Using coupling to design new functionalities for the magnetic tunnel junctions

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Magnetic tunnel junctions (MTJs) offer a number of advantages (e.g. electrical sensing, size, control flexibility, CMOS compatibility), making them very attractive for the development of digital technologies. By carefully adjusting the composition of the magnetic stacks and the control parameters (Fig. 1a), it is possible to implement different types of functions (e.g. memories, field sensors, oscillators, neurons, synapses) or to consider unconventional computing schemes (Ising machine, p-bits). The application potential of magnetic tunnel junctions is assessed here through several examples combining modeling and experimental studies that exploit the richness of magnetization dynamics

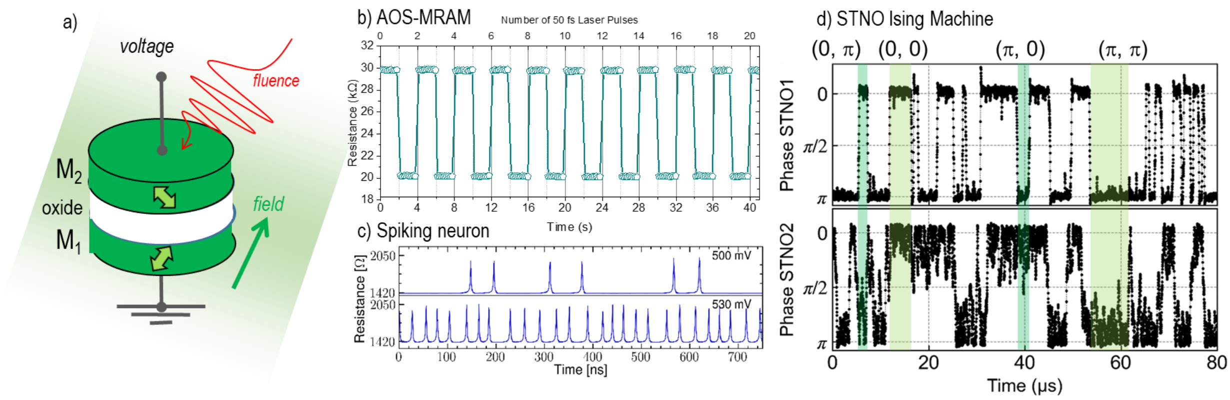

Fig. 1. a) Schematic of a multifunctional magnetic junction with associated stimuli: applied voltage, magnetic field or laser pulse. b) Electrical resistance of an MTJ after illumination by a sequence of 50 fs laser pulses. c) Sequence of resistance spikes generated by an MTJ biased with two different voltage values. d) Injection locking of two coupled spin-coupled nano-oscillators based on an MTJ.

An example of multiphysical coupling concerns the concept of an all-optical switched magnetic memory based on the interaction between magnetization and a femto-second laser pulse [1]. The dedicated storage layer (M2) has been designed on the basis of [Tb/Co] multilayers whose magnetization can be reliably switched by laser pulses with durations ranging from 10 ps to 50 fs (Fig.1b). The memory operation is enabled by the thermal fine control of the effective anisotropy of the active layer [2].

When the memory stability criterion is relaxed, the internal mutual coupling between the magnetic layers of the MTJ enables the magnetic junction to generate resistance spikes. This effect mimics the activity of neurons, as we have demonstrated with CoFeB-based MTJs (Fig.1c) [3]. The frequency of the spikes is tunable by both bias voltage and applied field, and approaches the tens of MHz regime.

Inter device coupling mechanism is extended to several magnetic tunnel junctions. The operating conditions have been chosen to bring the magnetization of the active layers to an oscillatory steady state. An additional RF field is applied leading to injection locking of the spin-torque nano-oscillators to the external field. The electrical coupling between the MTJs controls the phase difference of each oscillator with respect to the RF field, and thus the lifetime of the various possible states (Fig.1d). These characteristics are important for the implementation of an Ising machine based on MTJ-based spin-torque nano-oscillators.

References

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[3] L. Farcis et al., Spiking dynamics in dual free layer perpendicular magnetic tunnel junctions Nano. Lett. 23, 7869 (2023).