Journal of Materials Chemistry B

PAPER

Check for updates

Cite this: J. Mater. Chem. B, 2018, 6, 3048

MoS_2–ZnO nanocomposites as highly functional agents for anti-angiogenic and anti-cancer theranostics

Levna Chacko,†[a] Aswini Poyyakkara,†[b] V. B. Sameer Kumar*[b] and P. M. Aneesh*[a]

Received 17th January 2018, Accepted 16th April 2018

DOI: 10.1039/c8tb00142a

rsc.li/materials-b

Due to its excellent properties, 2D-MoS_2 finds potential applications in the fields of electronics, optoelectronics, energy storage and conversion, biomedicine, *etc.* This work deals with the incorporation of ZnO into 2D-MoS_2, its structural, morphological, optical, and magnetic studies and its application as an efficient cancer therapeutic agent. The MoS_2–ZnO nanocomposite exhibits remarkable excitation wavelength dependent down-conversion and up-conversion photoluminescence. The observation of wasp-waisted magnetism in the MoS_2–ZnO nanocomposite indicates the coupling of ZnO and MoS_2 materials inducing multimodal population. The MoS_2–ZnO nanocomposite showed cytotoxic properties with a safety index reaching up to ∼2. An *in ovo* xenograft assay revealed that the MoS_2–ZnO nanocomposite retards tumor growth by specifically activating caspase-3 and thereby inducing cellular apoptosis. Moreover, the treatment of xenografts with the MoS_2–ZnO nanocomposite down regulated the expression of major pro-angiogenic genes such as VEGF, VEGFR2 *etc.* thereby curtailing vascularization into the tumor intima. Treatment of tumor xenografts with the MoS_2–ZnO nanocomposite caused reduced expression of mesenchymal specific genes and elevated expression of epithelial specific genes, implying a role of the MoS_2–ZnO nanocomposite in retarding the process of epithelial to mesenchymal transition (EMT). This study highlights that the introduction of ZnO into MoS_2 nanostructures offers a unique idea to design efficient MoS_2-based multifunctional nanocomposites that provide opportunities in advanced biomedical and optoelectronic applications.

Introduction

The discovery of graphene in 2004 lead to a tremendous breakthrough into a whole range of 2D materials which include boron nitride, transition metal dichalcogenides (TMDCs), metal oxides and hydroxides, topological insulators *etc.*, due to their unique, novel functionalities and suitability for a wide range of applications.[1–3] In particular, MoS_2, a unique class of TMDC having a layered structure, is characterized by strong in-plane bonding and weak van der Waals interaction between the layers, and shows a wide range of mechanical, chemical, thermal, optical and electronic properties.[3,4] Kin Fai *et al.* reported that with decreasing layer thickness, the indirect band gap lying below the direct gap in the bulk material shifts upwards in energy by more than 0.6 eV.[5] Bulk MoS_2 has an indirect band gap of 1.2 eV, which originates from the valence band maximum located at the Γ point to the conduction band minimum located almost halfway along the Γ and K points.[6] As the layer number decreases, the lowest band in the conduction band moves upward, increasing the indirect band gap due to the quantum confinement effect in the *c*-axis of the crystal. Thus, at monolayer geometry MoS_2 undergoes a transition to a direct band gap of 1.9 eV[7] located at the K-point of the Brillouin zone different from zero band gap graphene and large band gap hBN. The indirect-to-direct band gap transition in 2D-MoS_2 is strongly evident from the emergence of strong photoluminescence thus presenting an intriguing prospect of scaling all semiconductor technology down to atomic scales. It is well-known that this semiconducting behavior of MoS_2 finds potential applications in lubricants, sensors, batteries, catalysts, LEDs, transistors *etc.* possessing next generation 2D alternatives to graphene.[7–11] Recent methodologies and research studies based on MoS_2 have indicated the bio-sensing, cell-targeted labelling and anti-cancer properties of these 2D materials, thus unveiling exotic biological applications in addition to their unique electronic and opto-electronic applications.[12–15]

Most interestingly, owing to their large surface area, two-dimensional MoS_2 nanostructures finds tremendous applications especially as biosensors, drug delivery systems *etc.* An MoS_2 based

[a] *Department of Physics, Central University of Kerala, Kasaragod, Kerala, 671314, India. E-mail: aneeshpm@cukerala.ac.in*

[b] *Department of Biochemistry and Molecular Biology, Central University of Kerala, Kasaragod, Kerala, 671314, India. E-mail: skumarvb@cukerala.ac.in*

† Equal contribution.

