Modulating the properties of MoS_2 by plasma thinning and defect engineering

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There is a great need for controlling the properties of two dimensional (2D) materials to fulfill the requirements of various applications.[1,2] Among the mostly investigated 2D layered materials, single and multilayer molybdenum disulphide (MoS_2) are semiconductors with bandgap of ~1.2-1.8 eV, which make them promising candidates for optoelectronic applications. Here, we present our results on the modulation of the properties of MoS_2 by plasma thinning and defect engineering.

The electronic structures of two dimensional materials are strongly dependent on their thicknesses, i.e. single layer MoS_2 is a direct bandgap material while bilayer MoS_2 has an indirect bandgap structure. A simple, efficient, and nondestructive way to control the thickness of MoS_2 is highly important for the study of thickness dependent properties as well as applications. We present layer-by-layer thinning of MoS_2 nanosheets down to single layer by using Ar^+ plasma. AFM, Raman, and photoluminescence (PL) spectra suggest that the top layer MoS_2 is totally removed by plasma while the bottom layer is almost unaffected. We also demonstrate that this method can be used to prepare two dimensional heterostructures with periodical single and bilayer MoS_2, by utilizing standard lithographic techniques. The plasma thinning is very reliable (almost 100% success rate), can be easily scaled up, and is compatible with standard semiconductor process to achieve heterostructures/patterns with nanometer sizes, which may bring out interesting properties and new physics.[3]

The PL quantum yield of as-prepared monolayer MoS_2 has been found to be quite low, due to the formation of negative charged excitons (also named as negative trions) in the naturally *n*-doped MoS_2. Structural defects have been observed both in pristine/as-grown MoS_2 and electron beam/plasma irradiated samples.[4] The proper utilization of these defects to improve the optical properties of MoS2 is highly desirable. We report a strong PL enhancement of monolayer MoS_2 through defect engineering and oxygen bonding. High resolution micro- PL and Raman images clearly reveal that the PL enhancement occurs at defects of MoS_2. The PL enhancement at defect sites can be as high as thousands of times after considering the laser spot size. First principle calculations reveal a strong binding energy and effective charge transfer for oxygen molecule adsorbed on an S vacancy of MoS_2. X-ray photoelectron spectroscopy further confirms the formation of Mo-O bonding. Our results provide a new route for modulating the optical properties of 2D semiconductors.[5]

References

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Figures

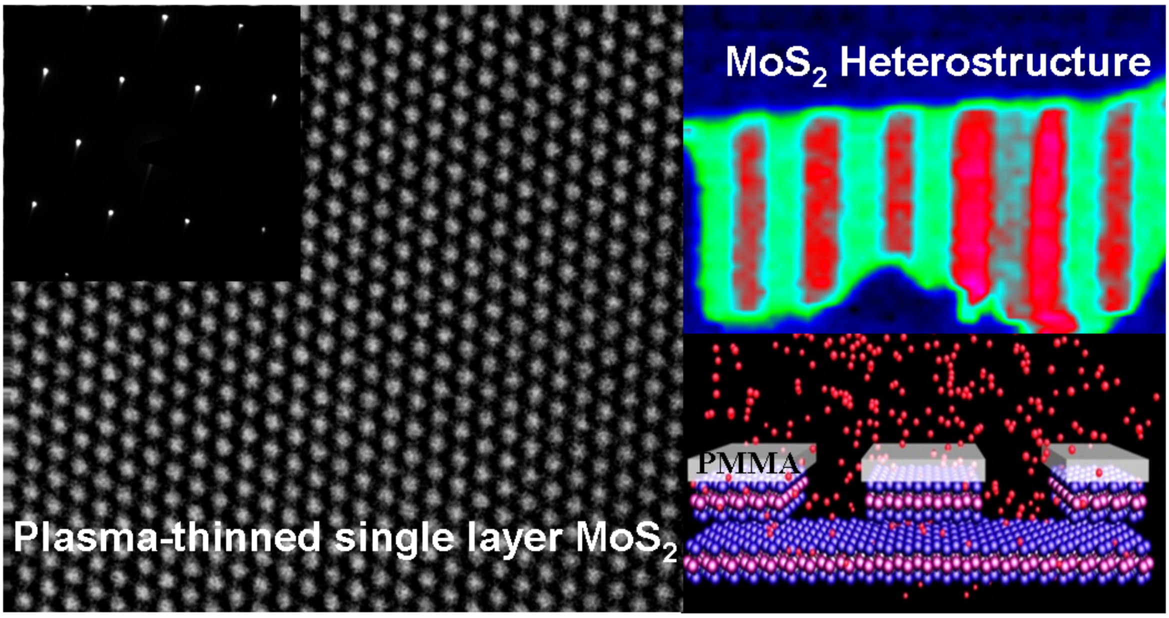

Fig. 1. Plasma thinning of MoS_2: The electron diffraction patterns and high resolution TEM image of plasma-thinned single layer MoS_2, and the Raman image of periodical 1/2/1/2/1…MoS_2 heterostructure obtained by plasma thinning and electron beam lithography.

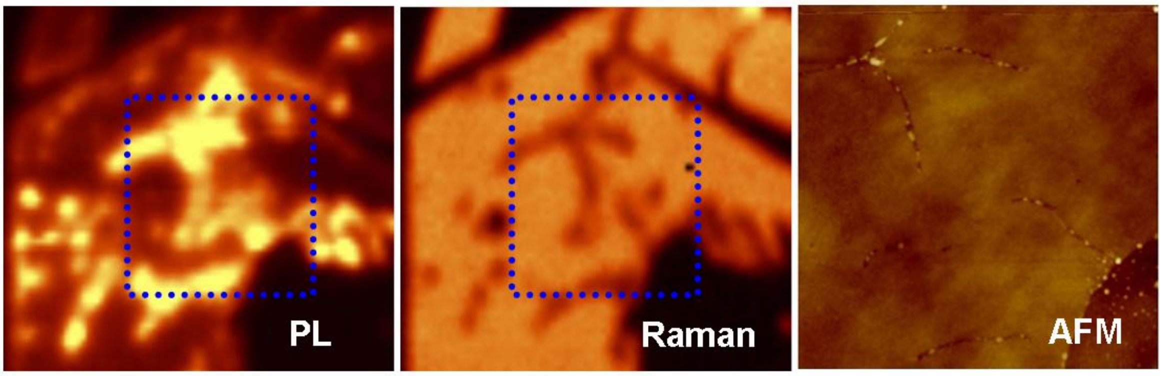

Fig. 2. PL enhancement of MoS_2 through defect engineering and oxygen bonding. High resolution micro- PL and Raman images, as well as AFM, clearly reveal that the PL enhancement occurs at cracks/defects of MoS_2.