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# Magnetoelectrics at nano-scale for advanced spintronic applications

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Among the technologies that could potentially represent a paradigm shift with respect to CMOS technology, spintronic computation presents several advantages to achieve area and power reduction. The possibility to perform complex logic functions as majority gates, and the non-volatility of the magnetic materials could provide new functionalities to circuit designers for various applications. However, no concept for a complete magnetic/spintronic computing system exists. Therefore, the spintronic devices need to be complemented by CMOS in a hybrid spintronic–CMOS system. A major limitation for the realization of a such hybrid technology is the lack of scalable and energy efficient transducers capable to couple efficiently the electric and magnetic domains.
Magnetoelectric composite materials consisting of piezoelectric and magnetostrictive films are one of the most promising approaches for the magnetization control by electric fields. In this case, the magnetoelectric coupling occurs via strain: applying an electric field (voltage) across the structure generates strain in piezoelectric layer, which is then transferred to the adjacent magnetostrictive layer. This leads to an effective magnetic field that can rotate the magnetization of the system, or to generate spin waves if radio-frequency voltages are applied. An analogous inverse effect also exists which links changes in the magnetization direction to strain, and consequently, to electric fields.
For microelectronic applications, magnetoelectric heterostructures must be integrated into devices and miniaturized to the nanoscale. Here I will present an overview of our recent work on magnetoelectric systems and discuss materials, device design and fabrication, as well as the impact of different effects (device geometry, scaling, etc.) on the voltage coupling coefficients. We show that the device downscaling can lead to an enormous increase in the voltage response of magnetoelectric structures. Moreover, many applications require fast responses of devices with targeted operational frequencies in the GHz range. I will present sub-micron scaled magnetoelectric spin-wave transducers and demonstrate their operation. COMSOL Multiphysics and micromagnetic MuMax software packages were further used to study the mechanical response and the magnetic behavior, respectively, of different magnetoelectric devices, both in the DC and RF regimes. The magnetoelastic fields were estimated as well. Finally, we discuss the potential of magnetoelectric transducers for spin-wave computing applications.