Atomic Resolution Imaging of Heterostructure Interfaces of 2D Transition Metal Dichalcogenide Monolayer

Xin, Y. (NHFML), Sahoo, P.K. (USF, Physics), Memaran, S. (FSU, Physics), Balicas, L. (FSU, Physics, and NHMFL) and Gutiérrez, H.R. (USF, Physics)

Introduction

Transition metal dichalcogenide (TMD) monolayers are atomically thin semiconductors of the type MX_2, with M a transition metal atom (Mo, W, etc.) and X a chalcogen atom (S, Se, or Te). TMD monolayers MoS_2, WS_2, $MoSe_2$, WSe_2, have a direct bandgap, and can be used in electronics as transistors and in optics as emitters and detectors. The work on TMD monolayers is an emerging research field since the discovery of the direct bandgap and two-dimensional heterojunctions have great potential for application in low power, high-performance and flexible electro-optical devices. In our work, we developed a method of one-pot growth of sequential edge-epitaxial heterostructures with $WSe_2/MoSe_2$ or WS_2/MoS_2. We are able to grow multi-junction heterostructures by selective water-oxidation and volatilization [1].

Experimental

High-angle-annular-dark-field-scanning transmission electron microscopy (HAADF-STEM) is used to image the $WSe_2/MoSe_2$ heterostructure interfaces. An aberration-corrected JEM-ARM200cF was used to image the monolayers of $MoSe_2$ and WSe_2. The images were acquired with a probe size 7c, 8cm camera length, which has a STEM resolution of 0.78 Å and inner collection angle of 76 mrad. The atom intensity is proportion to $Z^{1.7}$, so the W atom shows brightest contrast, Mo has less intensity, and the Se is the weakest ones.

Results and Discussion

Fig.1a is the photoluminescence intensity maps of a triangle-shaped single crystal that has a multilayer heterostructures [1]. The low magnification image shows two interfaces 1 and 2 that follows the growth sequence (Fig.1b). The atomic resolution image shows one W atom with two Se atoms in WSe_2 (Fig.1c), and one Mo atom with two Se atoms (Fig.1d). The interface images (Fig.1e-1f) clearly shows that the $MoSe_2$ grows after WSe_2 has sharp interface, but the interface has a transition width following growth from $MoSe_2$ to WSe_2.

Acknowledgements

TEM work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. DMR-1157490 and the State of Florida. This work was supported by the National Science Foundation (NSF) grant DMR-1557434 and the US Army Research Office MURI grant W911NF-11-1-0362 and the Office Naval Research DURIP Grant 11997003.

References

[1] Sahoo, P. K. *et al*., Nature, to be published, Jan. 4, (2018).

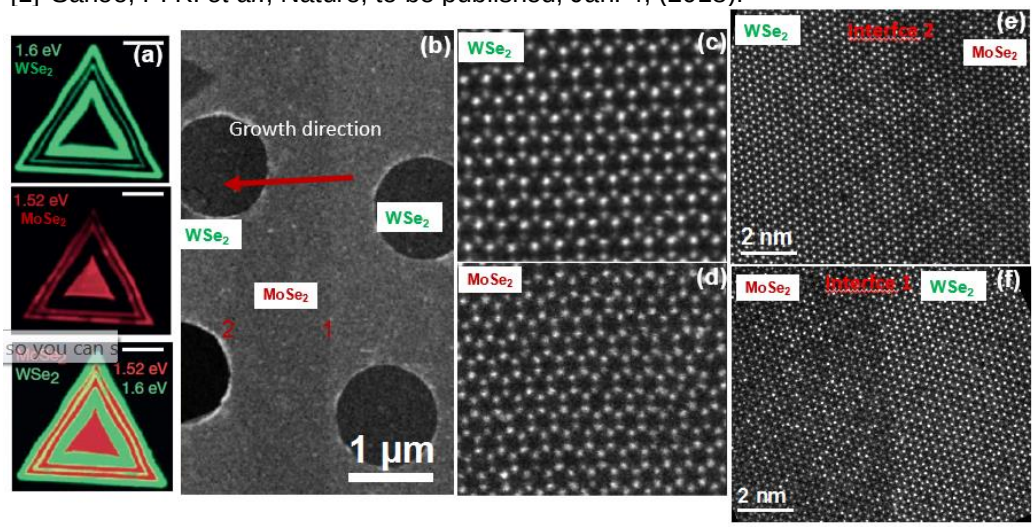

Fig.1 Photoluminescence intensity maps and HAADF-STEM images of the $WSe_2/MoSe_2$ heterostructures.