System Integration of Nanostructured Materials for Point-of-Care Immune Biosensing

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***Abstract*—We report on system integration of plasmonic nanoparticles and a few-layered molybdenum disulfide (MoS_2) photoconductive nanochannel sheet on a silicon substrate. Plasma-assisted electrostatic bonding and van der Waals bonding are employed to create a high-sensitivity photoelectronic biosensor for immunological analysis.**

I. Introduction And Background

In recent years, substantial research has focused on developing nanoplasmonic biosensors aimed at point-of-care (POC) immunological testing due to their robustness, label-free nature enabling rapid analysis, ease of integration in a miniaturized system, simple optics [1, 2]. However, their implementations in real clinical settings are yet to be realized due to their limited sensitivity. To fill the gap between a laboratory-based proof of concept and translational biosensor implementation, we have proposed synergetic integration of nanoplasmonic label-free biosensing structures and an ultralow noise MoS_2 photoconductive nanosheet channel (Fig.1 A, B) [3]. Structurally-engineered metallic nanoparticles used for our device yield a 1000-fold amplification of near-field light localization at their surfaces. This results in a shift of light transmission through the antibody-conjugated nanoparticles, which is extremely sensitive to protein surface binding (Fig.1 C) The nanosheet channel in our device has a few atomic layers of MoS_2. This channel is patterned and bonded onto a Si substrate by imprinting and electrostatic bonding after oxygen plasma surface treatment generating negative charges. The assembled MoS_2 nanosheet shows unique structural and electrical properties that permit high-sensitivity photo signal detection. The glass layer with the nanoparticles is assembled onto Au electrodes via van der Waals bonding.

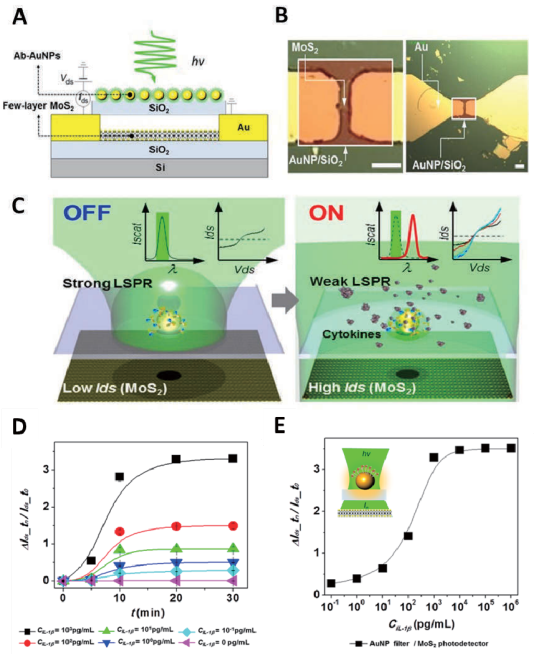

Fig. 1. Integration of bio-tunable nanoplasmonic optical filter and few-layer MoS_2 photodetector device. IL-1β detection in biotunable nanoplasmonic optical filter on few-layer MoS_2 photodetector. **(A)** Cross-sectional view of biosensor. **(B)** Optical image of biosensor. (*bar size = 20 μm*) **(C)** Illustration of biosensor principle. (Inset) *Ids* vs *Vds* curves of the few-layer MoS_2 photodetector at different IL-1β surface binding incubation time points for a fixed IL-1β concentration of $C_{IL\text{-}1\beta}$ = 10 pg/mL. **(D)** Photocurrent variation ($\Delta Ids\_t/Ids\_0$) during IL-1β surface binding incubation for different $C_{IL\text{-}1\beta}$ values. **(E)** standard curve of photo-electronic cytokine immune-biosensor incorporating biotunable nanoplasmonic optical filter on a few-layer MoS_2 photodetector.

II. Results

With the nano-material components integrated into a system, we constructed a biosensing pixel (~ 20 μm in diameter) targeting IL1-β, which is a cytokine biomarker relevant to pro-inflammatory disorders in the immune system. The measured photocurrent (I_{ds}) in the MoS_2 channel of our device increased over time with cytokine-antibody binding progressed on a nanoparticle surface. The I_{ds} variation ($\Delta I_{ds}/I_o$)-versus-time curves at a given light illumination quickly reached a steady state, indicating that a sampling-to-answer time can be as short as ~ 10 min (Fig.1 D). We further obtained a biosensor calibration curve for the IL-1β cytokine measurement (Fig.1 E). The sample volume required for the analysis was as small as 5 μL. The limit of detection (LOD) achieved by the biosensor was as small as 0.25 pg/mL (14 fM), and the sensor dynamic range was from 0.1pg/mL to 1ng/mL (4 orders of magnitude).

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References

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