Modification of topological phenomena at hybrid Bi2Se3/organic interfaces

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Background

Topological insulators such as Bi_2Se_3 have interesting transport properties, including undamped transport via topologically-protected surface electronic states[1]. Manipulation of surface plasmons has been previously demonstrated using magnetic dopants, but these cannot be altered after growth. In contrast, the use of organic molecular overlayers such as C_{60} could be advantageous because it is possible to 'gate' the C_{60} interaction through electrical biasing and thereby develop tunable devices[2]. Here, we investigate plasmonic interactions at the interface of an as-deposited thin film sample of Bi_2Se_3/C_{60} using electron energy loss spectroscopy (EELS). We show changes in the characteristic plasmonic behaviour of the Bi_2Se_3 surface in the presence of C_{60}, providing greater understanding of the topological insulator-organic interface.

Methods

Bi_2Se_3 thin films were grown on a c-plane sapphire substrate by molecular beam epitaxy (MBE) with immediate subsequent deposition of C_{60} overlayers to avoid interfacial contamination. Cross-sections were extracted from the thin films by focused ion beam techniques and thinned to an electron transparent thickness of 35 nm for imaging. STEM and EELS were carried out on a mono-chromated instrument at 60 kV (the Nion UltraSTEMTM 100MC 'HERMES' instrument at the UK SuperSTEM facility).

Momentum-resolved EELS was used to map the plasmon dispersion with a convergence and collection semi-angles of 2 mrad and 1.1 mrad respectively. Spectra were collected containing only electrons scattered with specific momentum transfer from the lattice at momenta 0.0±0.3, 0.7±0.3, 1.0±0.3 and 1.4±0.3 1/Å along the ΓM direction of the first Brillouin zone of Bi_2Se_3 to map the dispersion.

Results

EELS data and plasmon dispersions were obtained across two interfaces Al_2O_3/Bi_2Se_3 and Bi_2Se_3/C_{60} and are presented in figure 1. Panel is a HAADF STEM image of the stack, showing excellent film quality that includes clear crystallinity in the C_{60} layers. EELS spectra of bulk Bi_2Se_3 from the centre of the thin film (annotated blue in figure 1a) revealed two volume plasmons, at 7.2 and 17.3 eV, as well as two Bi core-loss edges between 25-28 eV (not shown). The dispersion of the 17.3 eV volume plasmon is shown in figure 1d and follows a parabolic trendline as expected from literature implying the classical nature of this plasmon. A surface plasmon from Bi_2Se_3 was observed at 5 eV, localised to the Al_2O_3/Bi_2Se_3 interface, as shown in figure 1b. Its plasmon dispersion was observed to follow either a linear or root trend, plotted in figure 1e, which is similar to that predicted for π-electrons in graphene[3] and suggests the presence of a strongly confining interfacial potential. Comparison with simulations suggests that the nature of this surface plasmon could be a result of Bi_2Se_3 π-electrons confined in 2D to the surface[3]. The carrier density obtained from a fit of the surface plasmon dispersion concurs with the predicted number of carriers arising from Bi_2Se_3 π-electrons by DFT simulations.

At the other side of the thin film, additional features could be isolated as originating from interaction with C_{60} due to their absence at the Al_2O_3/Bi_2Se_3 interface. Across the Bi_2Se_3/C_{60} interface, the surface plasmon energy was shifted higher in energy to 5.9 eV, shown in figure 1c. This interface contained features from bulk Bi_2Se_3 and C_{60} along with the additional surface plasmon. In bulk C_{60}, three interband transitions were observed, at 3.6, 4.7 and 5.8 eV, consistent with literature[4]; these exhibited very little dispersion with increasing momentum. At the Bi_2Se_3/C_{60} interface, some contribution of these non-dispersive interband transitions remained present. In momentum-resolved EELS spectra of this interface, dispersion of the observed surface plasmon was more difficult to map due to the additional spectral features present, however, the spectra could be decomposed into a linear combination of distinct contributions, revealing the presence of a dispersing feature, localised at the interface and that we identify as the interfacial plasmon.

Unusual plasmon dispersion of the Bi_2Se_3 surface plasmon was observed by momentum-resolved EELS similar to dispersion of 2D π-electrons in graphene. Upon fitting, an agreement in carrier concentration suggests the surface plasmon origin could be from the 2D confinement of Bi_2Se_3 π-electrons to the surface. Through the introduction of organic molecules such as C_{60}, the surface plasmon of Bi_2Se_3 was altered. Further work will characterise the interface between Bi_2Se_3 and other organic molecules such as H_2Pc.

Graphic:

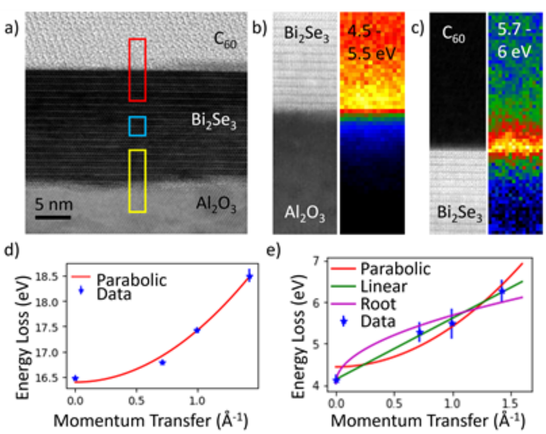

Figure 1: a) Bright field STEM image of a Al_2O_3/Bi_2Se_3/C_{60} thin film with regions of EELS maps indicated in yellow and red for panels b and c, b) EELS spectrum image at 4.5 to 5.5 eV across the Al_2O_3/Bi_2Se_3 interface where increase intensity at the interface shows a surface plasmon. c) EELS spectrum image at 5.7-6 eV across the Bi_2Se_3/C_{60} interface with a surface plasmon. d) Plasmon dispersion of the bulk Bi_2Se_3 volume plasmon obtained via peak fitting of momentum resolved EELS spectra which follows a clear parabolic trend. e) Plasmon dispersion of the surface plasmon in b which follows a root or linear trend.

Keywords:

EELS, topological insulator, plasmons

Reference:

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