Fabrication of Optoelectronic Cytokine Biosensors through Integration of Low-Noise MoS_2 Photodetectors and Biotunable Nanoplasmonic Windows

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Cytokines, immunomodulating protein biomarkers secreted by immune cells, are considered as promising indicators for monitoring the functional status of the human immune systems [1]. Since the concentrations of such cytokines are highly dependent on the progress of diseases, early detection and quantification of cytokines are of great importance for monitoring the time-varying immune status of an infected host [2]. To meet such a clinical need, localized surface plasmon resonance (LSPR) biosensors with label-free detection capability have been widely studied over the past decade [3]. However, the conventional LSPR biosensors typically suffer from a relatively poor detection limit and demand a bulky spectrometer to collect ultimate sensor reading signals, which makes them less competitive for rapid and sensitive biosensor applications, and especially not suitable for emerging point-of-care (PoC) diagnosis applications. In this regards, development of LSPR biosensors beyond such limits is highly desirable for realizing real-time high-resolution detection of disease-related cytokines.

Here, we present the fabrication of a novel cytokine biosensor, which involves the integration of a biotunable nanoplasmonic window and a few-layer MoS_2 photodetector. Such an integrative optoelectronic biosensor combines label-free detection capability of nanoplasmonic structures and low-electronic-noise characteristics of few-layer MoS_2 photosensitive channels, and therefore enables rapid and highly sensitive detection of target cytokines [4]. In addition, such an optoelectronic biosensor structure can be easily miniaturized for PoC applications.

Fig. 1a schematically illustrates the presented optoelectronic biosensor structure. In this structure, the nanoplasmonic window consists of a SiO_2 thin layer deposited with an array of gold nanoparticles functionalized by IL-1β-antibody molecules. This biotunable nanoplasmonic window is integrated on top of a MoS_2 photodetector. **Fig. 1b** displays the SEM image of representative 50 nm gold nanoparticles deposited on the SiO_2 thin layer. **Fig. 1c**. shows the optical micrograph of a few-layer MoS_2 photodetector located under the nanoplasmonic window. The intensity of incident light reaching to the MoS_2 photodetector channel can be sensitively tuned by biomolecular surface binding-induced LSPR shifts. Such LSPR shifts induced by fM-level cytokines cannot be fully distinguished by a conventional spectrometer but can be resolved by the underlying few-layer MoS_2 photodetector with a ultralow electronic noise level. **Fig. 2** plots time-dependent sensor response curves (*S*-*t* curves) measured at different IL-1β concentrations ($n_{IL\text{-}1\beta}$ = 0, 56, 560, and 5600 fM). Here, *S*, is defined by the relative percentage change in I_{ph} (*i.e.*, $S = 100\% \times (I_{ph} - I_{ph}(t=0))/I_{ph}(t=0)$). Using such biosensors, low limit-of-detection ~10 fM and fast detection time (10 min) for interleukin 1-beta (IL-1β) have been demonstrated.

This work could be further developed for realizing real-time point-of-care diagnosis and wearable bio/chemical/environmental monitoring applications.

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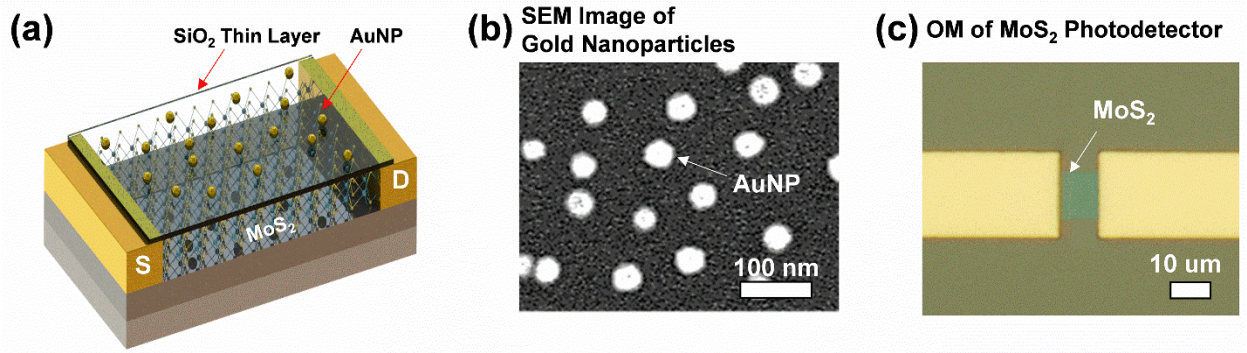

Fig. 1 Structure of the biosensor: (a) illustration of the biosensor integrated by the biotunable nanoplasmonic window and the few-layer MoS_2 photodetector; (b) SEM image of gold nanoparticles deposited on the SiO_2 thin layer; (c) optical micrograph of the few-layer MoS_2 photodetector.

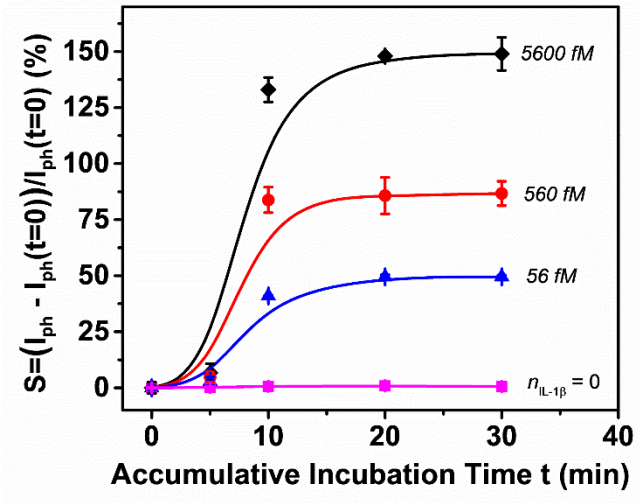

Fig. 2 Time dependent response curves (*S*-*t*) measured at different IL-1β concentrations ($n_{IL\text{-}1\beta}$ = 0, 56, 560, and 5600 fM).

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