Spectroscopy and Charge-Sensing using Defects Embedded in Waals Tunnel Barriers

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We study electronic transport in vertical structures where naturally occurring defects, found in exfoliated hexagonal Boron Nitride and transition metal dichalcogenides thin flakes, assist tunneling processes when those flakes serve as tunnel barriers. In our typical geometry, electrons tunnel from a source electrode, through the defect-bound state, to the drain. In this geometry, the defect exhibits transport features typical of single-charge tunneling through quantum dots with very high charging energies. We operate that the defect-bound dots in a number of transport regimes: (i) A defect-dot coupled to a superconductor (NbSe2) reveals sub-gap Andreev bound states (ABS). Analogous to nanowire systems, ABS related to defect-dots exhibit a magnetic-field driven singlet-to-doublet transition. (ii) We show that using graphene as a source electrode, the defect energy can be gate-tuned using electric field which penetrates the graphene. In this system, the dot serves as a stable spectral probe for graphene at high magnetic fields, and can also be used as a local compressibility probe. The local nature of the dot allows it to detect transitions between compressible and incompressible behavior at the broken-symmetry regime in graphene quantum Hall. (iii) Finally, we demonstrate that a gated dot, when coupled to a superconductor, can be energy tuned, and is thus used as a sensitive spectrometer. We demonstrate this by showing how defect-dot states couple to both superconducting gaps of NbSe2. Our results demonstrate the utility of defect-bound states as highly local and precise sensors.