Fabrication of MoS_2 Photodetectors for Near-Infrared Biosensing Applications

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Over the last few decades, researchers have been developing novel and high-performance diagnostic biosensors using metallic nanoparticle-based localized surface plasmon resonance (LSPR) components.[1] In these biosensing devices, photodetectors with high photoresponsivity and low internal noise level are required to detect the optical signals induced by biomarker binding events (i.e., Antigen-antibody binding). In recent years, atomically thin (i.e., 2-25 nm thick) molybdenum disulfide (MoS_2) channels have been integrated with LSPR structures to enable fast and sensitive colorimetric monitoring of disease-related biomarkers.[2] However, such biosensors are mostly operated in the ultraviolet/visible wavelength regimes, which demands a purification step to separate out a variety of unwanted biological species that absorb visible lights. This process typically takes several hours, which prevent implementation of such sensors for point-of-care (POC) scenarios. Therefore, it would be imperative to develop biosensors or immunoassay tools consistent with the whole blood assay with minimal sample preparation steps.[3] To meet this goal, a systematical study on high-performance near-infrared (NIR) photoconductors is strongly motivated because most biological species in the whole blood samples have high degrees of transparency for NIR lights.

In this work, we studied the photo-response properties (i.e., Photoresponsivity spectra) of in-plane MoS_2 photodetectors as the function of their geometric dimensions (e.g., thickness, length, and width of photoactive layers) as well as fabrication conditions (e.g., doping, etching, and substrate choice). This work has enabled the NIR operation capabilities of plasmonic colorimetric biosensing, thereby reducing assay times and background interference.

Fig. 1(a) shows an as-fabricated MoS_2 photoconductor structure with effective channel length of ~1 μm laterally sandwiched by a pair of Ti/Au electrode pads, which secures a smooth, single-crystal-domain sensing channel structure. The optimal MoS_2 channel thickness has been experimentally identified to be ~14 nm. To characterize optoelectronic properties of a MoS_2 photodetector, photocurrent is measured at fixed source-drain voltage, Vds = 1 V. **Fig. 1(b)** demonstrates the photoresponsivity spectra measured from a few-layer (FL) MoS_2 photodetector and a 14 nm thick multilayer MoS_2 photodetector. The 14 nm thick MoS_2 channel exhibits three-fold higher photoresponsivity as compared to that of the few-layer MoS_2 channel (3 nm thick) within the NIR region. Up to the present time, the technological utility of multilayer MoS_2 has been underappreciated in comparison with monolayer and few-layer MoS_2. However, our study indicates that multilayer MoS_2 films exhibit the higher photoresponsivity and light absorption coefficients than those of monolayer films under NIR illumination, which is attributed to the screening effect of the thicker MoS_2 films for unwanted interference signals from the backgrounds and complex analyte fluids. Furthermore, root mean square (RMS) noise values were measured from 3-nm thick and optimized 14 nm thick pristine MoS_2 photodetectors and a 14 nm thick O_2 plasma-treated MoS_2 photodetector, as shown in **Fig. 1(c).** This comparison shows that the 15-nm thick MoS_2 channel exhibits 100-fold lower noise level than that of the 3 nm thick MoS_2 photoconductor and the O_2 plasma-treated 14 nm MoS_2 photodetector. This result can be attributed to the minimized substrate scattering effect in the larger thickness (10–20 nm) and smooth surface MoS_2 channel layers.

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This work provides a guideline for making 2D-material-based NIR range photo-response devices implemented for the wash-free, mix-and-detection immunoassay of CEA in clinically relevant biofluids, including the whole blood.

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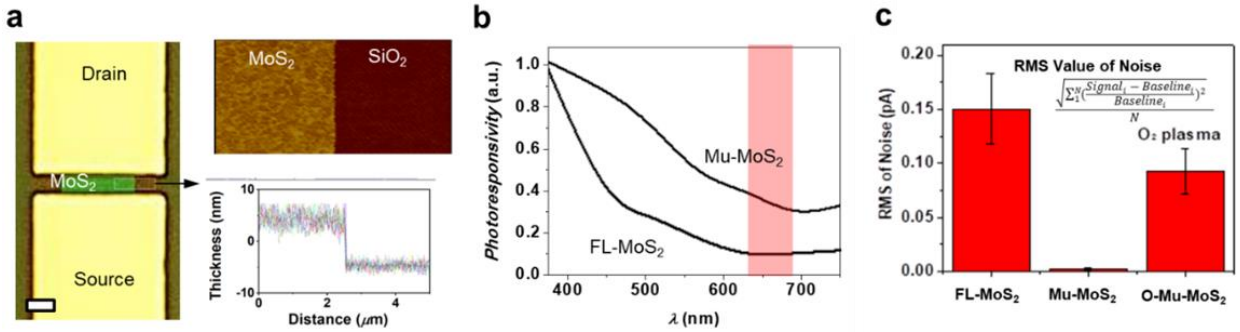

Fig. 1 MoS_2 photoconducting channels with different MoS_2 thicknesses: (a) Optical micrograph and AFM images showing the structure of a 15-nm thick MoS_2 channel with Ti/Au electrodes (Scale bar: 1 μm). (b) Photoresponsivity spectrum of 15-nm thick and 3nm thick few-layer MoS_2 sensing channels. The photoresponsivity is given by R = Iph/P, where Iph is the photocurrent and P is the intensity of the incident light. (c) RMS noise values measured for pristine MoS_2 channels of 3 and 14 nm in thickness, and O_2 plasma-treated 14 nm thickness, respectively.

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