Functional Materials

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Electrostatic potential mapping in topological insulators by inline electron holography

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Bi_2Se_3 has been known since decades as an insulating material that has good thermoelectric properties. In 2009 Xia *et al.* revealed a remarkable new characteristic [1]: Bi_2Se_3 is a clear experimental example of topological insulators. The bulk insulating Bi_2Se_3 bears a single singly-degenerate surface state within the band gap having a Dirac cone-like dispersion. As a consequence, Bi_2Se_3 became one of most popular materials that could be used to concretize quantum computers [2]. However, most of the time, the topological surface state of Bi_2Se_3 coexists with a two-dimensional electron gas (2DEG) at the surface. The electronic properties of the 2DEG in the reciprocal space have been studied using mainly Angle-resolved photon emission spectroscopy (ARPES)[3]. However, real-space observation and characterization of the 2DEG has not been reported. Here, we use electron holography method with sub-nm spatial resolution to investigate the 2DEG. This technique is able to map the mean inner potential distribution, since the holographically measured phase-shift is proportional to the projected potential according to equation (1)

(1).

From variations in the mean inner potential the charge density may be obtained, according to Poisson's equation (2)

(2).

In this study, the exit wave function has been reconstructed using inline electron holography. For this purpose, first a focal series comprising 11 bright-field (BF) images was recorded using the Zeiss SESAM (Carl Zeiss NTS GmbH, Germany). In order to achieve high spatial coherence the illuminated semi-convergence angle was set to 30 µrad. The defocus was changed in a cubic fashion in order to have small defocus variations of 300 nm close to Gaussian focus and still span the range of -30 µm to +30 µm defocus. Inline holograms recorded at large defocus encode low spatial frequency information in the phase shift with better signal-to-noise properties than those with just a small defocus. A 7 eV energy-selecting slit was used to remove the contribution from inelastically scattered electrons. The full-resolution wave reconstruction (FRWR) code [5] has been used for the focal series reconstruction of the amplitude and phase of the exit face wave function. The resulting phase map is shown in Figure 1b. The spatial resolution was limited to 0.8 nm by the objective aperture but was sufficiently high to resolve the quintuple layers which are spaced 0.9 nm apart.

Figure 2a shows the potential profile across the (0001) surface of Bi_2Se_3. In our specimen prepared by ultramicrotomy this surface seems to always be covered by an amorphous layer. Extracting this layer and also removing the sharp potential increase expected for a crystallographically sharp onset of the mean inner potential, smoothed to the resolution determined by the objective aperture, we obtain the mean inner potential profile from the surface towards the inside of the specimen (Figure 2b).). In the presented work, these potential profiles will be discussed in detail.

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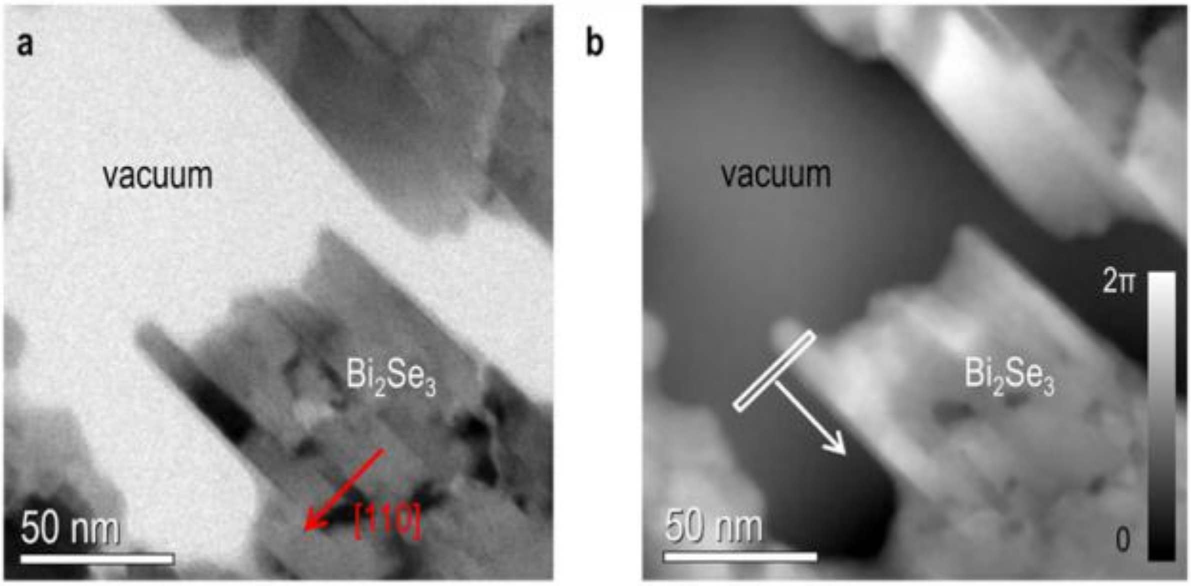

Figure 1 a) TEM bright-field image b) Phase map recovered using inline electron holography.

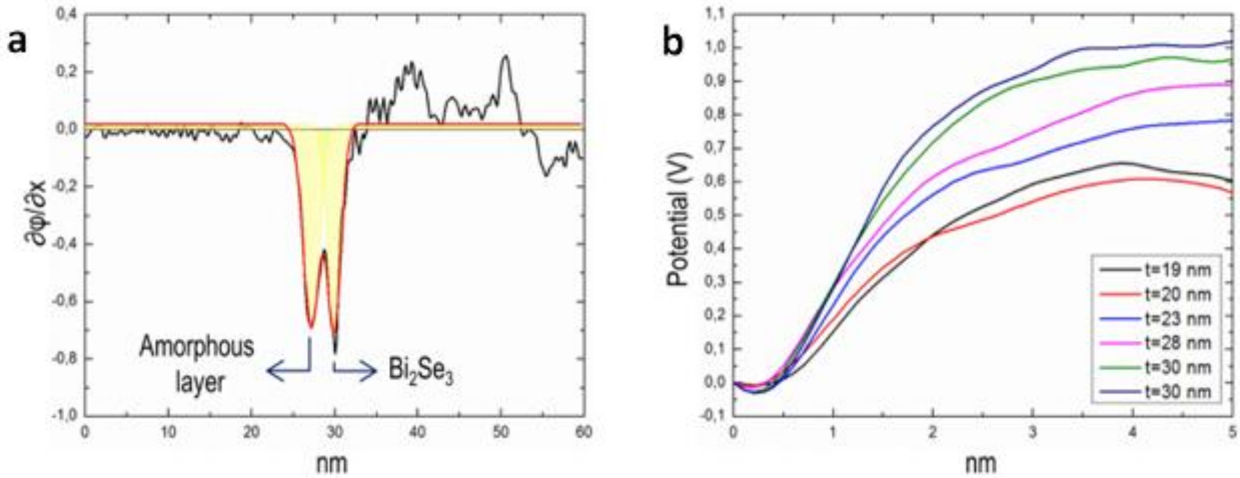

Figure 2 a) Profile of the gradient of the phase across the surface of the basal plane of Bi_2Se_3. b) Potential profiles from the surface towards the bulk material, after removing the potential step at the specimen surface.