Thickness Identification and Electronic Transport in Atomically Thin MoS_2 Layers

Song-Lin Li, Kazuhito Tsukagoshi

International Center for Materials Nanoarchitectonics, National Institute for Materials Science,
Namiki 1-1, Tsukuba, Ibaraki 305-0044,Japan
LI.Songlin@nims.go.jp

Abstract

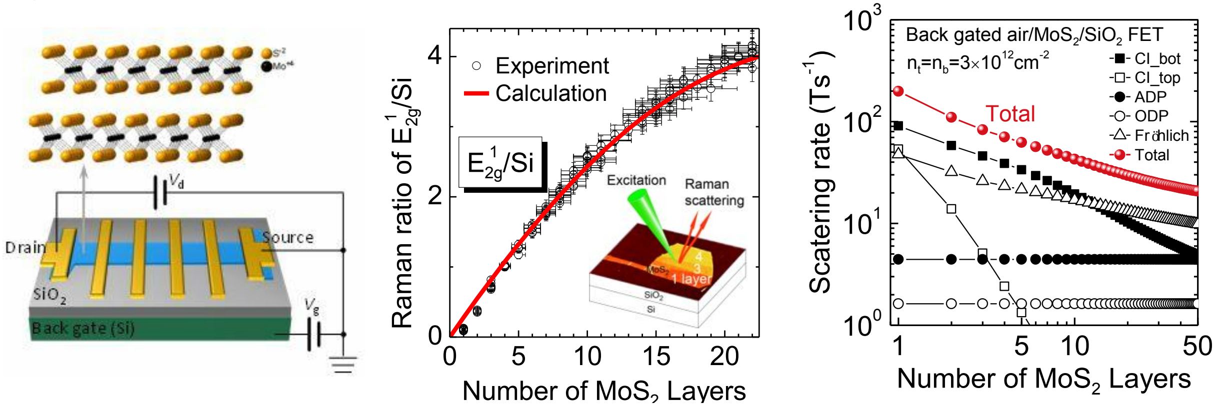
Two-dimensional semiconductors are promising for the ultimate atomic field-effect transistor (FET) technology after silicon because of their unique atomic-scale thickness and flatness. Here we first demonstrate a rapid and nondestructive layer counting technique for the atomically thin layers on insulating substrates by using an interference Raman spectroscopy [1]. As an example, atomically thin MoS_2 sheets with discrete numbers of layers from 1 to 20 are obtained. Based on the accurate information on sample layers, we performed combined experimental and theoretical studies and employed the channel thickness as a unique clue to clarify the underlying scattering mechanisms in atomically thin FETs [2]. Experimentally, the carrier mobility changes by one order of magnitude, increasing from ~10 to ~150 cm^2/Vs in pristine SiO_2/MoS_2/air structures, as the MoS_2 channel increases from monolayer to bulk. A careful comparison with theoretical calculation indicates that such thickness-dependent behavior is caused by: 1) shortened interaction distances between Coulomb impurities and carriers due to squeezed carrier distribution in ultrathin channels; 2) different Coulomb scattering sources located on the channel surfaces. For ultrathin channels, the high-density charged impurities on both the upper (i.e., the MoS_2/air interface) and lower MoS_2 surfaces (the MoS_2/SiO_2 interface) dominate the scattering events, while only these on the lower surface are the leading scatters for thick channels. This understanding well explains the long-standing puzzle of the general low carrier mobility of ultrathin channels as compared with corresponding bulks. The result highlights the critical roles of dielectric/channel interfacial quality and surface absorption in the electrical transport and provides direct guidance in performance improvement in atomic-scale FETs by reducing the Coulomb impurities at the dielectric/channel interface, which are essential for the ultimate post-silicon nanoelectronics.

References

[1] S.-L. Li, et al, ACS Nano, **6** (2012) 7381.

[2] S.-L. Li, et al, Nano Letters, **13** (2013) 3546.

Figures



Left: Schematic diagram of the back-gated air/MoS_2/SiO_2 FET. **Middle**: Comparison between calculation and experiment for intensity ratio of the MoS_2 E_{2g}^1 (~ 383 cm^{-1}) Raman mode to that of the Si substrate (520 cm^{-1}). This new quantity can be used as a unique criterion for counting the number of layers (NLs) for atomic sheets. The errors for the assgined NL values (by AFM) and intensity ratios are 10% and 5%, respectively. **Right**: Calculated scattering rates for different mechanisms, including Coulom impurity (CI) at bottom (bot) and top surfaces, lattice deformation by acoustic and optical phonons (ADP and ODP), and Fröhlich interaction.