

Electronic doorway states as efficient secondary electron escape channels in layered graphitic materials

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Low energy electron emission from highly oriented pyrolytic graphite, single- and bilayer graphene has been studied by detecting secondary electrons in coincidence with inelastically scattered primaries. Resonant features are identified in the coincidence spectra which are shown by DFT calculations to be signatures of Feshbach resonances resulting from the interlayer character of final states strongly coupling to vacuum, forming electronic doorway states enabling electron escape. The appearance of these states depends on the number of layers.

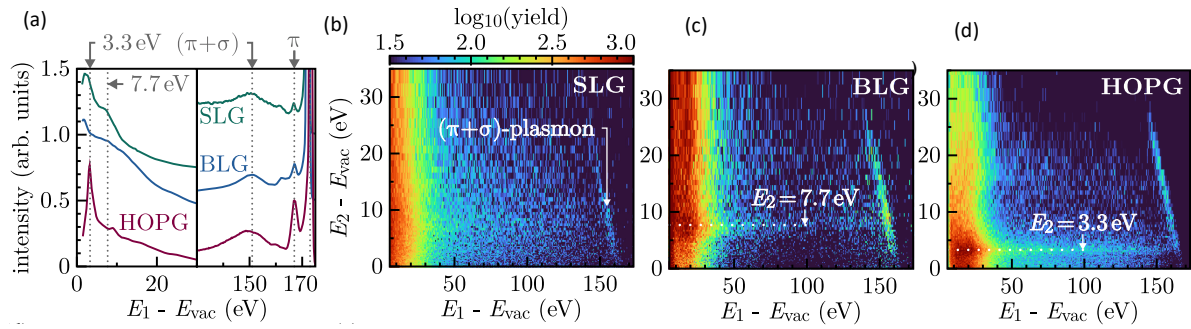


Figure 1. (a) Reflection electron energy loss spectra (REELS) for 173 eV electrons reflected from quasi-freestanding single-layer graphene (SLG, green), bilayer graphene (BLG, blue), and highly-oriented pyrolytic graphite (HOPG, red); (b-d) electron correlation maps of the two electrons leaving the surface (one reflected and one secondary), detected with a hemispherical energy analyzer (HEA, E_1) and a time-of-flight detector (TOF, E_2), respectively. All heat maps use the color scheme indicated in panel (b) representing the logarithm of the electron yield.

Figure 1a shows the reflection electron energy loss spectra of layered graphitic surfaces bombarded with 173 eV electrons. Panels b-e represent the double differential coincidence spectra on a false color scale. The strong resonance at $E_1 = 3.3$ eV for HOPG in Fig 1a is seen in the coincidence spectrum in Fig 1d as a horizontal stripe at $E_2 - E_{vac} = 3.3$ eV and has been christened X- peak [1] in the literature since its origin posed a riddle. Analysis of the coincidence data [2] revealed that it is caused by the liberation of solid-state electrons by plasmon-excitation (by the primary) and subsequent -decay which can escape via so-called doorway states, i.e., the coupling of quasi-bound conduction band states with free-electron vacuum states [3,4], which are formed in the course of the interaction. The coincidence spectrum of bilayer graphene displays a similar resonance, albeit at a different energy of ~ 7.7 eV, while no such feature was observed in single layer graphene.

The electronic structure of the studied materials in itself cannot explain the observed structures. However, DFT calculations prove that these resonances are signatures of Feshbach resonances acting as doorway states to the continuum states in vacuum. Their occurrence depends on the number of layers, demonstrated both by DFT calculations as well as experimentally [3] and are expected to be more generally observable for layered materials.

References

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