L.7: Development of a microscopic mechanical exfoliation setup for monolayer preparation of 2-D materials

Monolayers of two-dimensional (2D) semiconductors are potential candidates for optoelectronic and flexible devices. Two-dimensional semiconductor materials such as molybdenum disulfide (MoS_2) are van der Waals materials that are strongly bonded in two dimensions and are weakly bound in the third dimension. Due to this weak bonding in the third dimension, it is possible to prepare monolayers and a few layers of these materials. It actually transforms from indirect to direct bandgap when it is reduced to single layer. Such direct bandgap monolayer 2D materials have high carrier mobility, broadband optical absorption, and a large surface area, resulting in strong light-matter interaction. These materials make an attractive system for fundamental physics studies and optoelectronic applications.

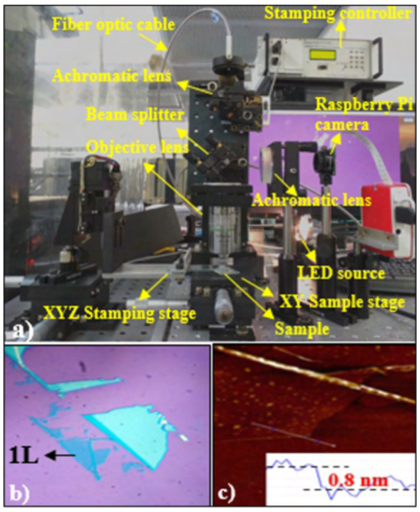

Fig. L.7.1: (a) An in-house developed microscope along with stamping mechanism to prepare monolayer, (b) optical microscope image of prepared monolayer, and (c) the AFM measurement on the prepared monolayer.

One of the critical challenges in harnessing the potential of monolayer MoS_2 lies in its synthesis and fabrication. Various methodologies have been developed to produce monolayer MoS_2, with mechanical exfoliation standing out as a technique that allows for the creation of high-quality, atomically thin layers. Mechanical exfoliation along with PDMS-gel dry transfer stamping method is developed to prepare monolayer MoS_2. In-house built optical microscope along with stamping stage is used to transfer monolayer MoS_2 on SiO_2/Si substrate by identifying the optical contrast (Fig. L.7.1). AFM analysis confirmed the height of monolayer MoS_2 to be 0.8 nm. Raman analysis also showed distinct peaks at E_{2g}^{1} (383.7 cm^{-1}) and A_{1g} (403.9 cm^{-1}) modes and peak difference of 20.2 cm^{-1} confirms the pristine monolayer nature of MoS_2 flake (Fig. L.7.2).

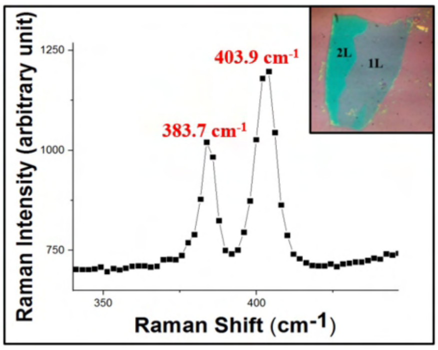

Fig. L.7.2: Raman measurement on large sized MoS_2 monolayer prepared by gold assisted mechanical exfoliation, inset shows the optical image of the sample.

For preparing much larger size flakes, gold assisted exfoliation is also performed. Gold-assisted exfoliation is an effective method to produce large-area monolayers, since sulphur is said to have a very strong affinity for gold. The exfoliated MoS_2 flakes is stacked with 150 nm gold. Thermal release tape (TRT) is pressed onto Au/MoS_2 stack and transferred onto SiO_2/Si substrate. TRT is released by heating at 90 °C and gold is etched away. This resulted in a few hundred microns in the size of the MoS_2 monolayer.

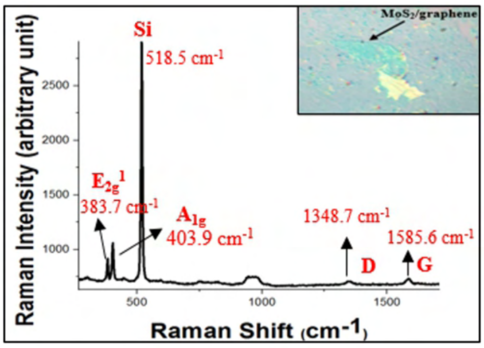

Fig. L.7.3: Raman measurement on MoS_2/graphene monolayer heterostructure prepared using stamping process. The inset shows the optical image of the sample.

Further, MoS_2/graphene heterostructure was prepared using stamping process. Commercial graphene monolayer on copper substrate was transferred to SiO_2/Si substrate and mechanically exfoliated monolayer of MoS_2 identified by optical contrast on PDMS-gel was stamped on top of Graphene monolayer on SiO_2/Si substrate. Raman analysis confirmed the presence of monolayer MoS_2 at E_{2g}^{1} (383.7 cm^{-1}) and A_{1g} (403.9 cm^{-1}). Graphene peaks were also seen at D (1348.7 cm^{-1}) and G bands (1585.6 cm^{-1}) (Fig. L.7.3). The observed broadening and enhanced defect states in the MoS_2/graphene heterostructure provided compelling evidence of interaction between the MoS_2 and graphene, which alters its optical and electronic properties.

Reported by:
Salahuddin Khan (skhan@rrcat.gov.in)