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Mapping Moiré Potentials with STEM EBIC Imaging

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Recently, van der Waals materials have proven to be excellent tunable testbeds of the rich condensed matter physics inherent in two-dimensional systems. And with the advent of moiré superlattice systems, formed by stacking two or more van der Waals materials, new devices with unique electronic and optical properties are now being created routinely [1]. However, theoretical predictions of moiré potentials – the energy landscapes induced by moiré superlattices – in these systems can underestimate the values obtained from experiment by as much as an order of magnitude [2], exposing a hole in our understanding of the behavior of these systems. Furthermore, inhomogeneous strain and twist relaxation typically make moiré patterns unpredictable and nonuniform (Fig. 1), which can affect device-scale behavior and confuse the experimental picture. Correlating electronic and optical properties with direct high resolution imaging would be immensely helpful in gaining an understanding of these devices.

Unfortunately, measuring the moiré potential thus far has required scanning probe techniques that are only surface-sensitive and require very clean and conductive surfaces. But real devices often have boron nitride encapsulation layers and graphitic contacts that preclude any such methods [2, 3]. Thus, new methods that can image moiré potentials embedded beyond the surface are highly desirable. Scanning transmission electron microscopy (STEM) imaging can reveal moiré patterns with relative ease [4] compared with the atomic lattice, and it has recently been demonstrated that moiré superlattices can be imaged in a scanning electron microscope with secondary electrons [3]. However, with both of these techniques, the pixel values are intensities in arbitrary units.

In STEM, when the high energy electron beam is incident upon the sample, secondary electrons are ejected from the sample in what is typically a negligible event. STEM secondary electron electron-beam-induced current (SEEBIC) measures the replacement current due to this emission of secondary electrons from the sample [5]. This current is correlated with the spatial position of the beam; the resultant image is made from meaningful electrical currents, combining transport with imaging. The ability to obtain work functions of metals using STEM SEEBIC has previously been demonstrated. There, the SEEBIC signal was dominated by a 5 nm thick layer of Ti encapsulated by 20 nm of Si_3N_4 below and 25 nm of Pt above. Thus, STEM SEEBIC images may have the potential to reveal buried moiré superlattices with high resolution. Here, we report attempts to reveal moiré superlattices with STEM SEEBIC [6].

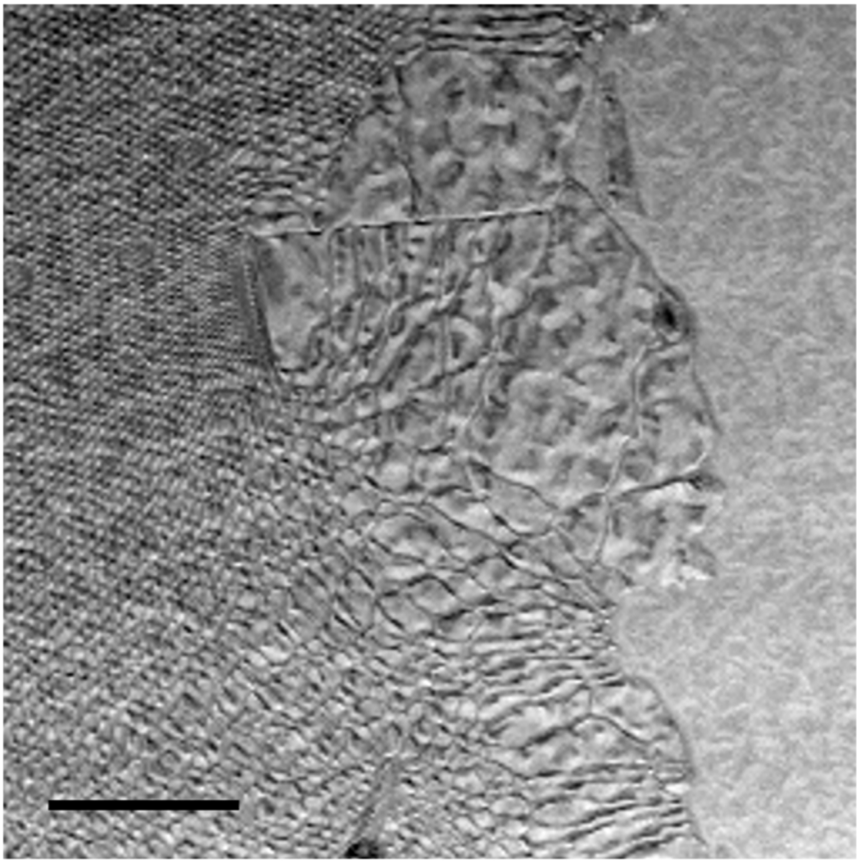

Fig. 1. An annular dark field (ADF) STEM image of a moiré pattern made from twisted WSe_2. The scale bar is 200 nm. The moiré periodicity varies across the field of view, ranging from 5 nm to 100 nm.

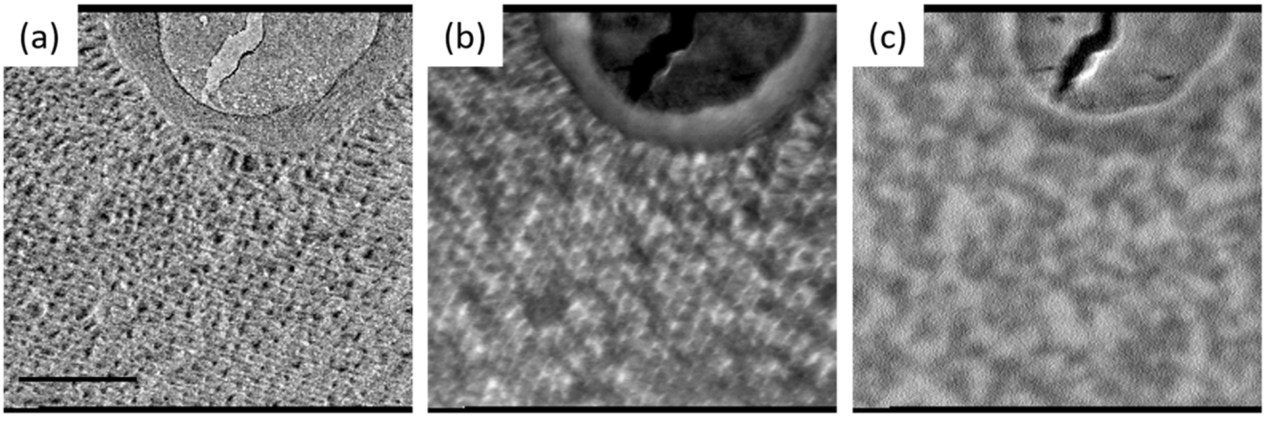

Fig. 2. **(a)** Coherent bright field, **(b)** ADF, and **(c)** SEEBIC images acquired concurrently from a twisted double bilayer WSe_2. The scale bar is 100 nm. The beam energy was 300 keV, with a beam current of 7 nA.

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