentally[3]. A possibility to excite a mutual synchronization in this type of spin-torque oscillators, however, has not been investigated yet.

In this work, we study the phase synchronization of spin-torque oscillators consisting of perpendicularly magnetized free layers and in-plane magnetized pinned layers[4]. We focus on the coupling of spin-torque oscillators through the current injection, and develop models of the coupling in the parallel and series circuits, which are schematically shown in Fig. 1(a). Solving the Landau-Lifshitz-Gilbert equation numerically, we show that two spin-torque oscillators indicate in-phase or antiphase synchronization depending on the way the oscillators are connected, as shown in Figs. 1(b) and 1(c).

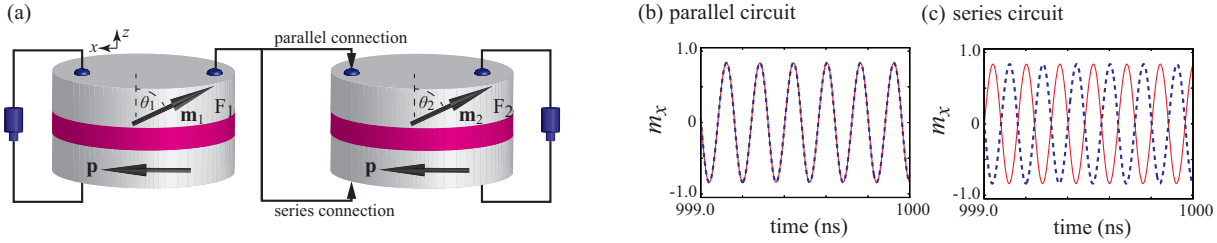

Figure 1: (a) Schematic view of the coupled spin-torque oscillators in the parallel or series circuits. The in-phase synchronization of the magnetizations is found in the parallel circuit, as shown in (b). On the other hand, the antiphase synchronization is found in the series circuit, as shown in (c).

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