Ultrasensitive surface-plasmon-resonance-based biosensor for efficient detection of SARS-CoV-2 Virus in near-infrared region

R. Runthala[1], and P. Arora,[1,*]

[1] Department of Electrical and Electronics Engineering, BITS PILANI Pilani Campus, Rajasthan, 333031, India

*email: pankaj.arora@pilani.bits-pilani.ac.in

IECB 2024 Conference
The 4th International Electronic Conference on Biosensors
20–22 May 2024 | Online

Abstract

An ultra-sensitive multilayered surface plasmon resonance-based biosensor is proposed that uses angular interrogation in the near-infrared region to detect the novel coronavirus. Using the strong binding efficiency of the 2D nanomaterial layer and the high dielectric constant layer, the biosensor exhibits excellent performance, facilitating its use in field of biomedical sensing applications.

Motivation

- Several sensors for virus detection have been developed using chemical and electrochemical approaches, but high performance, accurate identification, and fast real-time analysis are still difficult to achieve
- Optical biosensors based on surface plasmon resonance (SPR), which are highly sensitive to the variation of refractive index of the surrounding medium, are one way to achieve fast, real-time, and label-free sensing.
- Covering a broader spectral range with Aluminum as the plasmonic metal and establishing of stronger biomolecular interactions with 2D nanomaterials can be utilized for sensing applications in the NIR region

Principle of SPR

(a) Kretschmann Configuration

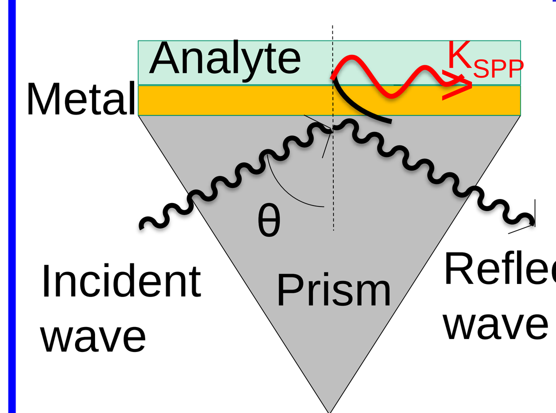
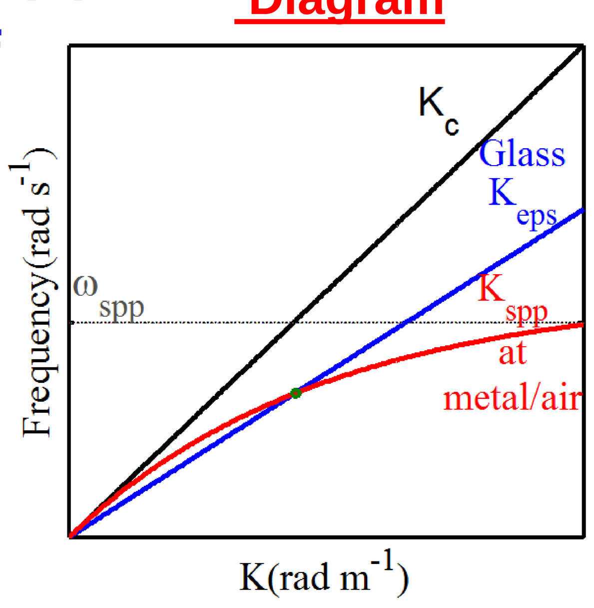


Fig. 1

(b) Dispersion Diagram



$$k_{spp} = k_0\sqrt{\frac{\varepsilon_m \varepsilon_a}{\varepsilon_m + \varepsilon_a}} = \frac{2\pi}{\lambda_0} n_p \sin\theta_{fixed}$$

- An evanescent field generated by a TM-polarized light under Total Internal Reflection (Fig. 1(a)), excites SPs at resonance angle on phase matching condition (Fig. 1(b)), resulting in SP dips in the captured reflected spectra

Schematic of proposed biosensor

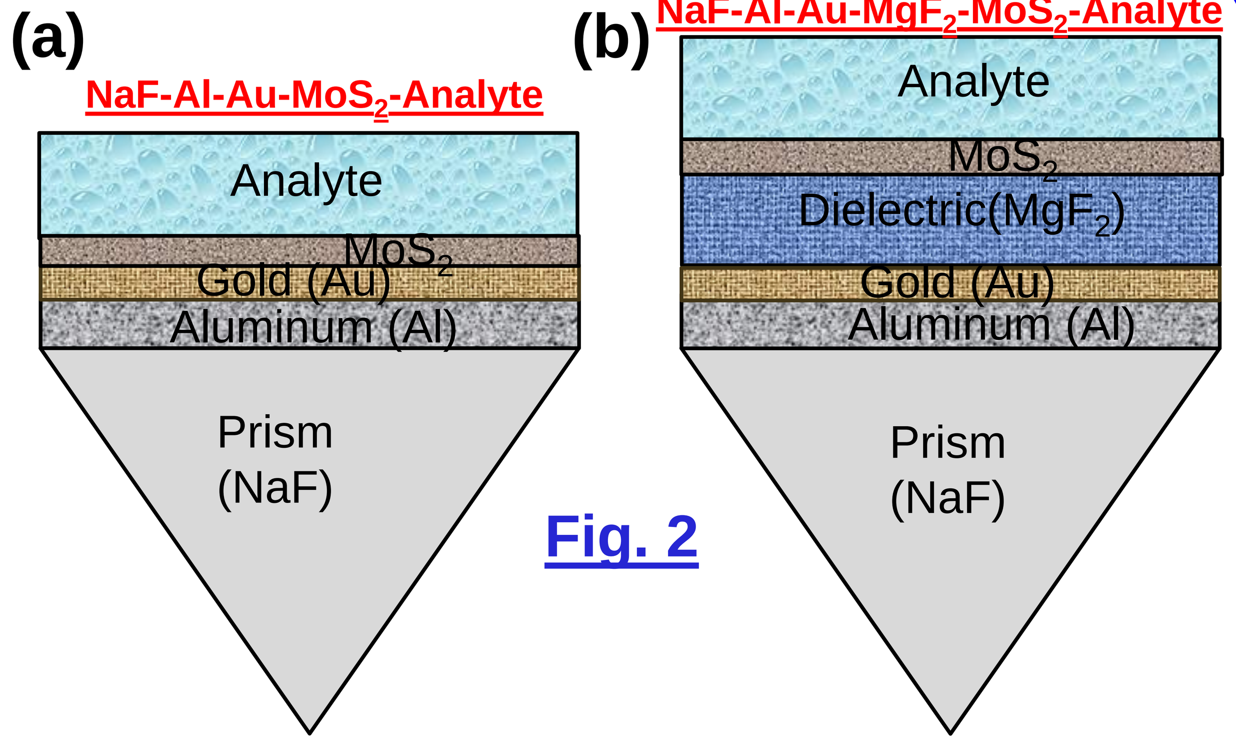


Fig. 2

- Fig. 2(a) shows the schematic of the proposed Al-Au-based biosensor without a dielectric layer (MgF_2), and Fig. 2(b) shows the schematic of the proposed biosensor after the inclusion of a dielectric (MgF_2) layer
- The high dielectric constant of the MgF_2 layer and the strong binding efficiency of the MoS_2 layers are utilized to enhance the sensing parameters, and a thin layer of gold over the Al layer is utilized to protect Al from the oxidation
- The layer-by-layer optimization is carried out by calculating the reflection characteristics of the proposed biosensor using Transfer matrix method and Comsol Multiphysics

Reflection characteristics for proposed biosensor

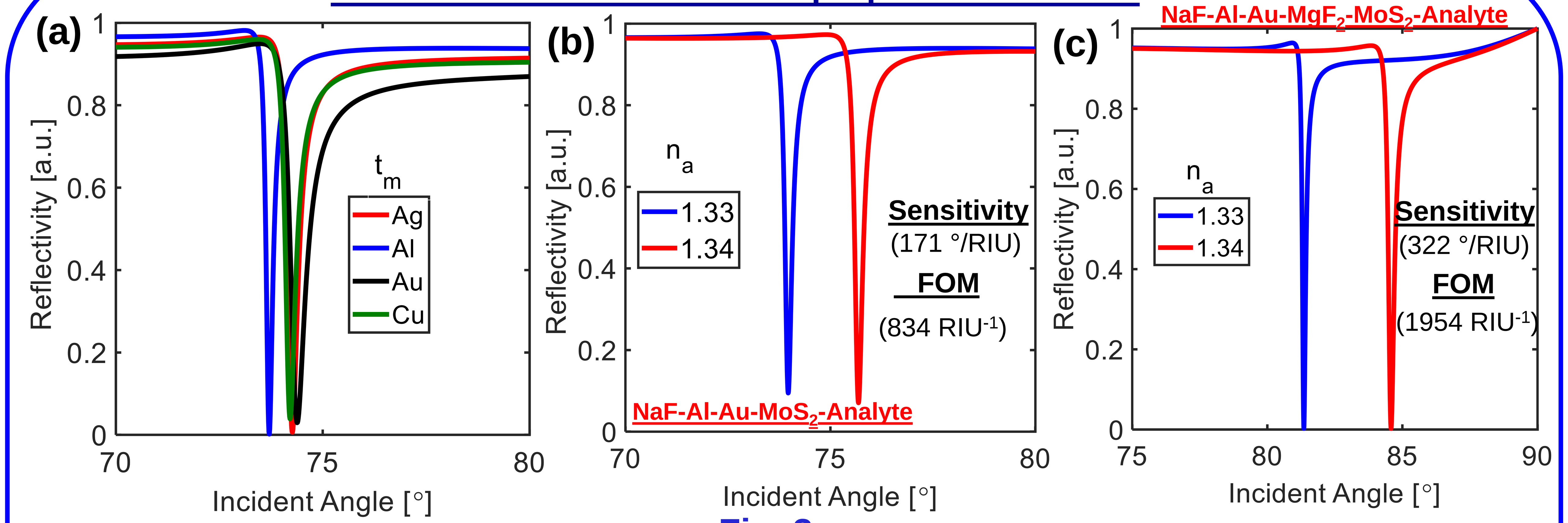


Fig. 3

- Al with thickness of 30 nm is chosen to be the plasmonic metal due to the narrow linewidth for SPR (Fig. 3(a))
- The proposed biosensor with configuration of NaF-Al-Au-MgF_2-MoS_2-Analyte offers higher sensitivity and FOM as shown in (Fig. 3(c)) after inclusion of MgF_2 layer as compared to NaF-Al-Au-MoS_2-Analyte (Fig. 3(b))

Engineering dielectric layer (MgF_2) in proposed biosensor

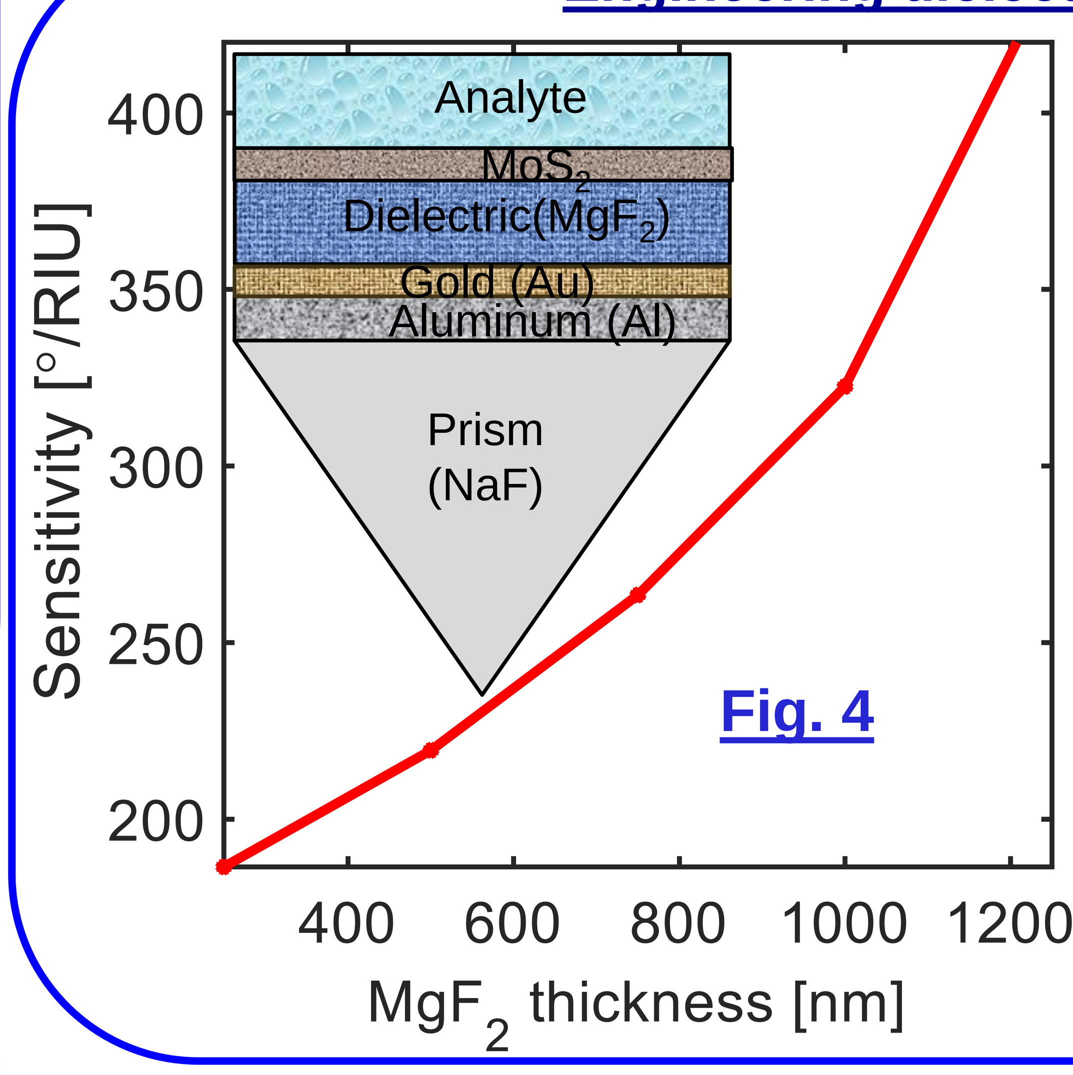
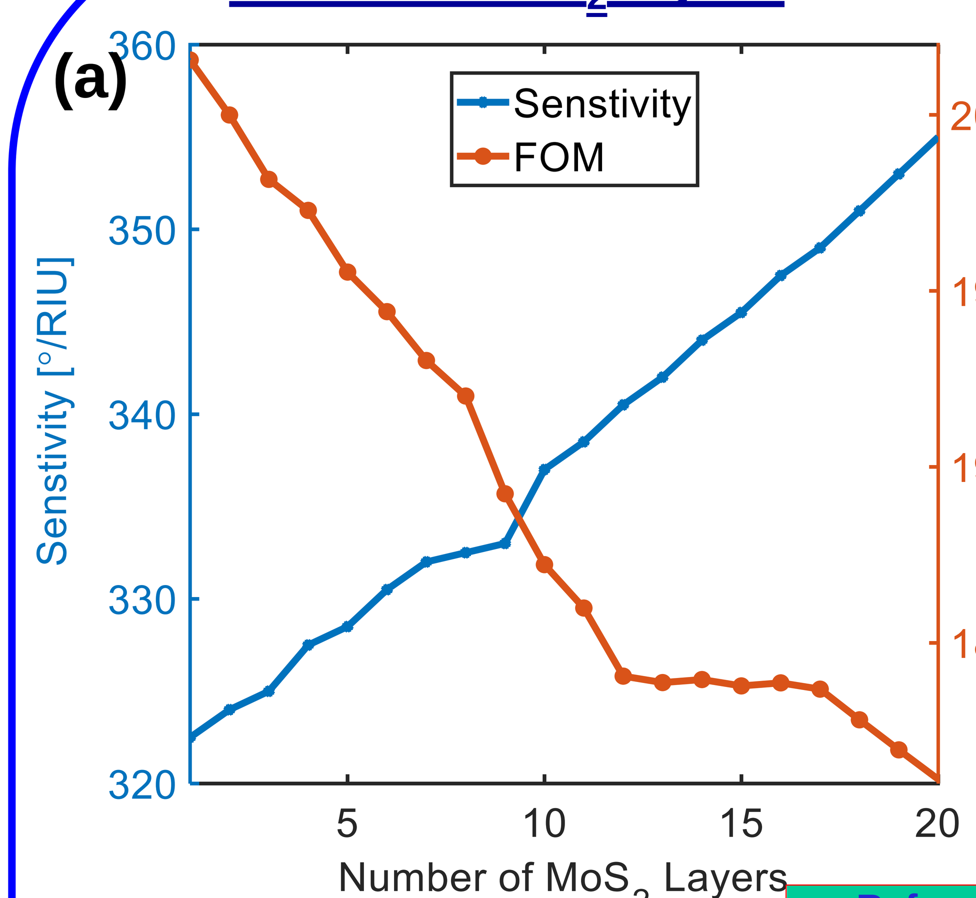


Fig. 4

Thickness [nm]	Sensitivity [°/RIU]	SPR angle shift [°]
250	186.5	76.58, 78.44
500	219.5	78.49, 80.68
750	263.5	79.98, 82.61
1000	322.5	81.35, 84.58
1250	440	82.86, 87.26

- An increase in the sensitivity value is observed with increase in the thickness of MgF_2 layer as shown in Fig. 4. A 1000 nm thickness of the MgF_2 layer is chosen to be the optimized vale since further increase in the thickness of MgF_2 layer leads to the SPR angle closer to 90°.

Effect of MoS_2 layers



- An optimized value of 10 for the number of MoS_2 layers is calculated after observing the effect of different numbers of MoS_2 layers on the sensitivity and FOM (Figure of Merit), as shown in Fig. 5(a)

Application to biosensing

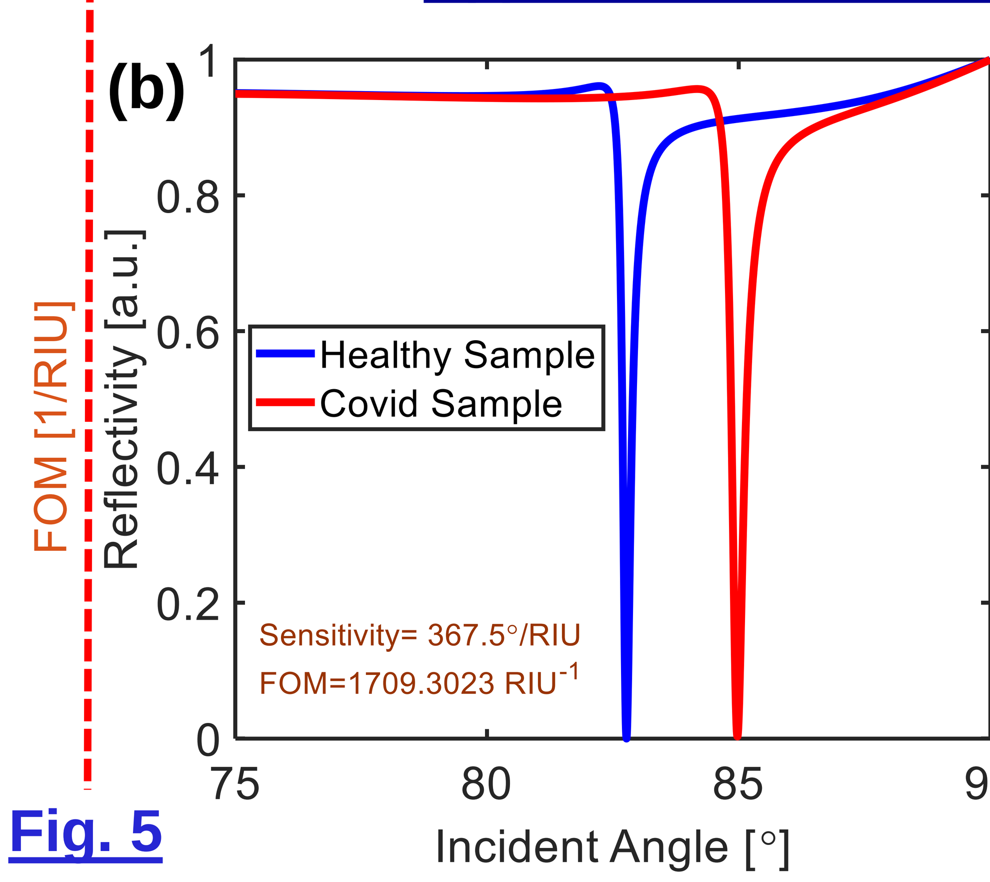


Fig. 5

- Finally, Covid sample testing is demonstrated over MoS_2-coated engineered plasmonic biosensor and a large shift in SPR angle is observed w. r. t. healthy and COVID-19 sample. (Fig. 5 (b))

References	Structure	Sensitivity	FOM	Year
Current Work	NaF-Al-Au-MgF_2-MoS_2	367 °/RIU	1709 RIU^{-1}	2024
1	BK_7/Cu/Ni/TiO_2/BP	502 °/RIU	100.56 RIU^{-1}	2024
2	BK_7/Ag/CNT/FG/Thiol	400 °/RIU	76 RIU^{-1}	2023
3	CaF_2/TiO_2/Ag/BP/Gr	390 °/RIU	87.95 RIU^{-1}	2023
4	CaF_2/Ag/TiO2/Mxene	346 °/RIU	119 RIU^{-1}	2023
5	BK_7/Ag/Fr/$BaTiO_3$/BP	331 °/RIU	119.69 RIU^{-1}	2023

References

1. S. Singh et al., IEEE Sensors, 24(1), 254-261, 2024
2. A. Uniyal et al., Physica B: Condensed Matter, 669, 415282, 2023.
3. A. Abdual et al., Optical & Quantum Electronics, 55(5), 448, 2023
4. S. Srivastava et al., Plasmonics, 1-12, 2023
5. V. Yesudasu et. Al., Plasmonics, 1-12, 2023

Conclusions

- A layer-by-layer optimization is demonstrated for the proposed plasmonic biosensor (NaF-Al-Au-MgF_2-MoS_2-Analyte)
- Utilized MgF_2 as a dielectric layer and MoS_2 as a binding layer for stronger interaction, resulting in enhanced sensing parameters
- The excellent performance parameters will make it easier to employ in the field of biomedical testing applications