- **Novel Topological Dirac and Weyl Semimetals (E, Jin Hu)**

The advances in condensed matter physics are driven by new materials. The discovery and growth of novel crystalline materials has been identified as an area that the U.S. should strengthen in the National Research Council (NRC) Report - "Frontiers in Crystalline Matter: From Discovery to Technology". Recently, three-dimensional (3D) topological Dirac [1-2] and Weyl semimetals [3-5] have attracted enormous interests, because they represent new topological states of matters and have opened a new era of condensed matter physics. These materials host relativistic Dirac or Weyl fermions with linear energy-momentum band dispersions protected by crystal symmetry, exhibiting technologically useful properties such as extremely high bulk carrier mobility [6-12], large magnetoresistance [6-12], potential topological superconductivity [13], and dissipationless transport [14]. The research activities in Hu Lab involves the discovery and growth of novel topological semimetals and their nanostructures, as well as finding and understand their exotic properties. The two projects listed below are particularly suitable in training undergraduate students in material science, an area of the national need.

Project 1. Spontaneous time-reversal symmetry (TRS) breaking Weyl semimetals. A Weyl state can be realized with breaking the inversion symmetry or the TRS. A magnetic field driven TRS-breaking Weyl state due to Zeeman splitting [15] or exchange field [16] has been reported in several materials, but there are very few examples for a Weyl state due to spontaneous TRS-breaking (e.g., ferromagnetism) [17]. Seek for such a quantum state has become one important direction, because it is expected to show exotic quantum properties such as intrinsic anomalous Hall effect with non-dissipative current [14]. In this project, we try to bring magnetic order in Dirac semimetals via chemical doping, which is a theoretically predicted approach to generate TRS-breaking Weyl state. We grow single crystals of various target materials using flux/self-flux and chemical vapor transport methods, characterize the phase and composition of the obtained crystals using x-ray diffraction (XRD) and Energy-dispersive spectroscopy (EDS), and seek experimental evidences of Weyl fermions via magneto-transport.

Project 2. Dirac and Weyl fermions in nanostructures. Another major research direction of the lab is to grow the nanostructures of Dirac and Weyl semimetals, with the expectation that quantum confinement in low dimensions could lead to additional novel properties, as has been observed in graphene [18] and mono-layer of transition metal dichalcogenides [19-20]. Furthermore, with greatly enhanced surface-to-bulk ratio, properties of the peculiar surface state of these materials can be probed in nanostructures [21]. We grow nanowire/nanoflake using physical/chemical vapor deposition (PVD/CVD) technique (Fig. 1), and characterize the phase and quality of the obtained nanostructures using Raman spectroscopy, atomic force microscopy (AFM), Scanning Electron Microscopy (SEM), and (Transmission electron microscopy) TEM.

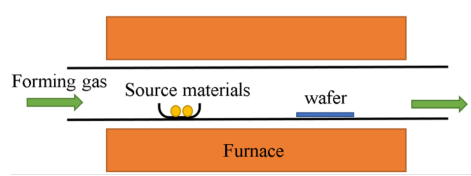

Figure 3. Schematic of PVD/CVD deposition

Skills and experience to be gained. The students are expected to gain valuable expertise in synthesizing and characterizing both bulk and nano materials. In both projects listed above, undergrads will be involved in the optimization of growth conditions and analyzing the characterization data. These skills are in high demand for material science research and applications in institutes and industry.

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