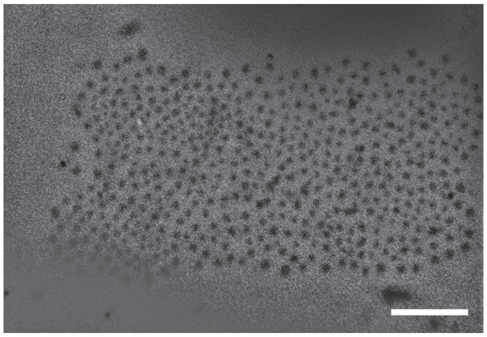

Figure 1 Skyrmion bubble lattices created by laser sweeping. The scale bar is 20 μm.

11:06

EC-12. Cascaded Skyrmion Logic System Inspired by Conservative Logic. *X. Hu*[1], M. Chauwin[1,2], F. Garcia-Sanchez[3], N. Betrabet[1], C. Moutafis[4] and J.S. Friedman[1] *1. Electrical and Computer Engineering, The University of Texas at Dallas, Richardson, TX, United States; 2. Department of Physics, Ecole Polytechnique, Palaiseau, France; 3. Istituto Nazionale di Ricerca Metrologica, Torino, Italy; 4. School of Computer Science, The University of Manchester, Manchester, United Kingdom*

The small size and efficient motion of magnetic skyrmions [1] inspire their use in next-generation computing systems. However, previous proposals for skyrmion-based logic [2], [3] have been hindered by the lack of a technique for cascading skyrmion logic gates, which is solved here for the first time. We propose a novel cascaded skyrmion logic system [4] that is inspired by conservative logic [5], which provides a vision for computing with zero energy consumption. This system leverages the rich physics of magnetic skyrmions, including the spin-Hall effect, skyrmion-Hall effect, skyrmion-skyrmion repulsion, repulsion between skyrmions and the track boundaries, and electrical current-control of notch depinning. Binary '1' and '0' values are represented by the presence and absence of skyrmions, respectively. In this skyrmion logic system [4], a spin-Hall current causes skyrmions to propagate through ferromagnet tracks (see Fig. 1) that perform basic Boolean logic operations such as AND, OR, XOR, inversion, and fanout through the skyrmion-Hall effect. Cascading these skyrmion logic gates enables the realization of complex logic functions, such as the full adder of Fig. 2. Skyrmions are never destroyed, and there is no need to create skyrmions during the operation of the system; each skyrmion is propagated from the input to the output of each gate, and then to the input of another gate. This skyrmion conservation provides significant advantages in terms of computing efficiency, and resolves the experimental difficulty of generating large numbers of skyrmions. In order to preserve signal integrity and preserve skyrmion synchronization, a simple global clock provides current pulses that shrink the skyrmions and enables them to pass notches in the nanowire tracks. As skyrmion motion is based on the propagation of magnetization rather than the transport of physical particles, this non-volatile system is an intriguing nanoscale implementation of conservative logic with the potential for high speed and minimal energy consumption.

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[4] M. Chauwin, X. Hu, F. Garcia-Sanchez, *et al.*, *arXiv*:1806.10337 (2018)
[5] E. Fredkin and T. Toffoli, *Int. J. Theor. Phys.*, vol. 21, pp. 219–253 (1982)

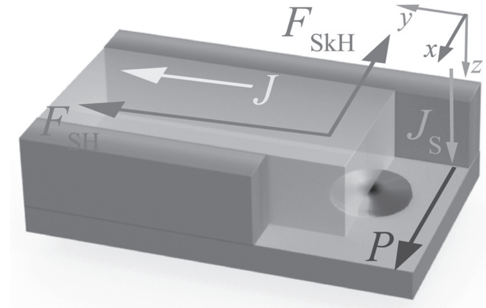

Fig. 1. Ferromagnetic nanowire track and the forces influencing skyrmion motion.

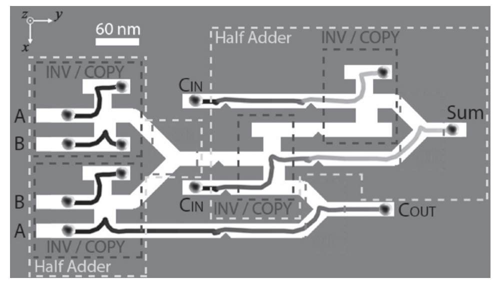

Fig. 2. Conservative skyrmion one-bit full adder.

11:18

EC-13. Thermally excited skyrmion diffusion used in a reshuffler device. J. Zazvorka[1], F. Jakobs[3], D. Heinze[1], K. Litzius[1,2], S. Jaiswal[1], S. Kromin[1], N. Keil[1], P. Virnau[1], D. Pinna[1], K. Everschor-Sitte[1,2], G. Jakob[1,2], A. Donges[3], U. Nowak[3] and *M. Kläui*[1,2] *1. Physics, Johannes Gutenberg-University Mainz, Mainz, Germany; 2. Graduate School of Excellence Materials Science in Mainz, Mainz, Germany; 3. Physics, University of Konstanz, Konstanz, Germany*

Thermally activated processes are key to understanding the dynamics of physical systems. Thermal diffusion of (quasi-)particles for instance not only yields information on transport and dissipation processes but is also an exponentially sensitive tool to reveal emergent systems properties and enable novel applications such as probabilistic computing. Here we probe the thermal dynamics of topologically stabilized magnetic skyrmion quasi-particles We have studied a Ta/CoFeB-based multilayer material where we can stabilize skyrmions and controllably nucleate and displace them by current pulses due to spin-orbit torques [1]. We find topologically non-trivial N=1 skyrmions that move in the direction of the current pulses. At zero applied current, we observe thermally activated skyrmion motion. We track the trajectories of skyrmions and from the dependence of their mean-square-displacement (MSD) on time, we can identify motion by diffusion and obtain the diffusion constant [1,2]. There is a strong dependence of the skyrmion diffusion parameter on temperature and the skyrmion size, which cannot be described by the previously developed analytical model [2]. We explain our observations by a non-flat energy landscape and we can qualitatively reproduce the temperature dependence of the diffusion constant using atomistic spin simulations [1]. Finally, we apply thermal skyrmion diffusion in a reshuffler device [3], which is an integral part of probabilistic computing. We demonstrate that skyrmions can be used to effectively reshuffle input streams while keeping their data (p-value) intact [1]. This shows that thermal skyrmion diffusion can actually be used for devices that go beyond conventional Boolean logic.

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