

Design and optimization of planar plasmonic nano-slit gratings for scalable refractive index sensing in visible–near-IR spectra

RABI PRAKASH MAHESWARI,^{1,4}  SANJOY MISHRA,¹ AMIT RAI,² BAMADEV DAS,^{3,5}
AND PITAMBER MAHANANDIA^{1,*} 

¹Department of Physics and Astronomy, National Institute of Technology, Rourkela, Odisha 769008, India

²School of Physical Sciences, Jawaharlal Nehru University, New Delhi 110067, India

³Photonics Research Group, INTEC Department-Ghent University, IMEC, Ghent 9052, Belgium

⁴rabiprakashmaheswari@gmail.com

⁵bamadevdas0@gmail.com

*pitam@nitrrkl.ac.in

Received 8 December 2025; revised 27 January 2026; accepted 27 January 2026; posted 28 January 2026; published 13 February 2026

This study explores the design and optimization of a planar plasmonic nano-slit array for scalable high-sensitivity refractive index sensing in the visible–near infrared (Vis-NIR) spectrum. This functionality arises from the excitation of surface plasmons (SPs) at the metal–dielectric interface, whose resonance position is acutely sensitive to minute variations in the refractive index (RI) of the adjacent medium. While many sensors report higher sensitivities, they often suffer from complex designs or multilayer architectures, which limit their practical viability and scalable production. Addressing this critical trade-off, the optimized geometry yields a high sensitivity of 458 nm/RIU, establishing an optimal balance between competitive performance and structural simplicity for scalable fabrication. Parametric analysis confirms that the sensitivity scales linearly with periodicity across the tested spectral range, while the figure of merit (FOM) is maximized at a periodicity of $P = 500$ nm, providing a clear design rule for efficient sensor fabrication. © 2026 Optica Publishing Group under the terms of the [Optica Open Access Publishing Agreement](#)

[Publishing Agreement](#)

<https://doi.org/10.1364/JOSAB.587162>

1. INTRODUCTION

Surface plasmons, which are collective oscillations of free electrons at a metal–dielectric interface, have attracted extensive research interest because of their remarkable ability to confine and enhance electromagnetic fields beyond the diffraction limit [1–3]. These unique properties have enabled a wide range of applications, including high-sensitivity refractive-index sensors [4–9], electromagnetic wave modulators [10,11], splitters [12,13], absorbers [14], and wavelength filters [15,16]. The earliest excitation of surface plasmons through prism-coupled thin films, as demonstrated by Otto (1968) and Kretschmann (1971), marked a significant milestone in plasmonics [17,18]. However, the bulky and alignment sensitive configuration of these systems limits their practical and commercial viability.

To overcome these limitations, subwavelength periodic metallic nanostructures capable of satisfying momentum-matching conditions to excite SP have emerged as compact and scalable alternatives [6,19–21]. These structures exploit various plasmonic modes—propagating surface plasmon polaritons (SPPs), localized surface plasmon resonances (LSPRs), and gap plasmons to achieve efficient coupling and field confinement

[22–26]. Among these, periodic nanostructures such as nanoholes and nanoslits have gained particular attention for their enhanced sensitivity, straightforward fabrication, and ease of positioning analytes directly within highly confined EM fields. Furthermore, extraordinary optical transmission (EOT) through subwavelength apertures [27] enables efficient light–matter interaction, surpassing conventional diffraction-limited optical platforms.

Over the past decade, significant efforts have been made to enhance the performance of plasmonic sensors by engineering advanced designs, such as multi-periodic gratings, hyperbolic metamaterials, hybrid plasmonic–photonic cavities, and metasurface-inspired architectures [25,28,29]. These designs leverage intricate geometries to achieve sharper resonance and higher field localization. Nevertheless, such complex structures require precise nanoscale fabrication, which increases the cost and limits scalability. Additionally, the broad resonance linewidths caused by radiative and ohmic losses reduce the detection resolution and overall figure of merit (FOM), underscoring the persistent trade-offs between sensitivity and simplicity of fabrication [30].

Motivated by these challenges, we propose a RI sensor based on a simple planar nano-slit grating operating in the Vis–NIR regime. In contrast to many previous nano-slit-based sensors that rely on additional surface features such as grooves, dielectric capping, or structural asymmetry to achieve narrow resonances [31–33], we leverage recent advances in nanofabrication to employ sub-25 nm slit widths. This dimensional regime has remained largely underexplored for RI sensing in uncapped planar nano-slits. By operating in this deep-subwavelength limit, radiative losses are effectively suppressed, enabling narrow resonance linewidths without introducing asymmetric slits or capping layer. Our approach therefore trades structural complexity for lithographic resolution, enhancing sensing performance while preserving the planar simplicity required for scalable fabrication. The proposed design is optimized through rigorous numerical simulations, yielding an optimal period of 500 nm and a slit width of 20 nm. By simultaneously addressing sensitivity, fabrication complexity, and resonance linewidths, the proposed design provides a practical pathway toward compact and high-performance plasmonic sensors for biochemical and environmental monitoring applications.

2. SURFACE PLASMON POLARITONS

The SPP wave vector K_{spp} is derived from Maxwell's equations for transverse magnetic (TM) polarization at a planar metal–dielectric interface [30,34,35]:

$$K_{\text{spp}} = K_0 \cdot \sqrt{\frac{\epsilon_m(\omega) \cdot \epsilon_d(\omega)}{\epsilon_m(\omega) + \epsilon_d(\omega)}}, \quad (1)$$

where $K_0 = \frac{2\pi}{\lambda}$ is the wavevector of free space waves, ϵ_m (complex and negative) and ϵ_d (positive) are the permittivity of the metal and dielectric, respectively. This highlights the momentum mismatch ($K_{\text{spp}} > K_0$) between the free space photons and SPPs, implying that the momentum mismatch must be overcome by certain mechanisms for the SPPs to be excited. Traditionally, this has been achieved using Otto and Kretschmann configurations, which suffered from practical limitations. Periodic nanostructure arrays can overcome momentum mismatch by introducing a reciprocal lattice vector to compensate for the extra momentum required. For a nano-slit array with period P , the grating contribution modifies the SPP wavevector as follows [35]:

$$K_{\text{spp}} = K_0 \sin \theta + mG = K_0 \sin \theta + \frac{2\pi m}{P}, \quad (2)$$

where m is an integer and G is the grating constant. With a grating structure, plasmons can be excited even at normal incidence ($\theta = 0$). At normal incidence, the equation becomes $K_{\text{spp}} = \frac{2m\pi}{P}$.

Using Eq. (1), we obtain

$$\lambda_{\text{spp}} = \frac{P}{m} \cdot \text{Re} \sqrt{\frac{\epsilon_m \epsilon_d}{\epsilon_m + \epsilon_d}}. \quad (3)$$

This dictates the sensing mechanism: a change in the refractive index of the analyte results in a shift in the resonance wavelength. The larger the shift in the resonance position for

a unit change in the refractive index, the more sensitive is the structure for sensing applications. Mathematically, the sensitivity is defined as $S = \frac{\Delta\lambda}{\Delta n}$, where $\Delta\lambda$ is the change in the resonance position, and Δn is the change in the refractive index of the analyte [25,34]. Since $\epsilon_m < 0$ for metals, from Eq. (3), it is essential that $\epsilon_m + \epsilon_d < 0$ for the SPPs to be excited. This requirement is predominantly fulfilled by noble metals such as gold (Au) and silver (Ag), which exhibit the necessary negative real permittivity within the Vis–NIR spectrum.

Let us assume that the refractive index of the analyte (n_d) varies as n_a and n_b . Using the relation $\epsilon_d = n_d^2$ in Eq. (3), for $m = 1$, the sensitivity is given by

$$S = \frac{\Delta\lambda}{\Delta n} = \frac{\lambda_{\text{spp}}(n_b) - \lambda_{\text{spp}}(n_a)}{n_b - n_a} = P \cdot \frac{\sqrt{\epsilon_m} \left(n_b \sqrt{\epsilon_m + n_a^2} - n_a \sqrt{\epsilon_m + n_b^2} \right)}{\left(\sqrt{\epsilon_m + n_a^2} \right) \left(\sqrt{\epsilon_m + n_b^2} \right) (n_b - n_a)}. \quad (4)$$

Therefore, it is evident from Eq. (4) that the sensitivity is directly proportional to grating periodicity.

However, sensitivity alone does not provide a complete assessment of a sensor's performance. Although some sensors offer higher sensitivity, they suffer from broader resonance peaks. The full width at half-maximum (FWHM) of a resonance peak plays an essential role, because it directly affects how precisely the peak position can be determined as it shifts with changing refractive index. A narrow FWHM allows for better tracking of small shifts, thereby enhancing the resolution with less ambiguity, particularly in noisy or low-resolution spectral environments. The figure of merit is defined as $\text{FOM} = \frac{S}{\text{FWHM}}$. A sensor with a higher FOM balances sensitivity and precision, ensures detectability of small RI changes in real-world conditions (noise and resolution limits) and is more efficient and reliable.

3. MODELING AND SIMULATION

Simulations were performed using the finite element method (FEM) to solve Maxwell's equations and model the optical response of the proposed refractive index sensor using a two-dimensional (2D) model of the nano-slit grating in the xz-cross-section. The simulated structure, shown in Fig. 1, consists of a gold film of thickness t deposited on top of a SiO_2 substrate of thickness t_s . The gold layer is entirely immersed within a surrounding simulation domain, whose refractive index matches that of the analyte under investigation. The optical properties of gold were modeled using experimentally measured permittivity data (Johnson and Christy). The silica (SiO_2) substrate and the analyte were modeled as non-dispersive over the simulated spectral window. The model dimensions and simulation parameters are summarized in Table 1.

A normally incident ($\theta = 0^\circ$) TM-polarized plane wave in the Vis–NIR range (300–900 nm) was launched via Port 1 in the analyte region above the grating with $\beta = k_0 n_d$. Port 2, located below the substrate, was used to monitor transmission, with its propagation constant matched to the substrate refractive index. To model an infinite periodic array, periodic boundary conditions were applied to the lateral boundaries.

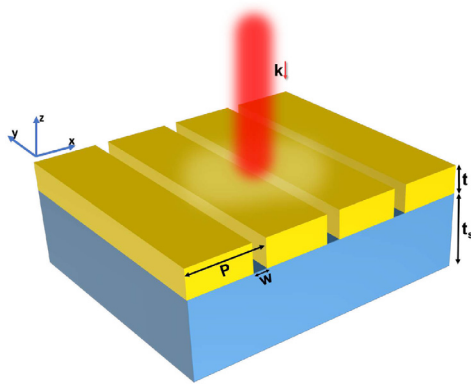


Fig. 1. Perspective view of the proposed structure.

Table 1. Simulation Parameters and Geometrical Specifications

Parameter Category	Parameter	Value/Setting
Geometry	Grating period (P)	500 nm
	Slit width (w)	20 nm
	Gold thickness	50 nm
	Analyte domain height	500 nm
	Substrate domain height	500 nm
	PML thickness	700 nm
Optical settings	Incident polarization	TM
	Wavelength range	300 nm–900 nm
	Gold permittivity model	Johnson and Christy
	Substrate refractive index	1.45 (Constant)
Boundary conditions	Lateral (x)	Periodic boundary condition (continuity)
	Top/bottom (z)	PML

Since the illumination was at normal incidence ($\theta = 0^\circ$), a continuity periodicity condition ($E_{src} = E_{dst}$ and $H_{src} = H_{dst}$) was employed. The top and bottom boundaries were terminated using perfectly matched layers (PMLs) to absorb outgoing radiation and suppress artificial reflections.

Adaptive meshing was employed with mesh refinement customized for each region. Areas with large field gradients, such as the metal–analyte interface where SPPs form, were meshed very finely with a minimum element size of 0.1 nm. However, regions of lower interest, including the air domain and the PML are meshed relatively coarsely to balance the simulation accuracy and efficient computational resource usage.

4. RESULTS AND DISCUSSION

The electric field distribution at a resonant wavelength of 691 nm ($P = 500$ nm) is shown in Fig. 2. The field profile helps explain the physical origin of the sensing capability, revealing two simultaneous resonance mechanisms. First, strong field confinement is observed within the nano-slit, corresponding to a localized cavity mode (gap plasmon) driven by the Fabry–Perot resonance of the slit waveguide. Second, the strong field

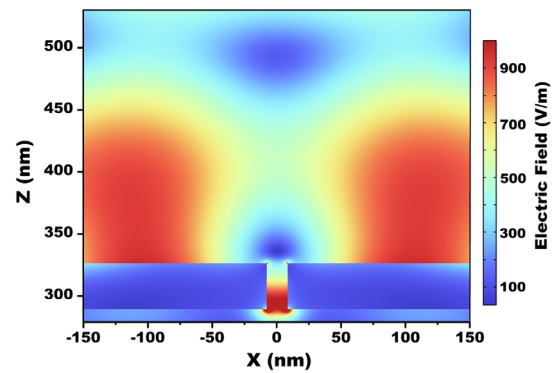


Fig. 2. Cross-sectional view of the absolute electric field magnitude ($|E|$) distribution at the resonant wavelength for $P = 500$ nm, $w = 20$ nm.

Table 2. Sensing Metrics for the Slit-Width (w) Sweep ($t = 50$ nm, $P = 500$ nm)

Slit Width w (nm)	Sensitivity S (nm/RIU)	FWHM (nm)	FOM
10	456	48.25	9.5
15	455	19.5	23.35
20	458	12	38
25	452	15.1	30

distribution extending along the upper metal–analyte interface confirms the excitation of SPPs. Crucially, the SPP mode exhibits an evanescent tail that significantly penetrates the analyte medium. This spatial overlap between the electromagnetic field and analyte ensures that the resonance condition is intrinsically coupled to the environment, thereby allowing even minute variations in the bulk refractive index to induce a measurable spectral shift.

The resonance wavelength λ_{res} is defined as the peak maximum of the dominant metal–analyte SPP mode. To ensure consistent extraction of sensing metrics, each spectrum is fitted using a Fano line-shape model, from which λ_{res} and the full width at half-maximum (FWHM) are obtained. Figures 3(a)–3(d) show the transmittance spectra of the device as a function of the gap width (w), illustrating the spectral response to variations in the analyte refractive index (n_d). As shown in Fig. 3(a), the spectrum is characterized by two distinct resonance features. The primary mode, appearing at approximately 690 nm (labeled Peak 1), corresponds to the excitation of SPPs at the metal–analyte interface. As the refractive index of the surrounding medium increases from 1.32 to 1.38, this peak exhibits a significant redshift, confirming the strong interaction between the evanescent SPP field and the analyte. Conversely, the secondary peak at longer wavelengths (~ 760 nm) is attributed to SPPs excited at the buried metal–substrate (SiO_2) interface. Because this interface is physically isolated from the sensing environment, its resonance position remains relatively static and is excluded from further sensing performance analysis.

Regarding device optimization, an overall increase in transmission intensity is observed as the slit width expands from 10 to 25 nm, which is attributed to the enhanced light throughput

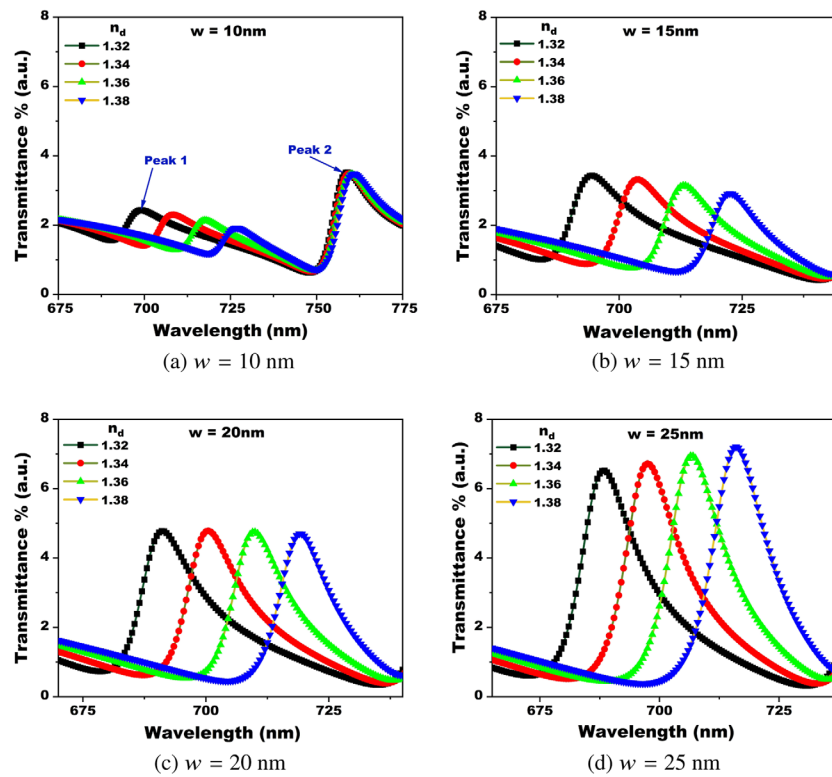


Fig. 3. Transmittance spectra for gratings with a fixed period of $P = 500$ nm, shown for different slit widths: (a) 10 nm, (b) 15 nm, (c) 20 nm, and (d) 25 nm.

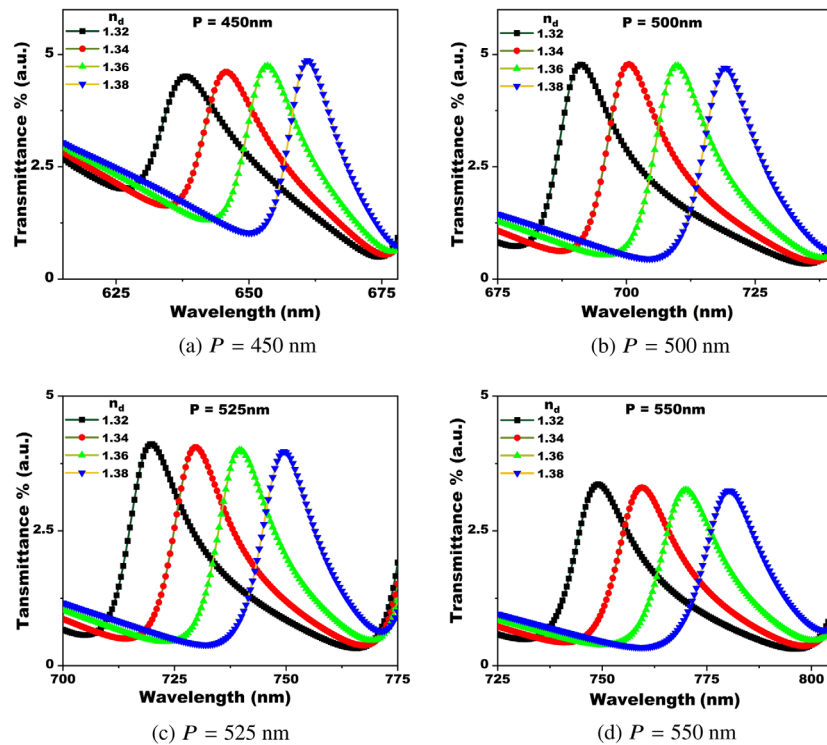


Fig. 4. Transmittance spectra for gratings with slit width fixed at $w = 20$ nm and film thickness of $t = 50$ nm, shown for varying grating periods: (a) 450 nm, (b) 500 nm, (c) 525 nm, and (d) 550 nm.

through the wider apertures. Interestingly, while the overall sensitivity remains almost invariant across different slit widths, the figure of merit reaches a maximum at a slit width of $w = 20$ nm.

The effect of slit width on the sensing performance is quantitatively summarized in Table 2 for a fixed metal thickness of $t = 50$ nm and period $P = 500$ nm.

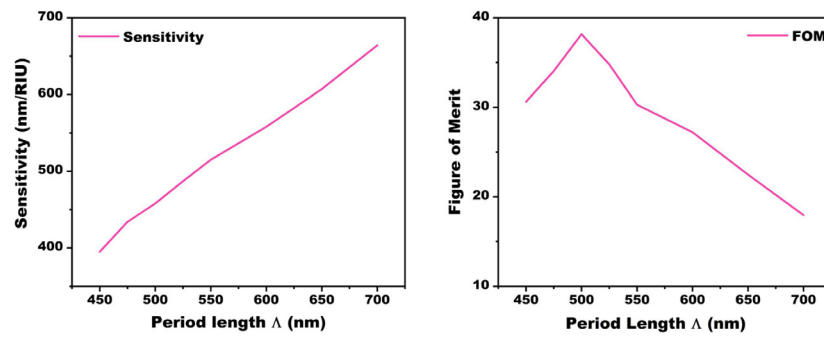


Fig. 5. Calculated sensitivity (S) and figure of merit (FOM) for the refractive index sensor at varying grating periods (P), with fixed slit width ($w = 20$ nm) and metal thickness ($t = 50$ nm).

Table 3. Calculated Sensitivity (S), Resonance Linewidth (FWHM), and Figure of Merit (FOM) for the Refractive Index Sensor at Varying Grating Periods (P), with Fixed Slit Width ($w = 20$ nm) and Metal Thickness ($t = 50$ nm)

P (nm)	S (nm/RIU)	FWHM (nm)	FOM
450	395	12.9	31
475	434	12.75	34
500	458	12	38
525	487	14	34.75
550	515	17	30.25
600	558	20.5	27.2
650	607	27	22.5
700	664	37	18

To explore the effect of the grating period on device performance, the period P was varied from 450 to 700 nm while keeping the width w fixed at 20 nm and the thickness t at 50 nm. The corresponding transmission spectra are shown in Fig. 4, and the resulting sensitivity, FWHM, and FOM values are summarized in Table 3. As shown in Fig. 5, the sensitivity increases linearly with increasing P in agreement with Eq. (4). However, for larger periods, the resonance peaks become noticeably broader, leading to a reduced FOM. Although the sensitivity continues to increase beyond $P = 500$ nm, the accompanying increase in the FWHM outweighs this effect, causing the FOM to decrease with further increases in P . Consequently, an optimal balance between sensitivity and linewidth is achieved at $P = 500$ nm, where the FOM attains its maximum value of 38.

A comparison of the theoretically predicted resonance wavelengths [using Eq. (3)] and the FEM simulation results are shown in Fig. 6. The theoretical calculation, derived solely from the SPP dispersion relation, serves as a first-order approximation and provides an initial validation of the expected resonances. However, a systematic offset is observed. This is expected, as the simplified analytical model does not consider several critical factors, such as the thickness of the gold layer (t) and the overall dielectric and radiation losses. Despite this offset, the resonance wavelengths calculated from the theoretical model remain a good initial estimate for further optimization.

The effect of gold layer thickness on the sensing performance is quantitatively summarized in Table 4 for a fixed slit width of $w = 20$ nm and period $P = 500$ nm. The transmission spectra for different gold film thicknesses, shown in Fig. 7, reveal that

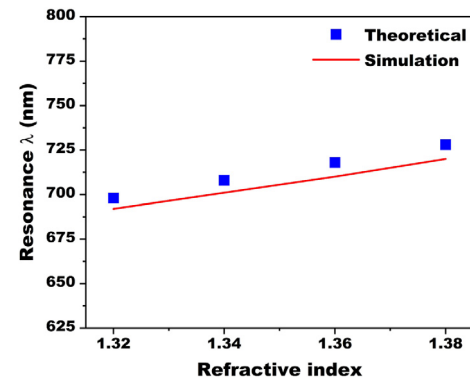


Fig. 6. Comparison of the resonance wavelengths between analytical calculation and the FEM simulation. The plot shows the resonance wavelength λ_{res} as a function of the analyte refractive index (n_d). The red line represents the resonance positions extracted from the FEM simulation, while the blue markers denote the corresponding λ_{res} calculated using the simplified analytical SPP dispersion relation [Eq. (3)] for the $m = 1$ diffraction order.

Table 4. Sensing Metrics for the Gold Thickness (t) Sweep ($w = 20$ nm, $P = 500$ nm)

Thickness t (nm)	Sensitivity S (nm/RIU)	FWHM (nm)	FOM
25	—	—	—
50	458	12.0	38.0
75	433	15.25	12.4

the thickness of the plasmonic material significantly affects sensitivity. P and w are kept fixed at 500 and 20 nm, respectively. For $t = 25$ nm, the resonances are broad and shallow despite the significantly higher transmission. The thickness of the Au layer is less than the skin depth, resulting in weak plasmonic coupling and poorer resonances. Consequently, a meaningful FWHM, and hence the FOM cannot be reliably extracted for this thickness. Increasing the thickness to 50 nm offers sharper resonances and better sensitivity, thus yielding the highest FOM and optimal sensing conditions. At $t = 75$ nm, the resonances become much less sensitive to changes in the ambient refractive index, as the increased metal thickness enhances absorption losses and suppresses transmission, leading to broadened linewidths and poorly defined spectral features. Overall, the 50 nm thickness provides the most favorable combination of sensitivity, peak

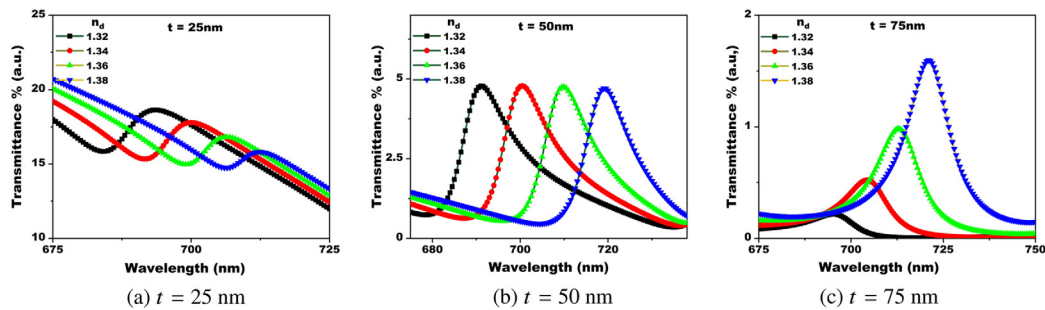


Fig. 7. Transmittance spectra for gratings with a fixed period of $P = 500$ nm and slit width of $w = 20$ nm, shown for varying metal film thicknesses: (a) $t = 25$ nm, (b) $t = 50$ nm, and (c) $t = 75$ nm.

Table 5. Quantitative Comparison of Sensitivity, FOM, and Fabrication Complexity between the Proposed Sensor against Relevant Devices in the Literature

Reference	Design/Resonance Type	S (nm/RIU)	FOM	Fabrication
Zhang <i>et al.</i> [36]	Ag nanohole array supporting extraordinary optical transmission	~ 648	—	Moderate–High
Martinez-Perdiguero <i>et al.</i> [37]	Gold nanohole array fabricated by nanoimprint lithography (EOT)	~ 126	—	Moderate
Malani and Viswanath [38]	Long-range ordered Au nanohole array with coupled LSPR–SPP modes	~ 470	~ 14.4	Moderate
Balderas-Valadez <i>et al.</i> [39]	Au nanohole array on porous silicon with hybrid plasmonic–FP resonance	~ 386	—	Moderate–High
Guang <i>et al.</i> [40]	Au nanohole array via nanosphere lithography exhibiting EOT dips	~ 162	2–4	Moderate
Present work	Planar plasmonic nanoslit grating	~ 460	38	Easy

sharpness, and signal strength for practical sensing applications. A quantitative comparison of sensitivity, FOM, and fabrication complexity between the proposed sensor against relevant devices in the literature has been provided in Table 5.

5. PRACTICAL CONSIDERATIONS

Excitation of the SPP in 1D grating structures fundamentally requires the TM polarization, which can be achieved using a standard linear polarizer, together with appropriate alignment of the incident field relative to the slit orientation. Features of the order of 20 nm can be achieved using established techniques such as electron-beam lithography, as well as focused ion beam milling for prototyping [41,42]. Moreover, once a high-resolution master mold is fabricated, large-area and cost-effective replication of sub-20 nm features can be achieved using nanoimprint lithography, enabling scalable fabrication [43]. Despite the need for nanoscale resolution, the sensor's planar, single-step design supports scalable fabrication and seamless integration into practical sensing environments.

6. CONCLUSION

In this study, a plasmonic nano-slit array was numerically investigated to determine the optimal geometric parameters for refractive index sensing. Analysis of the transmission spectra revealed a distinct trade-off, while the sensitivity scales linearly with periodicity across the tested spectrum, the FOM exhibits a non-monotonic trend, peaking at a periodicity of

$P = 500$ nm. Furthermore, optimization of the film thickness demonstrated that a 50 nm thick metal film maximizes the FOM by enhancing the electric field confinement. With optimized parameters ($P = 500$ nm, $w = 20$ nm, and $t = 50$ nm), the device achieved a sensitivity of 458 nm/RIU and an FOM of 38. Coupled with its planar geometry, this performance positions the proposed device as a highly practical alternative to complex metamaterials, offering a viable pathway toward scalable, low-cost, and chip-integrated sensing.

Disclosures. The authors declare no conflicts of interest.

Data availability. Data underlying the results presented in this paper are not publicly available at this time but may be obtained from the authors upon reasonable request.

REFERENCES

1. R. W. Wood, "On a remarkable case of uneven distribution of light in a diffraction grating spectrum," *Proc. Phys. Soc. London* **18**, 269–275 (1901).
2. U. Fano, "The theory of anomalous diffraction gratings and of quasi-stationary waves on metallic surfaces (Sommerfeld's waves)," *J. Opt. Soc. Am.* **31**, 213–222 (1941).
3. P. Gu, H. Yang, D. Li, *et al.*, "High-Q and intense lattice plasmon resonance in hexagonal nonclose packed thin silver nanoshells array," *J. Phys. Chem C* **128**, 6431–6437 (2024).
4. B. Liedberg, C. Nylander, and I. Ljunstrom, "Surface plasmon resonance for gas detection and biosensing," *Sensors Actuators* **2**, 299–304 (1983).
5. J. Homola, S. S. Yee, and G. Gauglitz, "Surface plasmon resonance sensors: review," *Sensors Actuators B Chem.* **54**, 3–15 (1999).

6. J. Divya, S. Selvendran, A. S. Raja, *et al.*, "Surface plasmon based plasmonic sensors: a review on their past, present and future," *Biosens. Bioelectron X* **11**, 100175 (2022).
7. R. Kumar, S. Agarwal, S. Pal, *et al.*, "Enhanced refractive index sensing using a surface plasmon resonance sensor with heterostructure," *Micro Nanostruct.* **183**, 207656 (2023).
8. D. Zhao, X. Wang, Y. Chen, *et al.*, "Quasi-bic mode and refractive index sensing by asymmetric silicon nanodisk arrays," *Opt. Commun.* **596**, 132421 (2025).
9. J. Gao, X. Wang, Y. Chen, *et al.*, "Triple Fano resonances induced by a square-elliptical cavity coupled with an MIM waveguide for high-sensitivity gas refractive index sensing," *J. Opt. Soc. Am. B* **42**, 742–748 (2025).
10. L. Zurak, C. Wolf, J. Meier, *et al.*, "Modulation of surface response in a single plasmonic nanoresonator," *Sci. Adv.* **10**, esdn5227 (2024).
11. A. Leinonen, K. Saastamoinen, H. Pesonen, *et al.*, "Polarization modulation by surface plasmons in Young's double-slit setup," *Phys. Rev. A* **104**, 043503 (2021).
12. Y. Ye, Y. Xie, T. Song, *et al.*, "Design of a novel plasmonic splitter with variable transmissions and selectable channels," *IEEE Trans. Nanotechnol.* **18**, 617–625 (2019).
13. X. Shi, W. Yang, H. Xing, *et al.*, "Design of power splitters based on hybrid plasmonic waveguides," *Appl. Sci.* **11**, 8644 (2021).
14. S. M. Ebadi and S. Khani, "Design of a tetra-band mim plasmonic absorber based on triangular arrays in an ultra-compact mim waveguide," *Opt. Quantum Electron.* **55**, 482 (2023).
15. M. Z. Hu, H. C. Zhang, J. Y. Yin, *et al.*, "Ultra-wideband filtering of spoof surface plasmon polaritons using deep subwavelength planar structures," *Sci. Rep.* **6**, 37605 (2016).
16. A. Afroozeh, "Numerical and analytical modeling of plasmonic filter with high Q-factor based on "nanostructured resonator," *Plasmonics* **17**, 371–379 (2022).
17. A. Otto, "Excitation of nonradiative surface plasma waves in silver by the method of frustrated total reflection," *Z. Phys.* **216**, 398–410 (1968).
18. E. Kretschmann and H. Raether, "Notizen: radiative decay of non radiative surface plasmons excited by light," *Z. Naturforsch. A* **23**, 2135–2136 (1919).
19. V. G. Kravets, A. V. Kabashin, W. L. Barnes, *et al.*, "Plasmonic surface lattice resonances: a review of properties and applications," *Chem. Rev.* **118**, 5912–5951 (2018).
20. C. Valsecchi and A. G. Brolo, "Periodic metallic nanostructures as plasmonic chemical sensors," *Langmuir* **29**, 5638–5649 (2013).
21. D. Murugan, M. Tintelott, M. S. Narayanan, *et al.*, "Recent advances in grating coupled surface plasmon resonance technology (Advanced optical materials 34/2024," *Adv. Opt. Mater.* **12**, 2470110 (2024).
22. A. Upadhyay, B. Das, S. Sharma, *et al.*, "Enhanced spontaneous emission in proximity of a plasmonic nano-slit antenna," *J. Appl. Phys.* **137**, 113106 (2025).
23. H. Wang, T. Wang, X. Yuan, *et al.*, "Plasmonic nanostructure biosensors: a review," *Sensors* **23**, 8156 (2023).
24. S. Kasani, K. Curtin, and N. Wu, "A review of 2D and 3D plasmonic nanostructure array patterns: fabrication, light management and sensing applications," *Nanophotonics* **8**, 2065–2089 (2019).
25. K. M. Mayer and J. H. Hafner, "Localized surface plasmon resonance sensors," *Chem. Rev.* **111**, 3828–3857 (2011).
26. M. Li, S. K. Cushing, and N. Wu, "Plasmon-enhanced optical sensors: a review," *Analyst* **140**, 386–406 (2015).
27. T. W. Ebbesen, H. J. Lezec, H. F. Ghaemi, *et al.*, "Extraordinary optical transmission through sub-wavelength hole arrays," *Nature* **391**, 667–669 (1998).
28. F. Capasso and N. Yu, "Flat optics with designer metasurfaces," *Nat. Mater.* **13**, 139–150 (2014).
29. C. Hou-Tong, J. T. Antoinette, and Y. Nanfang, "A review of meta-surfaces: physics and applications," *Rep. Prog. Phys.* **79**, 076401 (2016).
30. J. Homola, "Surface plasmon resonance sensors for detection of chemical and biological species," *Chem. Rev.* **108**, 462–493 (2008).
31. K.-L. Lee and P.-K. Wei, "Optimization of periodic gold nanostructures for intensity-sensitive detection," *Appl. Phys. Lett.* **99**, 083108 (2011).
32. X. Lu, L. Zhang, and T. Zhang, "Nanoslit-microcavity-based narrow band absorber for sensing applications," *Opt. Express* **23**, 20715–20720 (2015).
33. K.-L. Lee, S.-H. Wu, C.-W. Lee, *et al.*, "Sensitive biosensors using fano resonance in single gold nanoslit with periodic grooves," *Opt. Express* **19**, 24530–24539 (2011).
34. H. Raether, G. Hohler, and E. A. Niekisch, "Surface plasmons on smooth and rough surfaces and on gratings," *Springer Tracts Mod. Phys.* **111**, 136 (1988).
35. A. V. Zayats, I. I. Smolyaninov, and A. A. Maradudin, "Nano-optics of surface plasmon polaritons," *Phys. Rep.* **408**, 131–314 (2005).
36. X. Zhang, Z. Li, S. Ye, *et al.*, "Elevated ag nanohole arrays for high performance plasmonic sensors based on extraordinary optical transmission," *J. Mater. Chem.* **22**, 8903–8910 (2012).
37. J. Martinez-Perdiguero, A. Retolaza, D. Otaduy, *et al.*, "Real-time label-free surface plasmon resonance biosensing with gold nanohole arrays fabricated by nanoimprint lithography," *Sensors* **13**, 13960–13968 (2013).
38. S. Brindhu Malani and P. Viswanath, "Impact of ordering of gold nanohole arrays on refractive index sensing," *J. Opt. Soc. Am. B* **35**, 2501–2508 (2018).
39. R. F. Balderas-Valadez and C. Pacholski, "Plasmonic nanohole arrays on top of porous silicon sensors: a win-win situation," *ACS Appl. Mater. Interfaces* **13**, 36436–36444 (2021).
40. J. Guang, M. Lu, R. Li, *et al.*, "Visible light-illuminated gold nanohole arrays with tunable on-chip plasmonic sensing properties," *Photonic Sens.* **14**, 240311 (2024).
41. A. A. Tseng, "Recent developments in nanofabrication using focused ion beams," *Small* **1**, 924–939 (2025).
42. Y. Chen, "Nanofabrication by electron beam lithography and its applications: a review," *Microelectron. Eng.* **135**, 57–72 (2015).
43. S. Y. Chou, P. R. Krauss, and P. J. Renstrom, "Nanoimprint lithography," *J. Vac. Sci. Technol. B Microelectron. Nanometer Struct. Process. Meas. Phenom.* **14**, 4129–4133 (1996).