Skyrmions were at first a theoretical concept formulated by Tony Skyrme in 1962 in the context of nuclear physics, as a model for nucleons. Technically, they are “topological solitons” localized in space and with particle-like properties: they have quantized “topological charges”, interact via attractive and repulsive forces, and can condense into ordered phases. The concept of skyrmions has spread over various branches of physics, including especially condensed matter (for example the cases of liquid crystals, quantum Hall magnets and Bose-Einstein condensates). At the Institut NÉEL, we have been studying skyrmion effects in ultrathin-film ferromagnetic metals, i.e. systems where the magnetic moments (the spins of the atoms) normally align parallel to each other. In these materials, a skyrmion is an anomaly, a “defect”, that can arise spontaneously. It is a swirling spin “texture”, a circular region where the spins tilt progressively from “up” at the periphery to “down” at the centre, as illustrated in Fig. 1 below. The compact size and potential stability of such skyrmions make them promising candidates to serve as information carriers in future technologies. But such applications will require creating, deleting, and moving skyrmions, and that at room temperature.

As concerns moving the skyrmions, a recent observation of displacement of skyrmion bubbles (a type of skyrmion with larger dimensions) at room temperature, using relatively low current densities, was very promising. Creation and annihilation of skyrmions has been addressed by different techniques such as spin transfer torque, heat and strain. However, those techniques are either energy-consuming or difficult to integrate in functional devices. The use of electric field gating to manipulate skyrmions offers several advantages: low power consumption, possibility to act locally and an easy integration with conventional electronics. However, the only previous experiments attempting electrical switching of skyrmions were done at low temperature.

In our work, done in collaboration with Spintec Laboratory, Grenoble, we have achieved the room temperature electrical switching of skyrmion bubbles. Our experiments were carried out on an ultra-thin film structure deposited on a silicon wafer, a trilayer consisting of 3 nm of the non-magnetic metal platinum, 0.6 nm of the ferromagnetic metal cobalt and an aluminium oxide layer. This Pt/Co/oxide trilayer was imaged under an electric field applied by a transparent Indium Tin Oxide (ITO) electrode, using magneto-optical Kerr-effect microscopy, which gives grey contrast images where bright regions correspond to magnetization directed down and dark regions to magnetization directed up.

Spontaneous nucleation of skyrmion bubbles by thermal activation is observed, see Fig. 2a. We have used an analytical model to describe quantitatively the thermal nucleation and the stability of the observed skyrmion bubbles. This model gives detailed skyrmion bubble stability diagrams which compare quantitatively with experiment and demonstrates that a very particular interaction, the “Dzyaloshinskii-Moriya” interaction, which favors the tilting of spins that would otherwise be parallel, is at the origin of the stabilization of the skyrmion bubbles in our system.

Most importantly, we observed efficient and reproducible electric field “writing” and “deleting” (i.e. creating and annihilating) of skyrmion bubbles, via a skyrmion switch effect, see Fig. 2 (a & b). This is described very well by our analytical isolated skyrmion bubble model. These results constitute an important milestone towards the use of skyrmions for memory or logic devices.

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