Metasurface-Based Refractive Index Sensors: Navigating Functional Limits

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Refractive index sensing is a cornerstone of modern optical sensing technologies, enabling the detection of minute changes in material properties, environmental conditions, and biological interactions. Metasurfaces have emerged as powerful tools for advanced sensing and wavefront control. This research explores the use of metasurfaces in refractive index sensing by examining both their absorption-based behavior and susceptibility-based characterization under varying geometrical and dielectric conditions. First, a 3D silicon-based narrow-band absorber was simulated on a glass substrate and refined for high sensitivity and quality factor. The structure attained a sensitivity of ~0.004 RIU/nm and a Q-factor of 328 at a central wavelength of 1.15 µm, making it ideal for detecting biomarkers in biological samples. Additionally, a 3D unit cell was analyzed to assess how nearby dielectric materials affect metasurface susceptibilities. By varying permittivity and proximity, notable shifts in electromagnetic field distributions and susceptibility tensors were recorded, demonstrating potential for precise dielectric sensing. To offer a computationally efficient method, Generalized Sheet Transition Conditions (GSTCs) were employed, allowing the extraction of susceptibility values as a figure of merit. This avoids full-wave simulations for every setup while revealing insight into metasurface-material interactions. This work highlights metasurfaces as scalable, sensitive tools for liquid and dielectric sensing applications.

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