

Exploiting topology and strong interactions in electronics

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As Moore's Law grinds to a halt, we find ourselves entering a new world of software driven hardware, of Application Specific Integrated circuits (ASICs) and machine learning accelerators. This has opened up new opportunities for unique architectures that map onto specific computational paradigms, along with emerging materials underpinning them. Quantum computing, while being noteworthy for being disruptive in algorithmic scale-up, is limited severely by size scalability for embedded IoT applications. There are however many opportunities for classical computing with topological quantum states based on present day technology that can be quite disruptive even for embedded electronics. The focus of this talk is to show how one can capitalize on topological properties of materials to enable low-power electronic devices.

The specific example I will discuss exploits isolated, metastable skyrmions in thin magnetic films for temporal memory applications. These skyrmions can be generated as a topological defect by spatial symmetry breaking, such as by engineering interfacial Dzyaloshinskii-Moriya interactions (DMI) at the interface between a magnetic film and a heavy metal. I will discuss the physics of these skyrmions, such as how ferrimagnetic films near their compensation point reduce demagnetization field and shrink skyrmions, how we can increase their lifetime with film thickness and uniaxial anisotropy, and how the skyrmions can form elongated tubes stabilized by exchange stiffness even when the DMI decays sharply away from the interface. Furthermore, we discuss how the skyrmions tend to diffuse, how they can be localized with notches etched into racetracks, and how they can be driven with spin orbit torque at speeds comparable to domain walls, while simultaneously limited by topological damping (Magnus force), Gilbert damping, spatial distortion, and ultimately by transverse spin waves.

Where can this all lead us? Topological protection, while only partial for an isolated skyrmion, nonetheless allows to keep these skyrmions metastable at dimensions where perpendicular magnets get randomized by thermal fluctuations. This allows us to engineer skyrmions as tiny, mobile magnets with linear, current-tunable speeds. We can then use these magnets to do unary computing, encoding information in the analog spatial location of a single skyrmion along a racetrack, without the need for skyrmion creation or destruction. Skyrmions driven efficiently along racetracks, their quasi-linear operation and topologically stabilized lifetimes at ultra-small sizes can potentially function as temporal memory in race logic for rapid pattern matching and intermittent-sensor processing applications. I will discuss some of the practical challenges that need to be overcome, and the considerable payoffs that can come with overcoming those challenges.