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Momentum Dependent Electron Energy-loss in Graphene and MoS2 Investigated at 20 and 40kV

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Here we first are concerned with the dispersion of high-energy plasmons (>3eV), known as pi and pi-sigma plasmon in free-standing single- and multi-layer graphene. We have applied angle-resolved electron energy-loss spectroscopy in a low-voltage transmission electron microscope to measure the momentum-dependent energy-loss function of suspended single- and multi-layer graphene as well as mono-layer MoS2 for the two reciprocal symmetry direction Gamma-M and Gamma-K. Samples were prepared using mechanical exfoliation. Experiments were done on a Libra-based TEM prototype (ZEISS) operated at 20kV and 40kV. We determined the energy and momentum resolution to be 0.2eV and 0.1-0.2Å-1. Our achieved spatial resolution was around 100-200nm. For graphene we find the two plasmon peaks at small q-values to be around 5eV and 15eV for both symmetry directions. At smaller q-values the spectra for Gamma-M and Gamma-K are similar. We find significant differences at q-values larger than 0.5Å-1. In Gamma-M direction and above a value of 0.8Å-1 the pi-plasmon splits into two peaks with a shoulder at around 5eV similar to pi-plasmons observed in carbon nano-tubes and graphite. We see no shoulder for the Gamma-K direction. Comparison to density functional theory calculations in random phase approximation (RPA) shows, that in both cases the behavior of the pi-plasmon is well reproduced. In contrast RPA does not correctly describe the behavior of the pi-sigma-plasmon. Furthermore, for single-layer, free-standing graphene we report a quasi-linear dispersion of the pi-plasmon for both symmetry directions. In addition we present measurements, illustrating the changes of the energy-loss function with increasing number of graphene layers (up to 6). Here the behavior can be understood in terms of a simple layered electron gas model. Additionally we present the layer dependent plasmon dispersion behavior and compare it to graphite, showing that at small q-values 6-layered graphene is still significantly different from graphite but appears graphite-like at large q-values. In addition we will present experimental results of the energy-loss function of free-standing mono-layer MoS2, where we find significant differences to the bulk response of MoS2.