Vertical Heterostructures of MoS_2 and Graphene Nanoribbons by Two-Step Chemical Vapor Deposition for High-Gain Photodetectors

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Heterostructures of 2D layered materials have attracted great interest due to their electronic and optical properties, which are expected by combining different types of 2D materials [1]. On the other hand, reduction of the dimensionality from 2D to 1D, such as graphene nanoribbons (GNRs), is also interesting due to the electron confinement and unique edge effects [2]. Here, we demonstrate bottom-up growth of MoS_2/GNR heterostructures by a two-step chemical vapor deposition (CVD) method [3]. It is a unique growth process because 2D materials of MoS_2 could grow in 1D direction by following the 1D nature of our GNRs.

The GNRs were first grown by ambient pressure CVD on an epitaxial Cu(100) film as reported previously [4]. After transferring on SiO_2, the GNRs were subjected to the second CVD to grow MoS_2 using MoO_3 and S powder as feedstock. The MoS_2 layer was found to grow preferentially on the surface of the GNRs, while the coverage could be further tuned by adjusting the growth conditions. Figure 1a,b shows the SEM images after the second CVD with a substrate temperature of 900 ºC for 30 min, where the dark contrast corresponds to the MoS_2 grown on the GNR. Raman spectra confirmed a single-layer MoS_2 grown on GNR, while from the comparison with the single-layer MoS_2 domains grown on sapphire, we found that the PL quenching effect by GNRs. Furthermore, the transport properties under light illumination were measured, as illustrated in Figure 1c, and high photoinduced current modulation for the heterostructures were observed upon illumination with visible light (Figure 1d) [4]. This optical response is higher than that of the heterostructure of MoS_2/graphene sheet [5]. The ability to grow a novel 1D heterostructure of layered materials by bottom-up CVD approach will open a new avenue to expand the dimensionality of the material synthesis and applications.

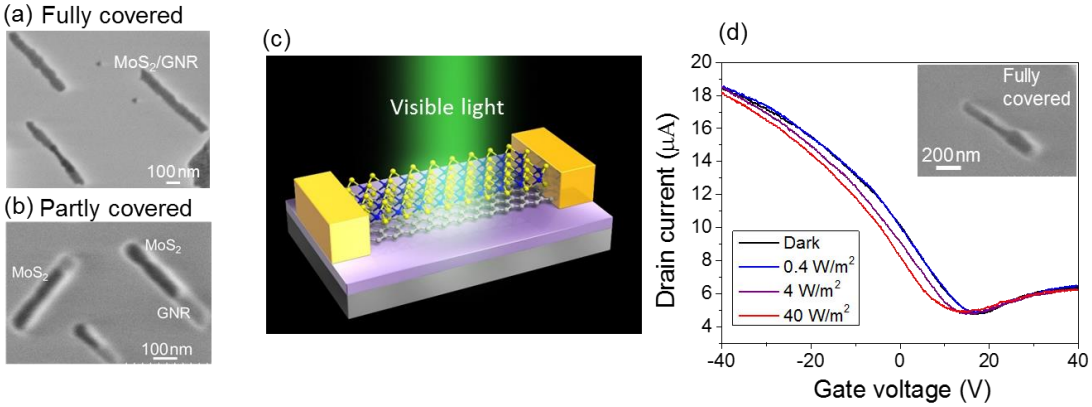

Figure 1. (a,b) SEM images of as-grown MoS_2/GNR heterostructures with different coverages. (c) Schematic diagram of the FET for fully covered MoS_2 on GNR with visible light illumination. (d) Transfer curves of the fully covered MoS_2/GNR device measured in dark and under illumination with different power densities. Inset shows a SEM image of fully covered MoS_2 on GNR, taken before making devices, which is the identical sample used to measure the transfer curve.

References: [1] H. Lim et al., Chem. Mater. **26** (2014) 4891. [2] X. Li et al., Science **319** (2008) 1229. [3] R. Mohamad Yunus et al., submitted. [4] R. Mohamad Yunus et al., Chem. Mater. **26** (2014) 5215. [5] H. Ago et al., ACS Appl. Mater. Interfaces **7** (2015) 5265.