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Fundamentals, Optimization, and Realization of Aluminum Plasmonics for Superior UV photodetector and SERRS Biosensor

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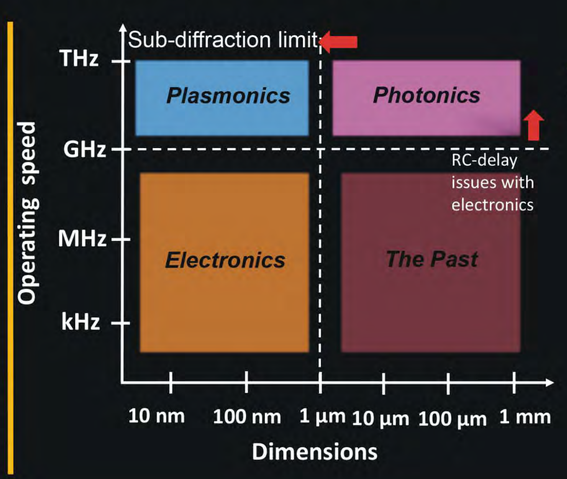
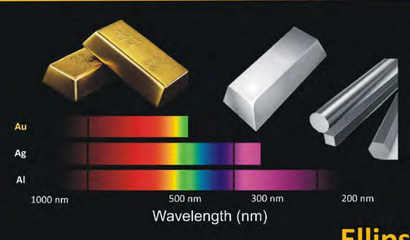
Abstract

Aluminum (Al) is the most perquisite choice beyond conventionally used noble metals, such as gold (Au) and silver (Ag). By using epitaxial Al metasurfaces, herein we report two unprecedented plasmonic applications in UV regimes- an ultrasensitive photodetector and a surface-enhanced resonance Raman spectroscopic (SERRS) biosensor. For the first UV plasmonic device, we demonstrated ultrasensitive photodetector by introducing an epitaxial single-crystalline Al metasurface on a wide bandgap semiconductor Gallium nitride (GaN) substrate. Therefore, we obtained a **higher detectivity** at the on-resonance wavelength of 355 nm. In addition, we also achieved broad bandwidth photodetection through the entire UV regime, owing to the coupling among nanoholes. Finally, there appeared a fast temporal response with a rise time of 51 ms and a fall time of 197 ms. To assess the performance of DUV-based SERRS substrate, we collected SERRS spectra of all the bases of **oligonucleotides** (adenine, cytosine, thymine, and guanine). In addition to this egregiously **high EF factor**, we further exhibit that our SERRS substrate is capable of detecting the **single base mutation** in the 12- mer ss-DNA. Such strong performance of Al for these two applications makes it sustainable and suitable choice for UV and DUV plasmonics based sensors.

2. Strategy and Demand





Resonance Raman Spectroscopy

Raman Intensity equation using Fermi-golden rule

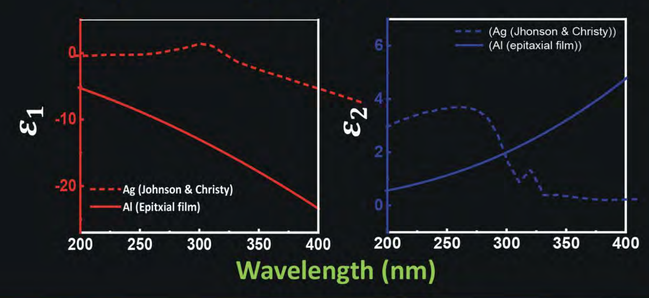
$$I(E_i) = C|\Sigma \frac{<f|H_{el-p}|b><b|H_{e-ph}|a><a|H_{el-p}|i>}{(|E_i - E_a - ik)\,(E_i - E_b - ik)}|^2$$

If $E_i = E_a$; $I(E_i)$ will increase ; Resonance Raman

Limit of Plasmonic Metals

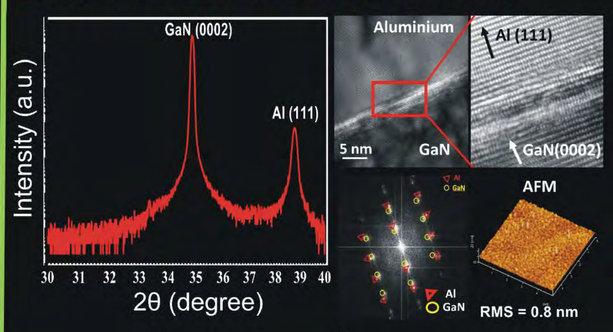
- ❑Au ~ 500 nm.
- ❑Ag ~ 300 nm.
- ❑Al ~ 200 nm.

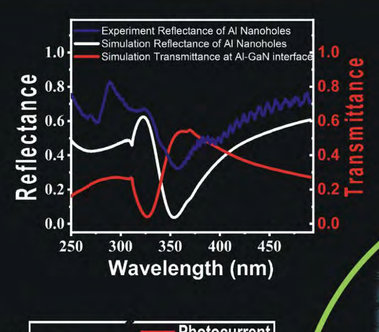
Ellipsometer Spectroscopy of epitaxial Aluminum film

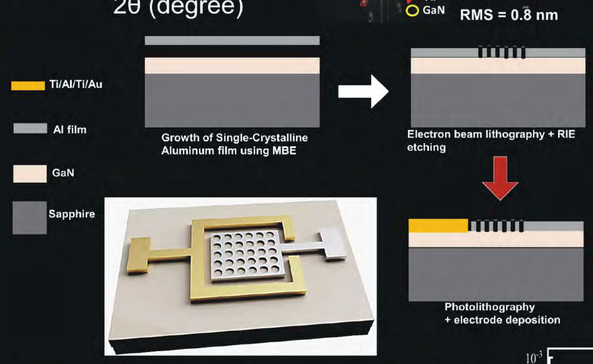


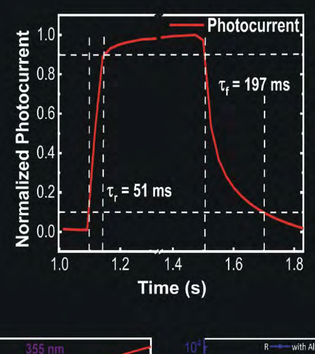
3. Results and Discussion

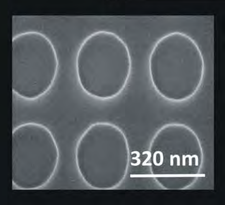
Ultrasensitive UV Photodetector

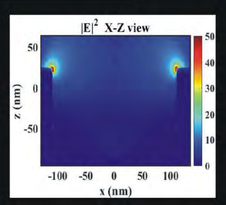


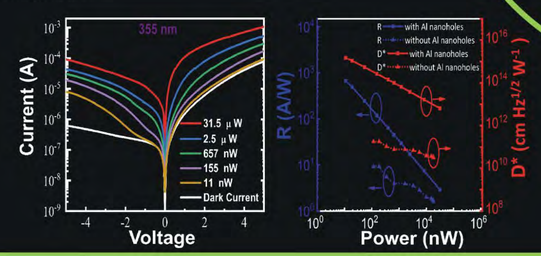




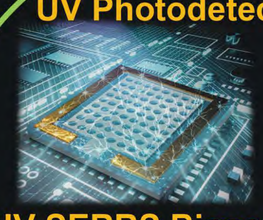




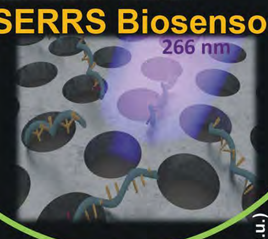




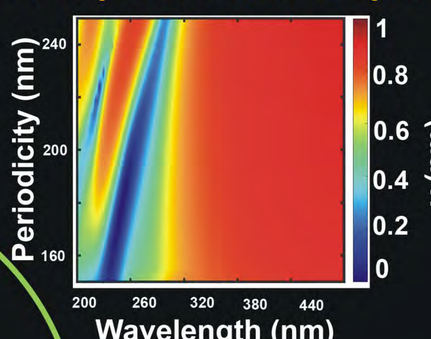
UV Photodetector

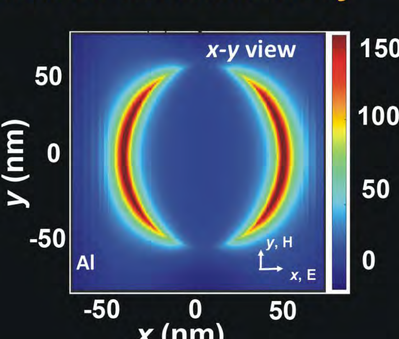


DUV-SERRS Biosensor



DUV-SERRS performance of epitaxial Al nanohole array





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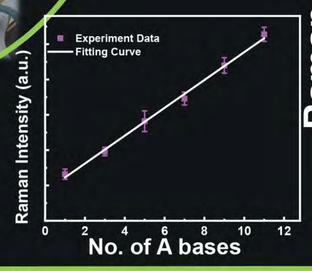

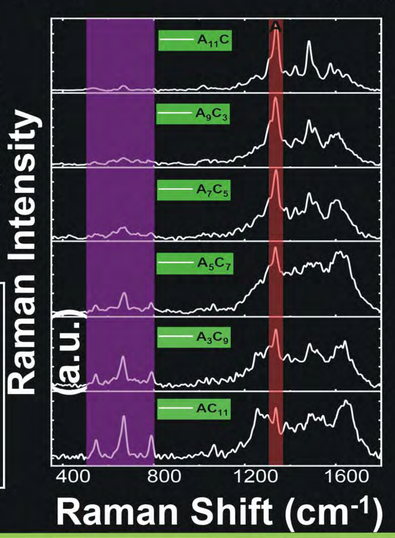

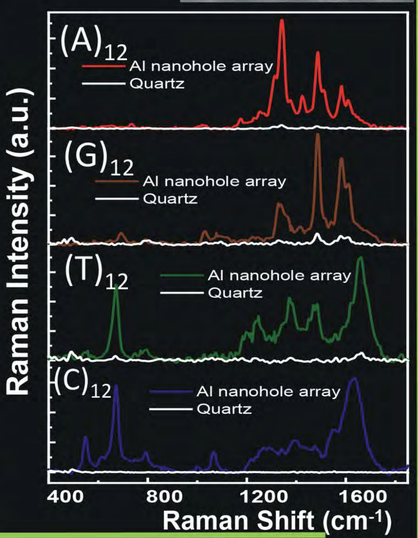

4. Conclusion

The present study demonstrates the ultrasensitive photodetector and label-free single base mutation detection using epitaxial Aluminum film. The resulting UV photodetector reveals the highest D* of 1.48×10^{15} cm $Hz^{1/2}$ W^{-1}. The designed Deep UV SERRS substrate is able to detect the single base mutation detection in the oligonucleotides. Further studies are currently directed at employing this SERRS driven approach to fabricate more precise and accurate analysis for single nucleotide polymorphism (SNP).

5. Publications

1. *Abhishek Dubey*, R. Mishra, C.-W. Cheng, Y.P. Kuang, Shangjr Gwo*, Ta-Jen Yen*, "Demonstration of a Superior Deep-UV Surface-Enhanced Resonance Raman Scattering (SERRS) Substrate and Single-Base Mutation Detection in Oligonucleotides". ***JACS 2021*** (Accepted). ***(IF: 15.8)***
2. Abhishek Dubey, R. Mishra, Y.-H. Hsieh, C.-W. Cheng, Lih-Juann Chen, Shangjr Gwo* & Ta-Jen Yen*, " *Aluminum Plasmonics Enriched ultraviolet GaN photodetector with ultrahigh responsivity, detectivity, and broad bandwidth*", ***Advanced Science*** 2020, 2002274. ***(IF: 16.8)***