Fabrication optimization of the photo-response characteristics of MoS2 photodetectors for biosensing applications

Seungjun Ki, Byunghoon Ryu*, Younggeun Park, Katsuo Kurabayashi, and Xiaogan Liang**

Mechanical Engineering Department, University of Michigan, Ann Arbor, MI 48109

* Argonne National Laboratory, Lemont, IL 60439

A therapeutic strategy guided by biomarkers, including cytokines and sepsis, has gained lots of attention because it can provide useful clinical information to determine immune status, disease presence, and progression.[1-2] Metallic nanoparticle-based localized surface plasmon resonance (LSRP) biosensors have been widely studied, seeking to achieve such immunological needs. In these biosensing devices, photodetectors with high responsivity and low internal noise levels need to be integrated to detect the subtle optical signals associated with biomarker binding events and therefore realize rapid, low-noise, and label-free detection capability as well as compatibility with point-of-care (PoC) setups. Recently, layered semiconductors (e.g., MoS_2 and WSe_2) have been emerging as strong candidate materials for this mission because of their outstanding photo-response characteristics. However, their practical implementation demands a systematical nanofabrication-oriented study to quantify and optimize the optoelectronic properties of MoS_2 photodetectors dedicated to biosensing applications.

In this work, we study the photo-response properties (e.g., photoresponsivity and noise equivalent power (NEP)) of in-plane MoS_2 photodetectors as the function of their geometric dimensions (e.g., thickness, length, and width of photoactive layers) and fabrication conditions (e.g., doping, etching, and substrate choice). This work enables the routine optimization for the photo-response characteristics of MoS_2-based biosensors, which are critical to optoelectronic biosensing applications.

Fig. 1 (a) shows the photo responsivity data measured from a set of MoS_2 photodetectors, plotted as the function of their MoS_2 photoactive layer thickness values. This result indicates that 7-20 nm thick MoS_2 photoactive layers results in relatively higher and constant photoresponsivity values. The MoS_2 thicknesses > 20 nm lead to a gradual decrease of photoresponsivity. This is attributed to the limited penetration depth of visible lights, resulting in a poor efficiency for collecting photo-generated carriers. When MoS_2 thickness < 7 nm, the photoresponsivity values are also relatively poor. This is attributed to the effects of dangling bonds or traps at MoS_2/SiO_2 interfaces. The thinner MoS_2 thickness is expected to result in a larger fraction of the photo-generated carriers, which can be attributed to the scattering effect by the dangling bonds or inter-layer defects on the SiO_2 substrate.[3] **Fig. 1 (b)** displays the low-frequency NEP spectra measured from the same set of MoS_2 photodetectors as well as a commercial CdS photodetector. For the optoelectronic biosensors, NEP plays an important role in determining the detection limits. Our devices exhibit a typical 1/f noise characteristic, which is attributed to MoS_2/SiO_2 inter-layer interfaces and charge impurities. Here, the NEP values at 1Hz are specifically chosen to further explore MoS_2-thickness-dependent noise characteristics because biomarker binding reaction events take place in a time scale of several seconds. **Fig. 1 (c)** exhibits that the devices with MoS_2 thickness in the range of 7-25 nm have the lowest NEP values, which are anticipated to lead to smaller detection limits for the optoelectronic biosensors. Figs. 1 (b) and (c) also indicate that the NEP values of all MoS_2 photodetectors are significantly lower than those measured from the

** Email: xiaoganl@umich.edu

commercial CdS photodetector. This strongly implies that MoS_2 is advantageous for making photodetectors dedicated to optoelectronic biosensing applications.

This work provides a guideline for making 2D-material-based photo-response devices implemented for optoelectronic biosensing systems.

[1] Park, Y., Ryu, B., Deng, Q., Pan, B., Song, Y., Tian, Y., Alam, H.B., Li, Y., Liang, X. and Kurabayashi, K., Small, **16**, p.1905611 (2020).
[2] Park, Y., Ryu, B., Oh, B.R., Song, Y., Liang, X. and Kurabayashi, K., Acs Nano, **11(6)**, pp.5697-5705 (2017).
[3] Scheuschner, N., Ochedowski, O., Kaulitz, A.M., Gillen, R., Schleberger, M. and Maultzsch, J., Physical Review B, **89(12)**, p.125406 (2014).

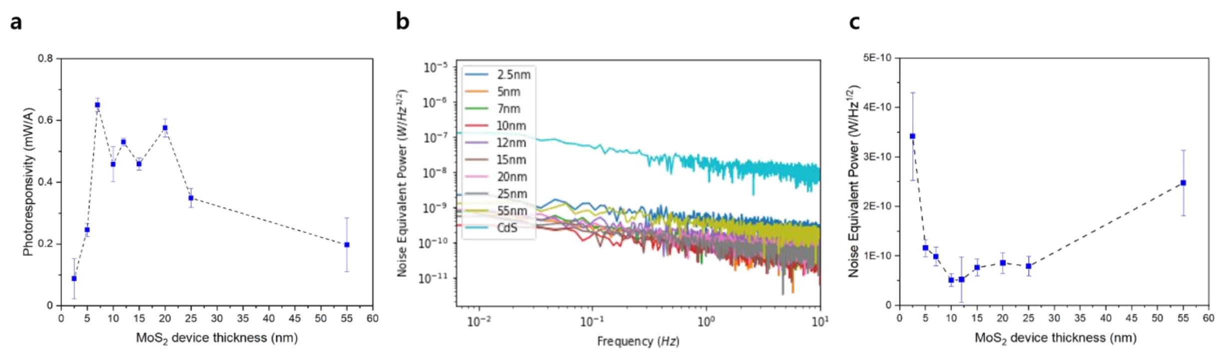

Fig. 1 Photo-response characteristics of the MoS_2 photodetectors with different MoS_2 thicknesses: (a) Photo responsivity as a function of MoS_2 photoactive thickness measured at Vds = 0.4V under light illumination at λ = 450 nm and P = 0.43 mW. (b) Noise equivalent power (NEP) spectra measured from MoS2 devices with different thicknesses as well as a commercial CdS photodetector for comparison. (c) NEP values captured at 1 Hz plotted as the function of MoS_2 thicknesses.

** Email: xiaoganl@umich.edu