Device Architectures for Characterizing Spin Transport through Chiral Defects in Semiconductors

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Recent theoretical studies have shown that screw dislocations (SDs) support the interplay of Rashba and Dresselhaus spin-orbit coupling (SOC). Such a phenomenon makes these line defects suitable hosts of coherent spin transport. Specifically, spin polarization arising from SD-induced coupling lies in a much narrower range of angles (0 to 90°) than that resulting from the Rashba or Dresselhaus effects. Furthermore, this spin polarization is protected from changes in electron momentum caused by scattering, potentially leading to a relatively long coherence time. In this work, we demonstrate the fabrication of device architectures for characterizing spin transport due to the unique interplay of Rashba and Dresselhaus SOC in SDs. We fabricated a vertical spin valve (VSV) based on single-crystalline semiconductor nanomembranes (NMs) engineered with 2D arrays of screw dislocations (SDs) throughout their thickness. The device includes a bottom soft ferromagnetic contact (e.g., NiFe), the NMs, and a top hard ferromagnetic contact (e.g., Co). The constitutive material of the NM may be Si, Ge, III-V compounds, or SiC. The first step in the fabrication of the VSV is patterning the NM into a 2D array of pixels with lateral sizes of a few hundred micrometers. At this stage of the process, the NM is bonded to a sacrificial-layer-coated substrate. The pixels are released in place by selective etching of the sacrificial layer. An adhesive stamp removes the pixels from the original substrate and transfers them onto a second array of patterned pixels at a controlled twist angle. Pixelation of NMs reduces the release time and increases the yield of the transfer process. The twisted NM pairs or twisted bicrystals (TBiCs) are then annealed at high temperature in an inert atmosphere to foster the propagation of the SDs. Annealed TBiCs are transferred to a bulk substrate coated with a soft ferromagnet. A dielectric barrier and a hard ferromagnet contact are fabricated using conventional top-down processes. The TBiCs top and bottom surfaces are left to oxidize in air at or above room temperature before the ferromagnets-NMs contacts are fabricated. We anticipate the interfacial oxides will facilitate spin injection from the ferromagnetic layers into SDs by direct tunneling. Structural characterization of the fabricated devices includes cross-sectional and plan-view transmission electron microscopy (TEM) to analyze the chemical and physical structure of the interfaces and verify the occurrence of the SDs, respectively. The coercivities of the ferromagnetic films used for the contacts are extracted from measured magnetization curves on a Quantum Design Magnetic Properties Measurement System 3 (QD-MPMS3). Magneto-transport measurements characterize the change in resistance of the VSV at different magnitudes of magnetic induction (B).

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