ARISTOTLE UNIVERSITY OF THESSALONIKI

RESEARCH COMMITTEE

# GROWTH, OPTICAL AND MECHANICAL PROPERTIES OF TWO-DIMENSIONAL $MoS_2$ AND $WS_2$ CRYSTALS

Molybdenum and tungsten disulfides ($MoS_2$, $WS_2$), possess unique optical properties and phenomena. An atmospheric pressure Chemical Vapour Deposition method for the production of large area $MoS_2$ and $WS_2$ crystals is presented. Continuous $MoS_2$ films with monolayer and few layer domains, isolated triangular $MoS_2$ monolayers or very large $WS_2$ monolayers with lateral dimensions exceeding 300 μm can be readily obtained. The optical and mechanical properties of the fabricated samples are deeply investigated.

**Application Field**

The team have intense collaborations with SMEs and industrial partners such as BIC Violex, Nanonics (Israel), Tipografio (Greece). Indicative services offered by the team:

**1.** Growth, and handling of 2D materials on suitable substrates for technological applications.

**2.** Fabrication of polymer nanocomposites based on 2D materials with superior electrical and mechanical properties for a variety of applications.

**3.** Modification of the optical properties of 2D materials by the application of external stimuli such as mechanical deformation (uniaxial, biaxial, hydrostatic), chemical and electrochemical doping.

**Services Offered to Third Parties**

**A.** Large scale growth by means of chemical vapour deposition of transition metal dichalcogenites (TMDs)

**B.** Photoluminescence emission from TMDs

**C.** Influence of uniaxial and biaxial mechanical deformation on the optical properties of $MoS_2$ and $WS_2$

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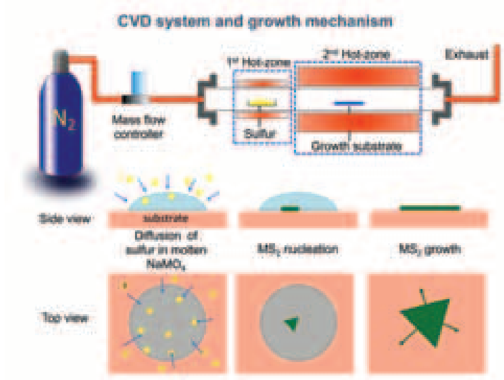


**Figure 1**
The atmospheric pressure CVD system is comprised of a two-zone quartz tube furnace. Inside the first zone an amount of elemental sulfur is placed. A Si/$SiO_2$ substrate coated with $Na_2MO_4$ (M = Mo, W) is placed in the second hot-zone. The system is flushed with nitrogen during the reaction which takes place at about 800°C. At this temperature $Na_2MO_4$ melts and sulfur vapors diffuse into the molten $Na_2MO_4$. Therefore, $MS_2$ nucleation occurs progressively forming isolated triangular monolayers or continuous TMD films.

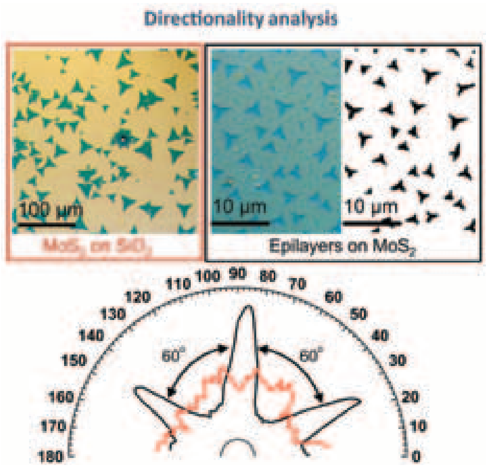


**Figure 2**
We find that crystals that grow on top of the amorphous $SiO_2$ their orientation is truly random. On the contrary, epilayers that nucleate and grow on top of a monolayer $MoS_2$ crystals exhibit strong directionality as can be seen in the directionality histogram.

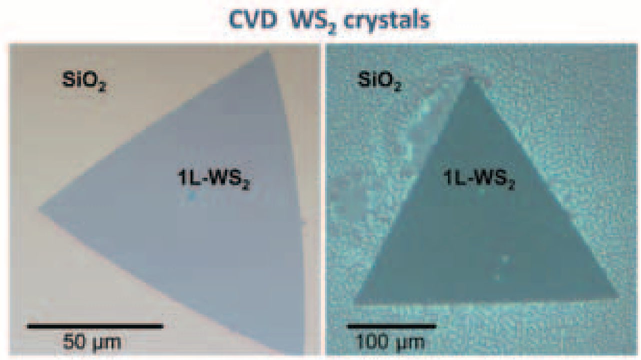


**Figure 3**
Utilizing $Na_2WO_4$ it is possible to grow large area single crystals of $WS_2$.

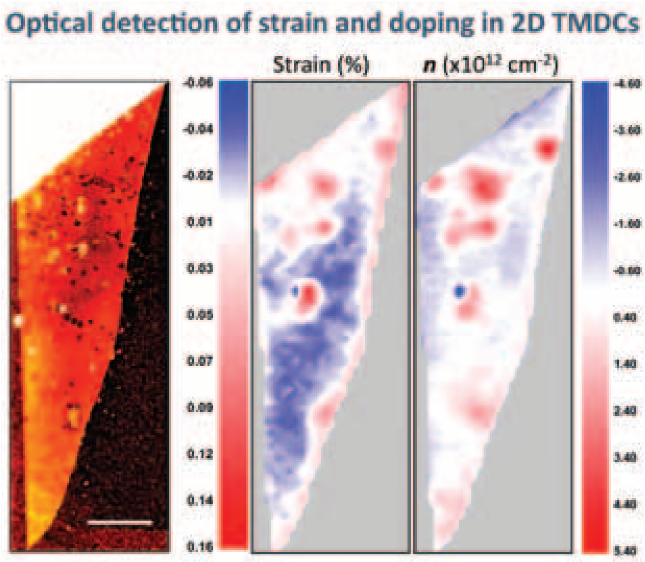


**Figure 4**
We have developed a purely optical analysis which enables the quantification of strain and doping levels present in a single layer $MoS_2$ crystal. In this example an AFM image of an exfoliated $MoS_2$ monolayer deposited on $SiO_2$ shows various structural defects. The strain and electron concentration maps can be extracted by a very detailed Raman mapping, which correlate very well with the AFM image, and are able to distinguish features as small as 300 nm (scale bar 3 μm).

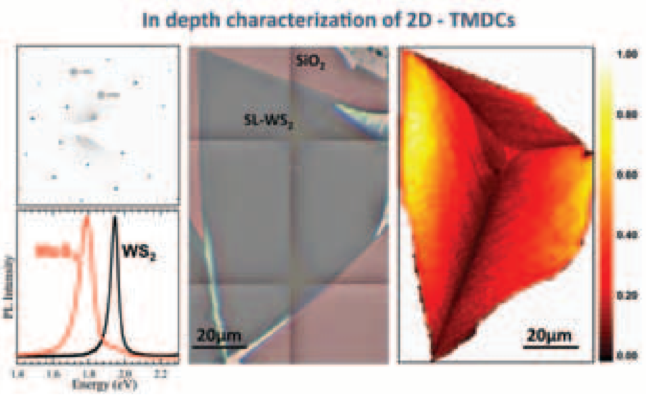


**Figure 5**
The synthesized crystals are studied by a variety of techniques including Optical microscopy, Atomic Force Microscopy, Transmission Electron Microscopy, Raman and Photoluminescence spectroscopies.

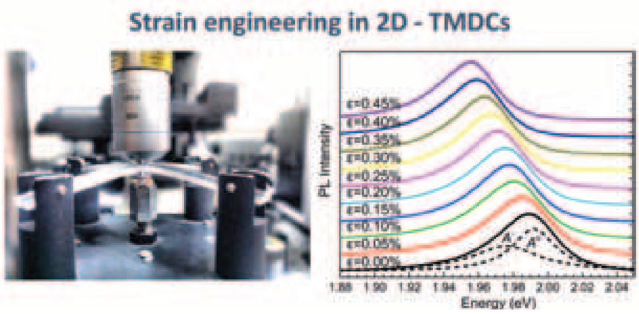


**Figure 6**
The optical response of the fabricated crystals is studied by in-situ Raman and PL spectroscopies. The crystals are transferred to a polymeric substrate shaped to a cruciform.