Research statement **Lucia Steinke**

The progressive miniaturization and increasing power density in modern semiconductor electronics drives a demand for new materials to improve device performance at ever decreasing length scales. Quantum materials can help tackle these challenges by replacing traditional transistors with quantum mechanical switches, but they also hold the promise of using quantum states for storing information, transport information, and use quantum states for computing and quantum cryptography.

Recently, topological insulators (TI) have garnered immense interest as potential new functional materials, owing to their protected surface or edge states that could allow for lossless charge transport or the transmission of quantum information over macroscopic length scales. However, we are only beginning to identify TI materials like $Bi_{1-x}Sb_x$ alloys, Bi_2Se_3 and Bi_2Te_3, as well as a few half-Heusler compounds like YPtBi, and attempts to develop applications based on TI, or to implement them with conventional semiconductor technology, have been limited.

My own research experience gives me a unique perspective on the challenges involved in developing new functional devices based on such new materials. In my PhD work, I studied quantum Hall effects – now recognized as the first realization of a TI state in two dimensions – in high-mobility GaAs/AlGaAs semiconductor nanostructures. Our devices were made using standard photolithography combined with advanced molecular beam epitaxy techniques like cleaved-edge overgrowth or corner overgrowth. Essentially, we created new quantum states by tailoring quantum confinement in heterostructures based on well-developed materials that were readily available as high-quality wafers. In contrast, my postdoc projects focused on the discovery of new bulk materials, with the aim to find new quantum critical magnetic systems or superconductors. Here, the materials themselves have interesting quantum properties, but fabricating even primitive devices like Hall bars for electrical characterization can be extremely challenging when working with small, bulk single crystals, as opposed to high-purity thin films on a substrate.

In my recent work I identified a potentially new route to topological states that originate from strong electronic correlations in native metallic surface states of the half - Heusler compound HfNiSn. Their surface origin makes topological states in HfNiSn especially accessible to manipulation of the quantum state by means of gate electrodes or proximitiy effects with quantum systems like superconductors.

Going forward, I plan to develop and improve methods of ion beam shaping and electrical characterization of small flux-grown single crystal TIs like HfNiSn. From an engineering perspective, this method will bypass lengthy synthesis optimization and thin film development of a single material, allowing rapid testing of a large variety of candidate materials and facilitating their integration as functional units with current semiconductor technology. Simultaneously, we will gain insights in the fundamental physics of HfNiSn and related materials, where even primitive first devices like Hall bars or simple gated structures will allow for advanced characterization of electronic properties, and reducing sample sizes to the mesoscopic limit will help us understand the quantum nature of transport in this material.

In my present position in the department of Physics & Astronomy at Texas A & M University, I have already developed a method to identify topological states in bulk single crystals via systematic combinations of simple transport experiments, and trained both undergraduate and graduate students to apply these concepts to identify new topological materials we discover. I initiated a collaboration with H. Rusty Harris's group in Electrical & Computer Engineering, to start working on device fabrication. Our first tests of metal deposition on HfNiSn single crystals have already shown an exotic proximity effect with the superconductor Niobium, with an apparent conductance quantization in half-integer fractions of the conductance quantum.

I am convinced that these discoveries will be the basis of many fruitful research projects and continued collaboration between condensed matter physics and electrical and computer engineering. Beyond topological systems, the ability to do advanced electrical characterizations of new materials at a very early stage of discovery – literally when the first tiny single crystals come out of a crucible – will dramatically accelerate the identification of the most interesting properties, and remove technological hurdles to applications of newly discovered solids.