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Magnetization reversal driven by low dimensional chaos in a nanoscale ferromagnet

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Energy-efficient magnetization switching is an essential problem in the realization of practical nonvolatile magnetic storage [1] and magnetic neuromorphic computing [2]. In the past two decades, several efficient methods of magnetic switching were demonstrated including spin torque, magneto-electric, and microwave-assisted switching mechanisms. In this talk, we experimentally demonstrate that low dimensional magnetic chaos [3] induced by alternating spin torque can strongly increase the rate of thermally-activated magnetic switching of the free layer in a magnetic tunnel junction (MTJ)[4]. This mechanism exhibits a well-pronounced threshold character in spin torque amplitude and its efficiency increases with decreasing spin torque frequency, as illustrated in Fig. 1.

We present analytical and numerical calculations that quantitatively explain these experimental findings and reveal the crucial role played by low dimensional magnetic chaos near saddle equilibria in enhancement of the switching rate. This work shows that ac spin torque driven chaos can facilitate thermally-assisted switching of magnetization in a MTJ [5] and provides a new path towards improved energy efficiency of spin torque memory based on thermally stable MTJs. Furthermore, MTJs with superparamagnetic free layers are attractive for neuromorphic computing. Our results show that low dimensional can be used to tune the switching rate of such systems, and therefore, may lead to computing schemes that simultaneously harness stochasticity and deterministic chaos.

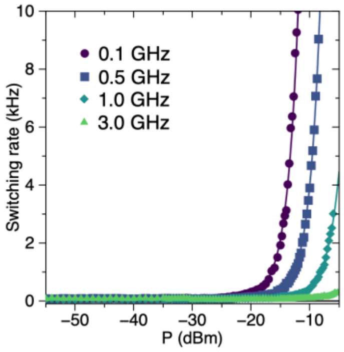

Fig. 1. Switching rate of superparamagnetic MTJ under ac spin transfer torque drive. For small amplitude drive, the switching rate remains constant. Above a threshold drive, the switching rate rapidly increases. The threshold drive is lower for lower frequencies. These effects are signatures of low dimensional chaos.

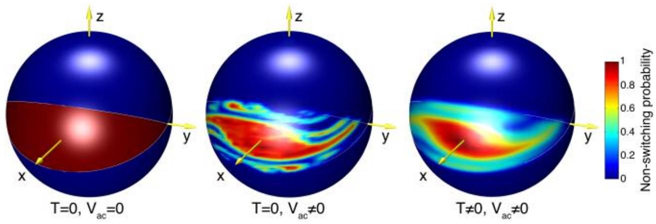

Fig. 2. Directional map of probability of magnetization initially within the easy axis potential well $x > 0$ to remain within this well after 5 periods of alternating spin torque drive. Red color marks the initial direction of magnetization resulting in magnetization staying within the well, while blue color marks initial magnetization direction resulting in escaping the well. (left) At zero temperature and in the absence of spin torque, any initial direction of magnetization within the well indefinitely remains within the well. (middle) At zero temperature and alternating spin torque exceeding the threshold value, chaotic dynamics cause regions of initial magnetization directions within the well that now lead to escape with fractal structure. It is clear from this figure that chaotic dynamics induced by alternating spin torque decreases the basin of stability to a region in the center of the well, thereby reducing the effective energy barrier between the two wells. (right) At room temperature and spin torque drive exceeding the threshold value, the fractal lobe structure of the well is blurred by thermal fluctuations but the chaos-induced erosion of the basin of stability is still apparent.

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