

## **Ultrafast Nonlinear Optical Effects in 2D Semiconductors**

By

*Prof. Jun WANG,*  
*Professor, Shanghai Institute of Optics and Fine Mechanics (SIOM),*  
*Chinese Academy of Sciences (CAS)*

**Date: 14 September 2016 (Wednesday)**

**Time: 15:00**

**Venue: E12-G021**

### **Abstract**

As a class of semiconductors, transition metal dichalcogenides (TMDs) have the formula  $\text{MX}_2$ , where M stands for a transition metal (i.e., Mo, W, Ti, Nb, etc.) and X stands for a chalcogen (i.e., S, Se or Te). TMDs show graphene-like layered structure. Strong covalent bonds in layers and weak van der Waals interaction between layers allow TMDs to form a robust 2D nanostructure. In a TMD monolayer, the single transition metal layer is sandwiched between the two chalcogen layers. Owing to the specific 2D confinement of electron motion and the absence of interlayer coupling perturbation, 2D layered TMDs show unique photonics-related physical properties, e.g.,

- 1) Sizable and layer-dependent bandgap, typically in the 1-2 eV range;
- 2) Indirect-to-direct bandgap transition as the decreasing of the number of monolayer;
- 3) Fairly good photoluminescence and electroluminescence properties;
- 4) Remarkable excitonic effects, i.e., high binding energy, large oscillator strength and long lifetime.

In combination of the ultrafast carrier dynamics and molecular-scale thickness, the prominent properties manifest the 2D TMDs a huge potential in the development of photonic devices and components with high performance and unique functions.

We have extensively studied the ultrafast nonlinear absorption and nonlinear refraction of layered  $\text{MX}_2$  ( $\text{X}=\text{S}, \text{Se}, \text{Te}$ ) over broad wavelength (Vis-NIR) and time (fs-ps-ns) ranges. Large area MoS<sub>2</sub> neat films with controllable thicknesses were fabricated from liquid-exfoliated MoS<sub>2</sub> dispersions by vacuum filtration. The MoS<sub>2</sub> films show superior broadband ultrafast saturable absorption (SA) performance, in comparison with the graphene films and the MoS<sub>2</sub> dispersions. Very recently, we observed giant two-photon absorption (TPA) coefficient in a WS<sub>2</sub> monolayer. The order of magnitude of TPA coefficient in WS<sub>2</sub> monolayer (~100 cm/MW) exceeds that of the conventional

semiconductors (e.g., CdTe, GaAs, ZnS, ZnO, etc.) by a factor of 3-4. This is also the first Z-scan performance on an optical medium with a thickness as tiny as 0.75 nm. Moreover, a comprehensive study on the layer-dependent nonlinear photonic effect was carried out in MoS<sub>2</sub> mono- and few-layers by CVD growth. SA to TPA transition was confirmed when the thickness changes from few-layer to monolayer. In addition, a spatial self-phase modulation method has been applied to tune the nonlinear refractive index of TMD dispersions. The above-mentioned works have opened up a door towards 2D semiconductor based nonlinear photonics, spectroscopy and relevant photonic devices.

### **Biography**

Jun WANG, born in Nov. 1979, is a Professor at Shanghai Institute of Optics and Fine Mechanics (SIOM), Chinese Academy of Sciences (CAS). He was awarded his PhD degree in materials science and engineering from the Chinese University of Hong Kong in 2006. Then he was granted an IRCSET postdoctoral fellowship and joined Prof. Werner Blau's group at Trinity College Dublin. In 2011, he obtained the financial support from the 100-Talent Program of CAS and relocated his research activities to SIOM. In 2013, he was awarded by the National 10000-Talent Program. His research interests are focused on ultrafast nonlinear optics in low-dimensional nanomaterials. So far he has published more than 80 peer-reviewed SCI journal papers in Nature Nanotech., Nature Commun. , Adv. Mater., Prog. Mater. Sci., ACS Nano, Laser Photon. Rev., Nanoscale, etc., including 4 ESI Highly cited paper and/or Hot paper and having over 1600 citations and a h-index: 20.

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