Transverse Electron Mean Free Path through Few-layer Graphene in eV-Transmission Electron Microscopy

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The transverse electron mean free path (MFP) in graphene has received less attention than its in-plane counterpart, although van der Waals heterostructures often rely on out-of-plane conduction and suspended graphene layers are commonly used as substrates in transmission electron microscopy. In order to probe the transverse MFP in the 0-100 eV range, we added a second electron source to an aberration corrected low energy electron microscopy (AC-LEEM) setup, enabling imaging in both transmission and reflection mode at nanometer (nm) resolution.
We have measured the energy-dependent transmissivity and reflectivity of 2D graphene layers up to 75 eV above the vacuum level and obtained the energy-dependent transverse electron MFP. Below approx. 30 eV we find an increase in MFP. However, the MFP is always much shorter than suggested by the so-called ‘universal curve’ [1] and exhibits characteristic maxima.
The observed splitting of the elastic MFP maximum around 2.5 eV (see figure) in multi-layer graphene is explained by a model [2] in close analogy to optical multilayer antireflection coatings: The electron wave is partially reflected and partially transmitted at each graphene layer, leading to interference of the multiply reflected waves. By scanning the energy, the electron wavelength is varied and the MFP maxima form whenever transmitted and multiply reflected waves interfere constructively.
Due to their high transmissivity at low energy, graphene membranes are suited as support films in eV-TEM [3]. As the resonant increases in MFP were attributed to interference effects, they can also be expected in other layered materials, providing a new perspective on the ‘universal’ curve in the low-energy regime.

REFERENCES

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FIGURES

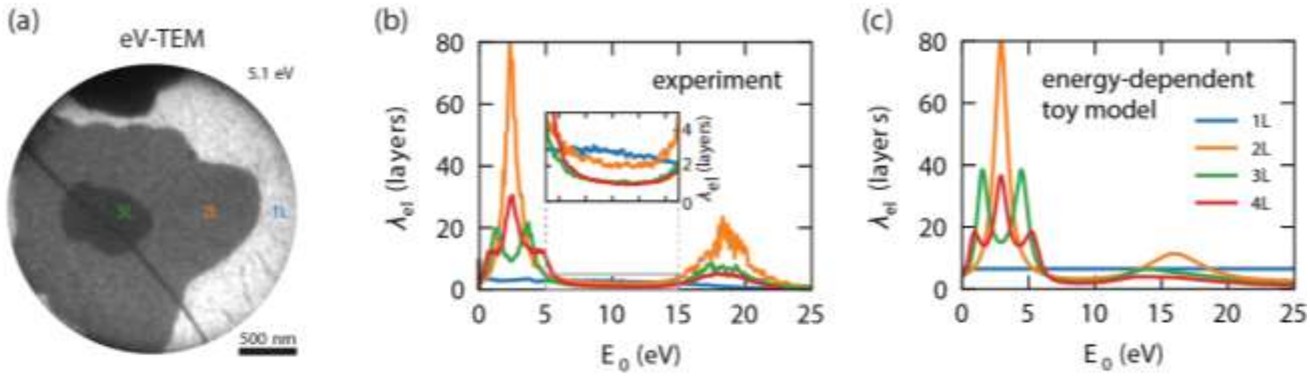

Figure 1: (a) Transmission Electron Micrograph at 5.1 eV electron energy of mono-, bi- and tri-layer graphene areas. (b) Elastic mean free path extracted from transmission and reflection spectra. (c) Elastic mean free path according to a toy model inspired by optical thin-film interference.