# Rapid and Sensitive Cytokine Optoelectronic Immunosensing by Bio-Tunable Nanoplasmonic Filter on Few-Layer $MoS_2$

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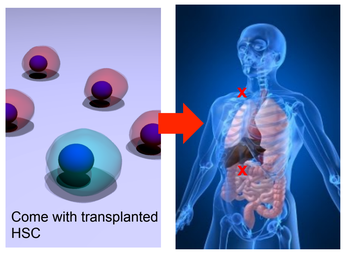
## Abstract

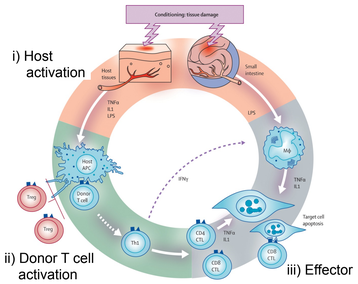
Monitoring of the time sensitive immune status of a diseased host often needs rapid and sensitive detection of **cytokines**. Nano biosensors based on localized surface plasmon resonance (LSPR) hold promise to meet this clinical requirement by allowing label-free detection of target biomolecules. However, these nano biosensors continuously suffer from relatively low sensitivity as compared to conventional immunoassay methods (ex. Enzyme linked immuno assay, ELISA) involving labelling processes. Their detection time also need to be faster to provide rapid cytokine quantification for following critical steps in time.
Here, we report a biosensor integrating a bio-tunable nanoplasmonic filter and a highly sensitive few-layer molybdenum disulfide ($MoS_2$) photodetector. This integration can serve as a generic device platform to meet the need of rapid cytokine detection with high sensitivity. The bio-tunable nanoplasmonic filter consists of anti-cytokine antibody-conjugated gold nanoparticles (AuNPs) on a $SiO_2$ thin spacer that is placed 170 μm above a few-layer $MoS_2$ photodetector. The delivering incident light to the few-layer MoS2 photodetector is tuned by the nanoplasmonic filter. Depends on cytokine concentration in the nanoplasmonic filter, LSPR change in the conjugated gold nanoparticle leads to the tunability. Using the developed LSPR-modulated optoelectronic biosensor, we have successfully demonstrated label-free detection of Interleukin-1 beta, a pro-inflammatory cytokine, with a limit of detection of 14 fM, a large dynamic range of $10^6$, and a short assay time of 10 min. We anticipate that this biosensing approach can be generalized for point-of-care diagnosis, wearable bio/chemical sensing, and environmental monitoring.

## Immune System and Guest Versus Host Diseases (GVHD)

- **Guest versus host disease**

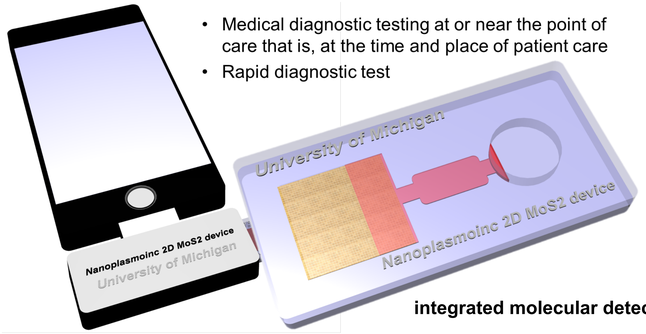



- **Cytokines in GVHD**




Ref) J. Ferrara et. al. *The Lancet* 2009

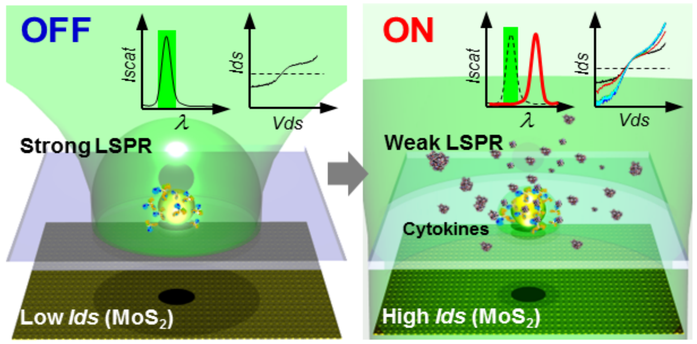
- **Point-of-care device**
  - Medical diagnostic testing at or near the point of care that is, at the time and place of patient care
  - Rapid diagnostic test



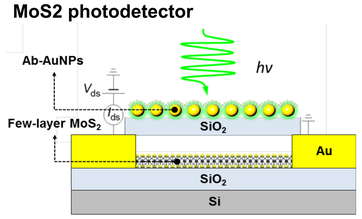

**integrated molecular detection**

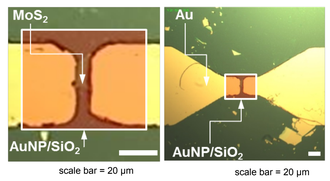
## Nanoplasmonic Filter on atomic $MoS_2$

- **Bio-Tunable Nanoplasmonic Filter on Few-Layer $MoS_2$**




- **Structure of the decoupled nanoplasmonic optical filter and the few-layer MoS2 photodetector**




## LSPR induced Nanoplasmonic filter

- **Design of nanoplasmonic filter**

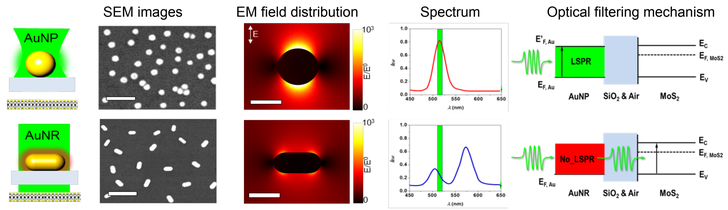



Figure. Plasmonic resonance induces optical filtering effects. The selective photodetection based on plasmon resonance is verified by comparison between AuNP (d = 50 nm) and AuNR (d/l = 40/68 nm)-coated $SiO_2$ layers.

- **LSPR-induced selective photo-enhancement effect**

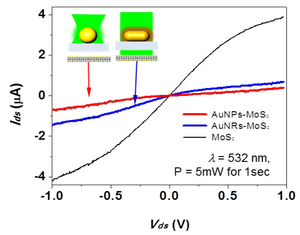



Figure. Comparison of photocurrent between the AuNP and the AuNR

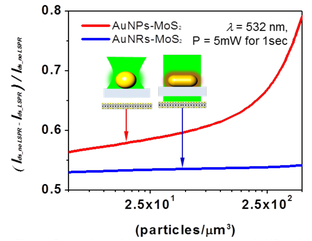
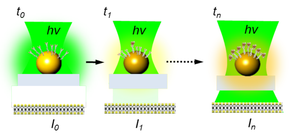



Figure. Comparison of photocurrent between the AuNP and the AuNR

## Rapid Cytokine Detection

- **Time dependent bio-tunability**




- Rapid detection (< 10min ) performance of bio-tunable nanoplasmonic optical filter on few-layer MoS2 photodetector.

- **Dynamic Monitoring**

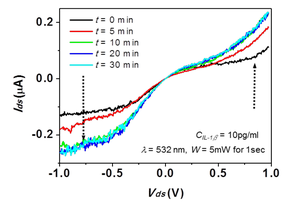



Figure. Ids vs Vds curves of the few-layer MoS2 photodetector as function of binding incubation time at $C_{IL\text{-}1\beta}$ = 10 pg/mL.

- **Rapid detection**

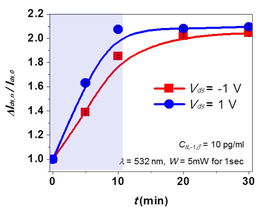
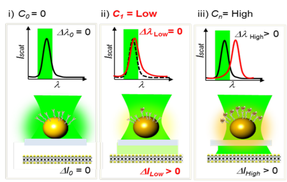



Figure. photocurrent variation over time during incubation process at Vds = 1.0 and −1.0 V at $C_{IL\text{-}1\beta}$ = 10 pg/mL.

## Highly Sensitive Cytokine Detection

- **Highly sensitive photodetector, $MoS_2$**




- Label-free detection of Interleukin-1 beta, a pro-inflammatory cytokine, with a limit of detection of 14 fM, a large dynamic range of $10^6$

- **Highly sensitive detection**.

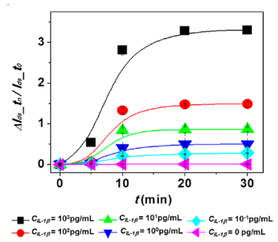



Figure. Photocurrent variation (ΔIds_t/Ids_0) during IL-1β surface binding incubation for different CIL-1β values.

- **Wide range of detection**

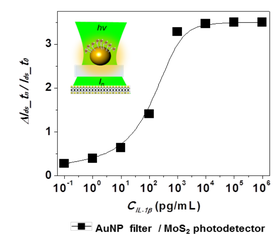



Figure. Photocurrent variation (ΔIds_t/Ids_0) during IL-1β surface binding incubation for different CIL-1β values.

## Conclusion

- **Unique integration of nanoplasmonic Filter on atomic $MoS_2$**
- **LSPR-induced selective photo-enhancement effect**
- **Rapid detection (< 10min ) performance**
- **Highly Sensitive Cytokine Detection of 14 fM, a large dynamic range of $10^6$**

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