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Synchronization Phenomena in Spin Torque and Spin Hall Nano-Oscillators

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Abstract

Spin-torque oscillators (STOs) belong to a novel class of spintronic devices and exhibit a broad operating frequency and high modulation rates. STOs take advantage of several physical phenomena such as giant magnetoresistance (GMR), spin Hal effect (SHE), spin-transfer torque (STT), and tunneling magnetoresistance (TMR) to operate. In this work, it has been attempted to understand and study the excited magnetodynamical modes in three different classes of STOs i.e. nanocontact STOs (NCSTOs), spin Hall nano-oscillators (SHNOs), and hybrid magnetic tunnel junctions (MTJs). Synchronization has been considered as a primary vehicle to increase the output power and mode uniformity in NCSTOs and SHNOs. In the quest to achieve high signal quality for applications, a completely new class of devices, hybrid MTJs, has been studied. Therefore this work can be principally divided into three parts:

GMR-based NCSTOs: Synchronization has been shown to be mediated by propagating spin waves (SWs). The Oersted magnetic field produced by the current going through the NCs can alter the SW propagating pattern. In this work, the synchronization behavior of multiple NCs has been studied utilizing two different orientations of NCs.The Oersted field landscape is shown to promote or impede SW propagating depending on the device geometry. Synchronization of up to five NCs, a new record, is thus achieved. It is shown that the synchronization is no longer mutual in nature but driven by the NC from which the SWs are emitted.

SHNOs: The basic operation and characterization of SHNOs are demonstrated through electrical measurement and confirmed by micromagnetic simulations. Ultra-small constrictions are fabricated and shown to possess ultra-low operating currents and an improved conversion efficiency. High efficiency mutual synchronization of nine SHNOs is demonstrated. Furthermore, by tailoring the connection region, the synchronization range can be extended to 4 μm. Furthermore, for the first time the synchronization state is directly probed utilizing micro-Brillouin light scattering.

Hybrid MTJs: While MTJs based oscillators utilizing a nanopilar geometry have been shown to deliver output powers much greater than GMR-based NCSTOs, they often suffer from higher linewidths. A hybrid device is fabricated to combine the high output power of nanopillar MTJs and low linewidths of NCSTOs. Realization of such devices is demonstrated and, for the first time, their magnetodynamical behavior is meticulously studied. Experimental results show evidence of both localized and propagating SW modes. Generating propagating SWs in these devices paves the way for synchronizing multiple hybrid MTJs sharing the same free layer, thus improving the oscillator performance.

Keywords: Spintronics, driven synchronization, mutual synchronization, spin transfer torque, spin torque oscillator, spin Hall oscillator, magnetic tunnel junctions, nanocontact, nanoconstriction, nanopillar, hybrid nanocontact, magnetodynamics, spin wave bullet, propagating spin wave, Brillouin light scattering.