Scalable Synthesis of One-Dimensional Quantum Matter

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We present our recent efforts in the area of controlled synthesis of screw dislocations. Dislocations in semiconductors and other materials are generally considered detrimental in that they create scattering centers that lower carrier mobility, act as non-radiative carrier recombination centers, and induce growth instability of coherent thin films. Therefore, past research efforts have focused on hindering the formation of these line defects or annihilating them. Recent theoretical studies have demonstrated the prospect of repurposing screw dislocations as one-dimensional quantum matter [1,2], with potential applications in quantum computation and spintronics. These findings motivated our research on synthesis protocols of screw dislocations to achieve predictive control of their spacing, arrangement, and width. Specifically, we investigated and established approaches to fabricate SDs in single-crystalline and widely used semiconductors, such as Si, GaAs, and SiC. The semiconductors are in nanomembrane (NM) form or sheets with nanoscale thickness and a lateral size-to-thickness ratio of at least 10^2. Our approach to controlled synthesis of SDs relies on overlaying two arrays of pixelated NMs of the same material at a non-zero twist angle or twisted bicrystals (TBiCs). Through this process, we create an array of disregistries at the interface that will serve as seeds for the growth of SDs. Pixelated NMs are obtained by top-down processing multilayered structures such as epitaxially grown GaAs thin films on AlGaAs sacrificial layers-coated GaAs substrates or SiC on insulator wafers. NMs provide more uniform interfacial bonding than their bulk counterpart and expand the palette of SDs hosts to include epitaxially grown ternary and quaternary alloys. High-temperature furnace annealing of TBiCs fosters the propagation of SDs from the interfacial seeds across the thickness of the NMs. We characterize the spatial distribution of SDs in NMs by plan-view transmission electron microscopy under a weak-beam condition. The spacing between SDs is correlated to theoretically calculated values using the measured twist angle between the NMs. The twist angle is obtained by selected area electron diffraction (SAED) patterns acquired from the TBiC.

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ACKNOWLEDGEMENT. Work at the University of New Mexico was supported by the NSF CAREER award No. 2144944. This work was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. DOE's National Nuclear Security Administration under contract DE-NA-0003525. The views expressed in the article do not necessarily represent the views of the U.S. DOE or the United States Government.