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Wasp-waisted magnetism in hydrothermally grown MoS_2 nanoflakes

Levna Chacko[1], A K Swetha[1], R Anjana[2], M K Jayaraj[2] and P M Aneesh[1]

[1] Department of Physics, Central University of Kerala, Padannakad, Kasaragod, Kerala 671314, India
[2] Centre for Advanced Materials, Department of Physics, Cochin University of Science and Technology, Kochi, Kerala 682022, India

E-mail: aneeshpm@cukerala.ac.in

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Abstract

Two-dimensional semiconducting materials are emanating as a requisite group of materials for future nanoscale electronics and optoelectronics. Particularly, transition-metal dichalcogenides like molybdenum disulphide (MoS_2), a semiconducting inorganic counterpart of graphene have intrigued intensive interest as two-dimensional materials due to its novel functionalities. In this work, the utilization of high pressure and low temperature hydrothermal method offers a facile, versatile synthetic tool for MoS_2 nanoflakes formation without the addition of any surfactants. Our experimental results resolve the formation of hexagonal phase, well-ordered stacking of S–Mo–S layers, quantum confinement and interlayer interaction. The strong spin–orbit coupling in MoS_2 provides enthralling optical and magnetic properties. A large optical absorption in 400–700 nm region and strong luminescence provide evidence for the indirect to direct band gap transition in MoS_2. Magnetic measurement results reveal ferromagnetism for all the MoS_2 nanoflakes and also indicate an increase in saturation magnetization with increase in duration of growth. In addition, a wasp-waisted hysteresis loop was also observed for the first time in MoS_2 nanostructures indicating multimodal population, increased grain growth and MoS_2–MoO_3 coupling. Our findings provide important insights into the future applications of MoS_2 in high-performance nanodevices and spintronics.

1. Introduction

Nanoscale size effects intensely revise the fundamental properties of semiconductors. Low-dimensional nanomaterials having confined geometries are of profound interest for exploring exotic and novel physical and condensed matter phenomena that opens up new prospects in the field of semiconductor devices. Materialization of graphene, the first real two-dimensional (2D) material, with massless Dirac Fermions [1], strong covalent in-plane bonds and weak van der Waals-like coupling between layers [2] opened up a unified vision regarding the new perspectives and potential applications of 2D materials. The rapid pace of progress in 2D materials have sparked a renewed interest in related layered crystalline materials with unique electronic, optical and optoelectronic properties. Layered transition metal dichalcogenides (TMDCs), in particular molybdenum disulphide (MoS_2) have attracted significant interest recently due to their intriguing electrical and optical properties that open new horizons in applications such as lubrication, lithium-ion batteries [3], sensors [4, 5], supercapacitors [6], light emitting diodes, transistors [4, 5], catalysis [7], ultrafast photonic devices, photo-conducting cells [8], p–n junctions, low-dimensional magneto-optical nanostructures etc TMDCs are a group of materials having MX_2-type configuration where M is a transition metal element from groups IV (Ti, Zr, Hf), V (V, Nb, Ta) and VI (Mo, W) and X represents the chalcogen species (S, Se, Te) [9]. These include metallic NbS_2 and VSe_2, superconducting $NbSe_2$ and TaS_2, semi-metallic WTe_2, $TiSe_2$ and $MoTe_2$, semiconducting MoS_2 and WS_2, and insulating HfS_2 etc [9]. It should be highlighted that the coordination geometry of the transition metal, the presence of unsaturated d-orbitals and the progressive filling of the non-bonding d-orbitals to the band structure of TMDCs introduces a multitude of fascinating properties such as tunable band gap, phase transitions, carrier density waves, magnetism, conductivity, superconductivity etc [10].