Dipolar field interaction between two adjacent vortex spin torque oscillators: synchronization and coupling strength quantification

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I. INTRODUCTION

In the emerging technique of microwave-assisted magnetic recording (MAMR), a spin torque oscillator (STO), with microwave output driven by a DC current, provides a coherent drive to switch adjacent magnetic domains through dipole radiation. Understanding dipole radiation from STOs, as well as improving their behaviors, are essential to design and optimize their functionality for MAMR applications. For example, the recent fast development of synchronizing multiple STOs provide a simple on-chip approach to greatly enhance their output powers and spectral purity.

This presentation will focus on the characterization of two laterally aligned vortex STOs that are strongly coupled by the dynamic dipolar field (Fig. 1). We show that dipolar field is sufficient to synchronize the two STOs [1], resulting in an enhanced power more than their sums and reduced output linewidth [2]. Then we demonstrate microwave-assisted switching of vortex polarity of the two synchronized STOs with device selectivity [2], which provides a mean to control their synchronization states. Furthermore, we show an experimental technique [3] to quantify the dipolar interaction of the two STOs which agrees well with theoretical predictions [4]. We show the existence of phase lagging in the dipolar coupling, which is attributed to the nonlinearity of the STOs.

II. EXPERIMENT CONFIGURATIONS

The sample consists of two adjacent cylindrical nanopillar STOs with a layer structure of Py(15 nm)/Cu(10 nm)/Py(4 nm) (Fig. 1). They have common top and bottom electrodes and identical nominal diameters 2R, with an edge-to-edge separation of L. We have characterized two different samples with (1) 2R=200 nm, L=50 nm; (2) 2R=400 nm, L=200 nm. The small gaps of L enable strong dipolar coupling of the vortex gyrotropic motions. An antenna is fabricated on top of the sample to generate an in-plane microwave field. During the experiments, the common dc current is set to be about twice the critical current for spin transfer induced vortex core auto-oscillation. The auto-oscillation is dominated by the Py(15 nm) layers, whose polarity states will be referred to throughout the paper. The thinner Py layers, also in the vortex state, act as the polarizers. A perpendicular biasing field is applied to tune the output frequency.

III. RESULTS AND DISCUSSIONS

First we demonstrate efficient mutual synchronization between two adjacent vortex STOs by the dipolar interaction [1], which is demonstrated in Fig. 2. Synchronization can be achieved with both parallel and antiparallel vortex polarity alignment of the two STOs, with the phase-locking bandwidths differing by a factor of 2.4. Their ratio agrees with the analytical calculations of dynamic dipolar coupling [4]. In Fig. 3 we show the microwave-assisted switching diagram of the vortex polarities of the two synchronized STOs [2]. The diagram can be distinctly decomposed by the superposition of the two cone regions for the two STOs. Independent measurements show that the switching boundaries coincide with the boundaries of the two individual STOs, which means that the microwave-assisted polarity switching condition is not

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Category: Microwave-Assisted Magnetic Recording (MAMR)

sensitive to the strong dipolar coupling. In Fig. 4 we demonstrate remote frequency pulling when one STO is phase-locked to an external microwave field [3]. This is due to the phase-locked dipolar interactions from the microwave field and from the locked STO onto the second STO. Within an analytical model we can quantify the dipolar interaction of the two STOs, which agrees with the theoretical prediction [4].

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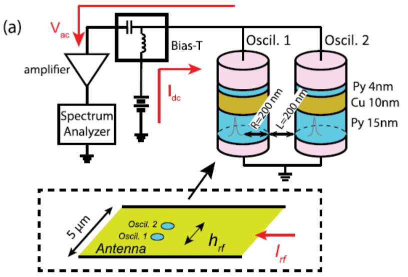

Fig 1: Schematics of the sample and electrical circuit

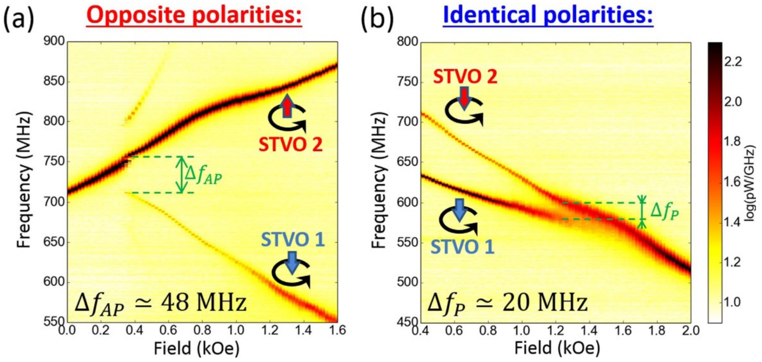

Fig 2: Power spectrum maps versus perpendicular field, in a case when vortices have opposite polarities (a) and when vortices have identical polarities (b).

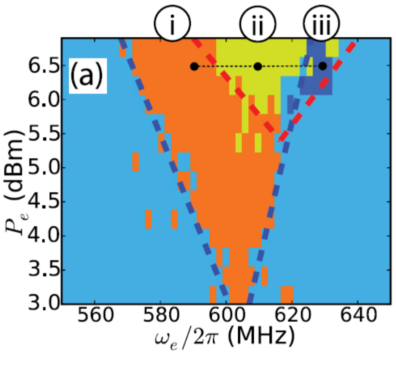

Fig 3: Microwave switching portraits of vortex polarities for <↑↓2↓> initial polarity states. The final states are: lightblue <1↓2↓>; orange <1↓2↑>; darkblue <1↑2↓>; yellow <1↑2↑>.

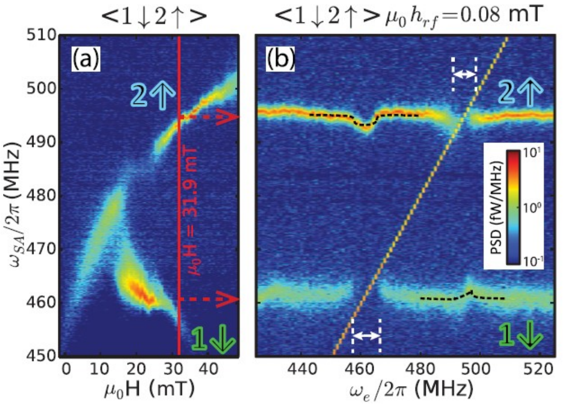

Fig 4: (a) Location of spectra at the <1↓2↑> state for the microwave study. (b) Auto-oscillation spectra as a function of microwave field frequency for μ₀H=31.9 mT. Signal from the source appears as the oblique narrow line. White arrows show the phase-locking bandwidths. Black dashed curves are the fits to the analytical model.