Connecting Medium Range Ordering to Topological Properties of Amorphous Bi2Se3

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Meeting-report

Connecting Medium Range Ordering to Topological Properties of Amorphous Bi_2Se_3

Gabriel Calderon[1], Kazi Aatish Imroz[2], Sadikul Alam[1], Yuan-Ming Lu[2], Jyoti Katoch[3], Roland Kawakami[2], and Jinwoo Hwang[1,*]

[1]*Department of Materials Science and Engineering, The Ohio State University, Columbus, OH, USA*
[2]*Department of Physics, The Ohio State University, Columbus, OH, USA*
[3]*Department of Physics, Carnegie Mellon University, Pittsburgh, PA, USA*

*Corresponding author: hwang.458@osu.edu

With the surface states protected by the time-reversal symmetry, topological materials are robust against impurities and local perturbations, making them attractive for their potential applications in advanced spintronics, magnetoelectronic and optoelectronic devices, and many others. While research in topological materials has seen great advances in recent years, the current knowledge of topological materials is largely based on materials with long-range atomic ordering (LRO), or crystal structure with well-defined symmetry. A fundamental question rises regarding whether topological states can exist in materials without LRO, *i.e.* non-crystalline or amorphous materials. Amorphous materials are ubiquitous in nature and being utilized in numerous technologically important applications, but understanding their basic properties, such as band gaps and topological behaviors, has remained very challenging. Theoretical works *e.g.* [1] have recently suggested that amorphous materials can indeed have topological states without any crystalline order. Instead, it has been suggested that the atomic connections (ordering) at the very local level may be the key to understanding and controlling the topological phases in amorphous materials. However, both the experimental demonstration [2] and theoretical understanding of topological amorphous materials still remain very premature, leaving the door wide open for further investigation and exciting new discovery.

We gain fundamental understanding on how topological phases can be formed, controlled, and changed in amorphous materials. Using unique approaches based on 4-dimensional scanning transmission electron microscopy (4D-STEM), we characterize the local atomic ordering in amorphous materials and correlate it with the formation of topological phases predicted by theory and measured by angle resolved photoemission spectroscopy (ARPES). A particular emphasis is given on measuring and understanding short-range and medium-range atomic ordering (SRO and MRO, respectively) in these materials, and directly establishing their connection to the formation of topological states.

Amorphous Bi_2Se_3 films were grown using 3 different conditions, (i) high temperature, (ii) low temperature, and (iii) low temperature with Pd deposition on the surface of the SiO_2 substrate using molecular beam epitaxy. The purpose of the Pd deposition in sample (iii) was to make the surface rougher, further preventing crystallization of Bi_2Se_3 on the surface. 4D-STEM nanodiffraction patterns were acquired using 256 by 256 grid positions from the cross-sectional view of the sample (Fig. 1), and the patterns were analyzed using angular correlation and power spectrum mapping method shown in Fig. 2. [3]. The result shows that sample (i) has some local crystallinity (i.e. hotspots in the power spectrum map) which is also evidenced in the sharp peaks in the angular correlation. However, the degree of ordering decreases in sample (ii), and it further decreases in (iii), which indicates the effectiveness of the low temperature and Pd surface deposition in preventing crystallization. We will discuss how the MRO information from 4D-STEM correlates to the potential topological properties measured using transport measurement (*e.g.* thermal Hall effect) and ARPES [4].

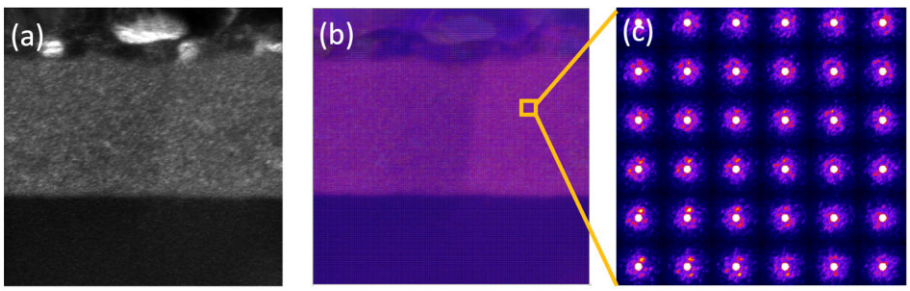

Fig. 1. (a) 4D-STEM dark field image of the amorphous Bi_2Se_3 film from the cross section. (b) Montage of 256 by 256 nanodiffraction patterns from the area and (c) a zoomed-in view of the patterns.

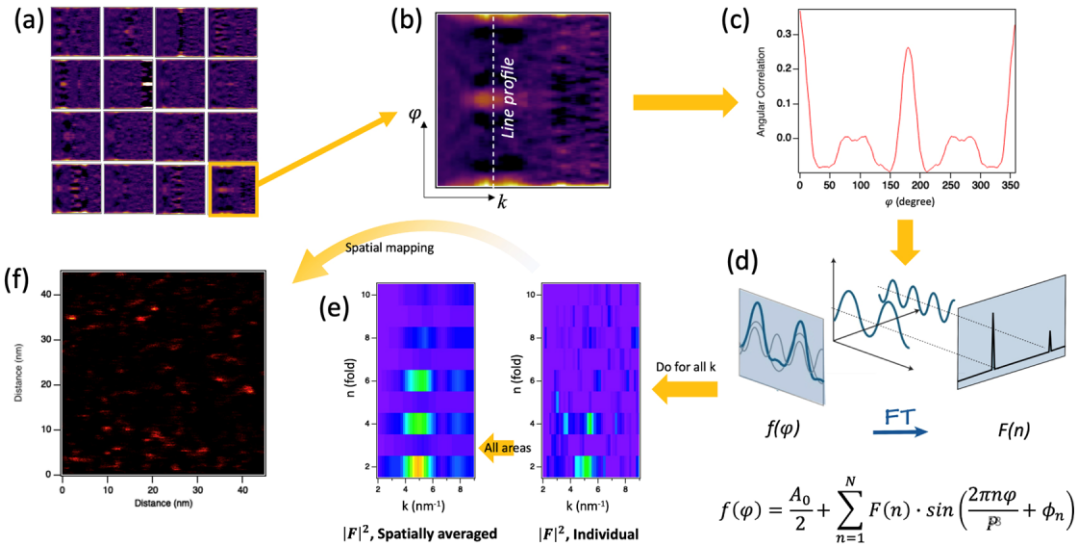

Fig. 2. Process of the power spectrum analysis. (a) 2D array of angular correlation function. (b) Each angular correlation function is (c and d) Fourier transformed, and the frequency, n, of the sinusoidal waves in the Fourier series represents the n-fold rotational symmetry of MRO, which we plot against the scattering vector k, shown in (e). In (e), the right is the power spectrum from an individual nanodiffraction pattern, and the left is the power spectrum averaged over the entire area of the sample. (f) Reconstructed map of n = 2 in real space, revealing the distribution of MRO with 2-fold symmetry.

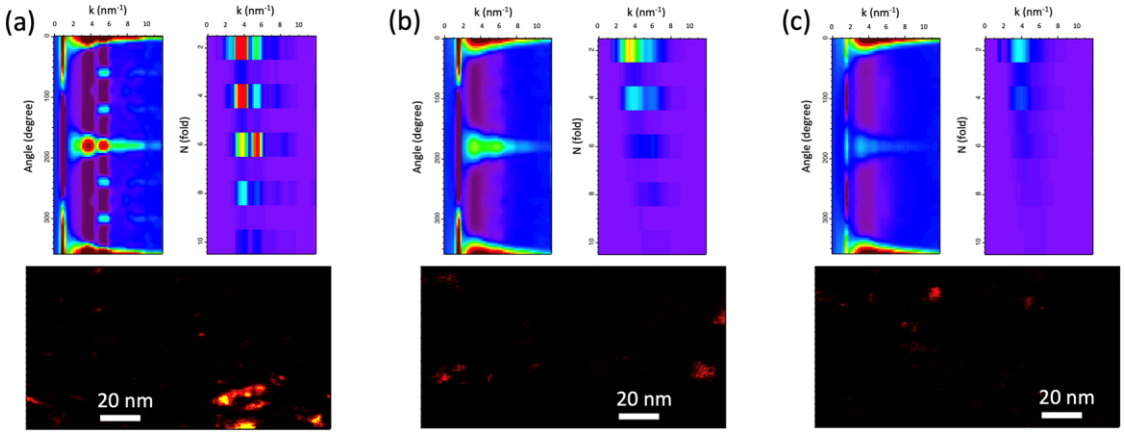

Fig. 3. (Left) Angular correlation, (right) power spectrum, and (bottom) n = 2 maps from the film grown on (a) high temperature, (b) low temperature, and (c) low temperature with Pd surface treatment.

References

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