Modeling of Au:VO_2 Plasmon Nanomodulators

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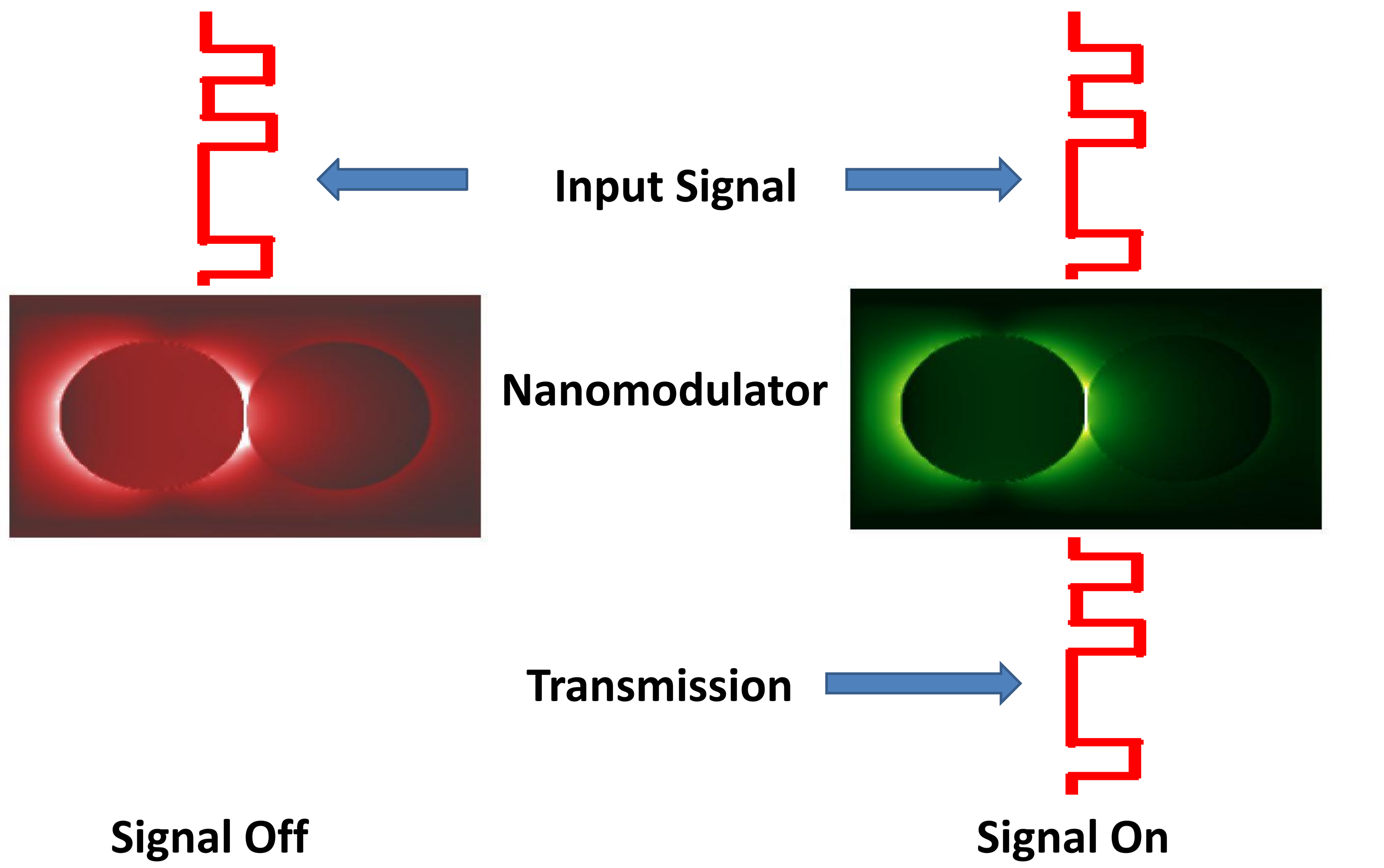
What are nanomodulators?



What is inside the black box?

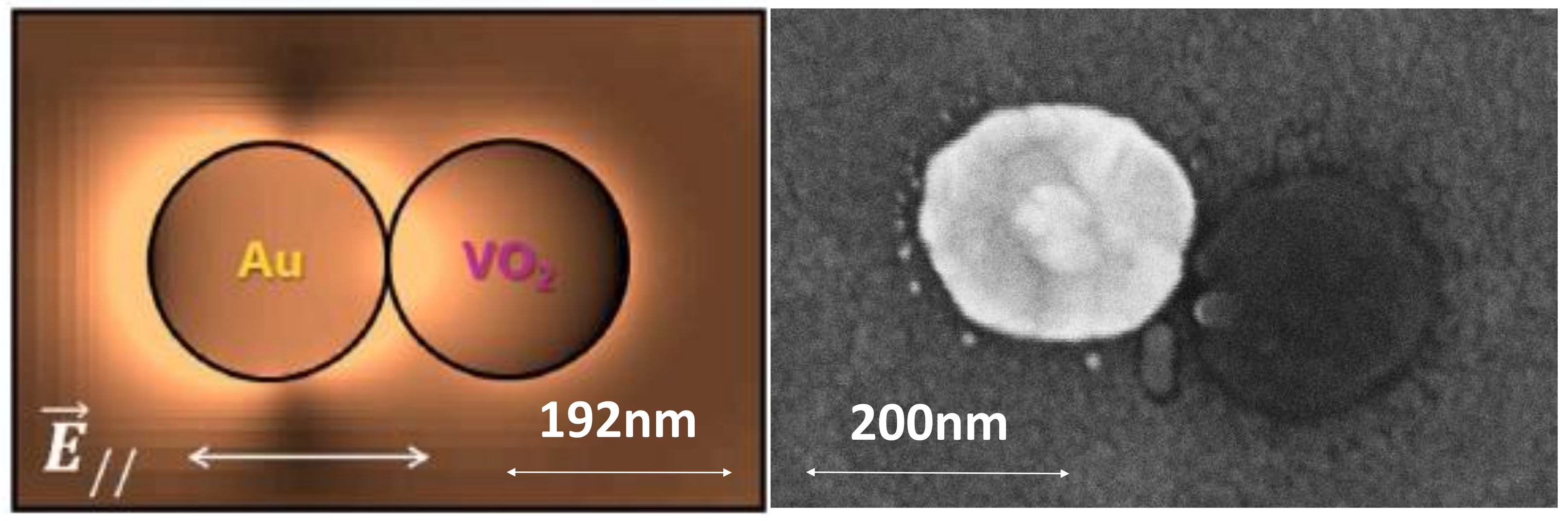


Figure 1[1] (top left): Parallel electric field applied to **Au:VO_2 dimer**. The **gold electrons recognize the VO_2.**

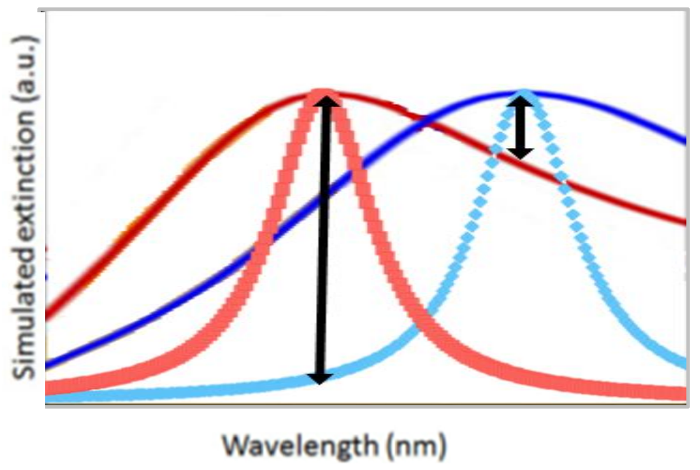
Figure 2 (bottom left): Actual SEM Image *Courtesy of Kannatassen Appavoo*

Hybrid Au:VO_2 Plasmon Nanomodulator

Active Material-VO_2 Metal Insulator Transition

Issues with this Design/Motivation

- Charge distribution uniform around disk => fewer Au electrons see VO_2
- Charge distribution non-uniform around rod (higher on ends) => **more Au electrons see VO_2**

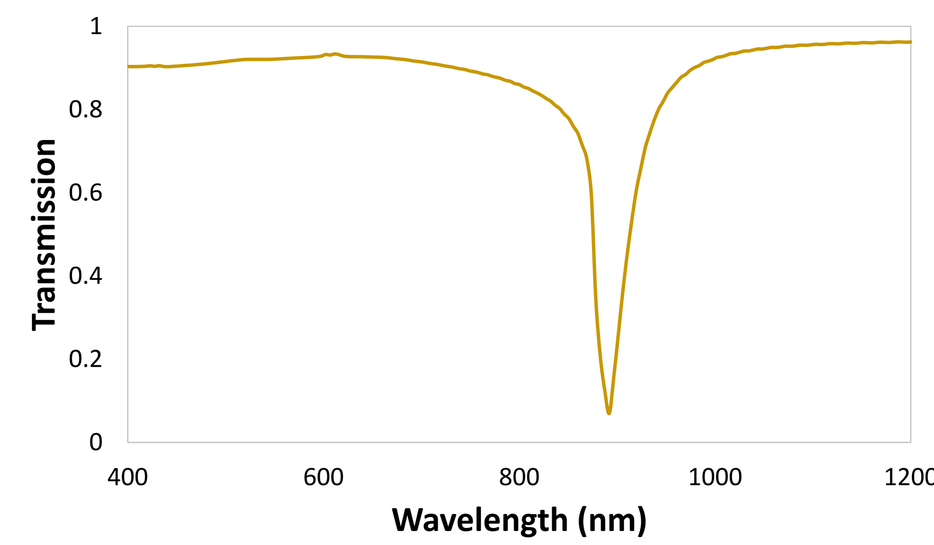


Device Requirements

- Small footprint
- Really fast [switch on timescale of 1ps (10^{-12}s)]
- Large difference between on and off switching (large modulation depth)
- Energy Cost: < 10^{-13} Joules per switch

FDTD modeling in Lumerical

- FDTD= **Finite Difference Time Domain**
- Solves Maxwell's Equations
- Fourier Analysis
- Mesh and Boundary Conditions
- Gives Map of **Frequency Dependent Response** and **Electromagnetic Field Distribution**



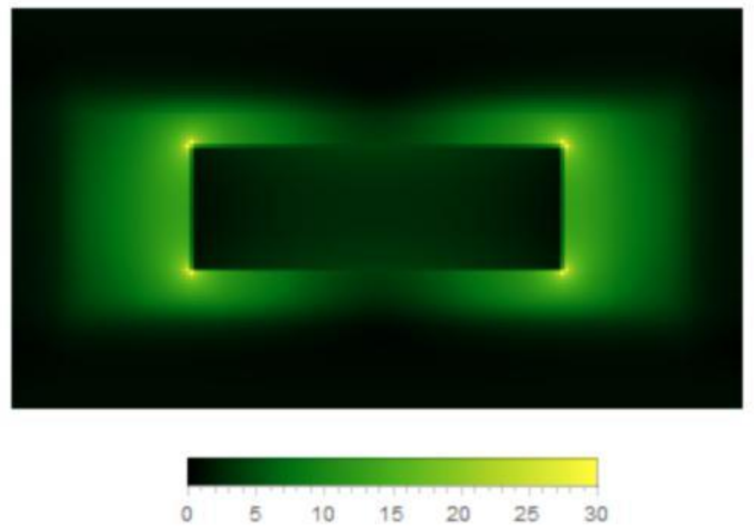


Figure 4 (above left): Frequency dependent response for 3:1 aspect ratio rod. Resonance wavelength: 892nm. **Narrow FWHM**=46nm. *Figure 5 (above right)*: Electric field intensity diagram at resonance for nanorod in Figure 4.

Reproducing previous simulations

- Simulation by Appavoo[1] repeated for results duplication
- Used dimensions from Figure 1
- Results proved to be reproducible

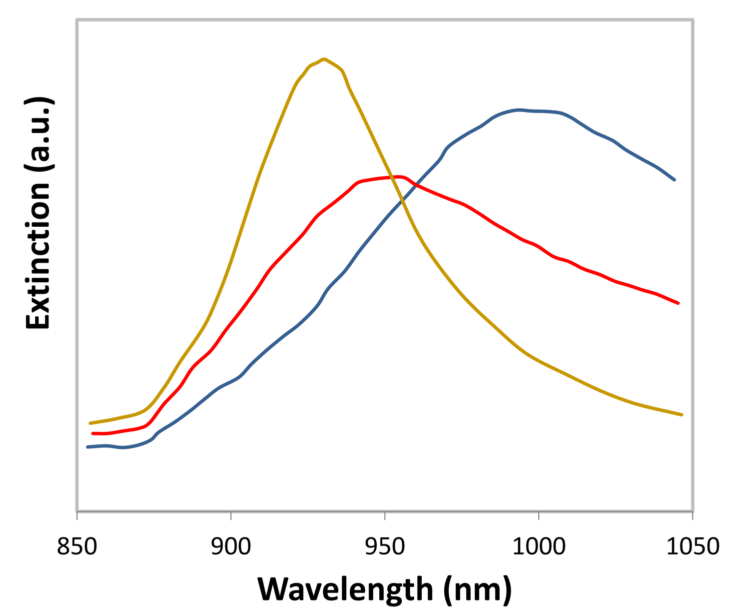


Figure 6: Appavoo's Results[1], Distance between nanodisks=0nm, Curves represent the gold optical response to hot VO_2 (red), cold VO_2 (blue), and without VO_2 (yellow)

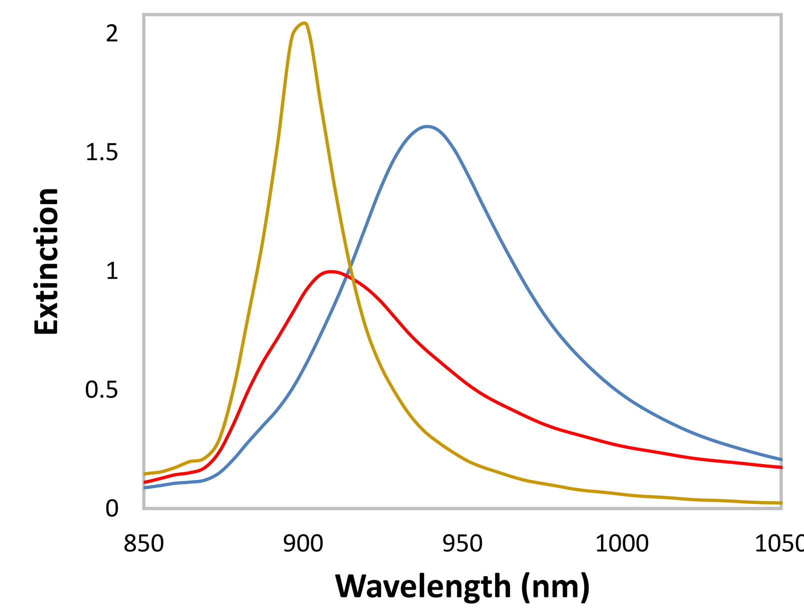
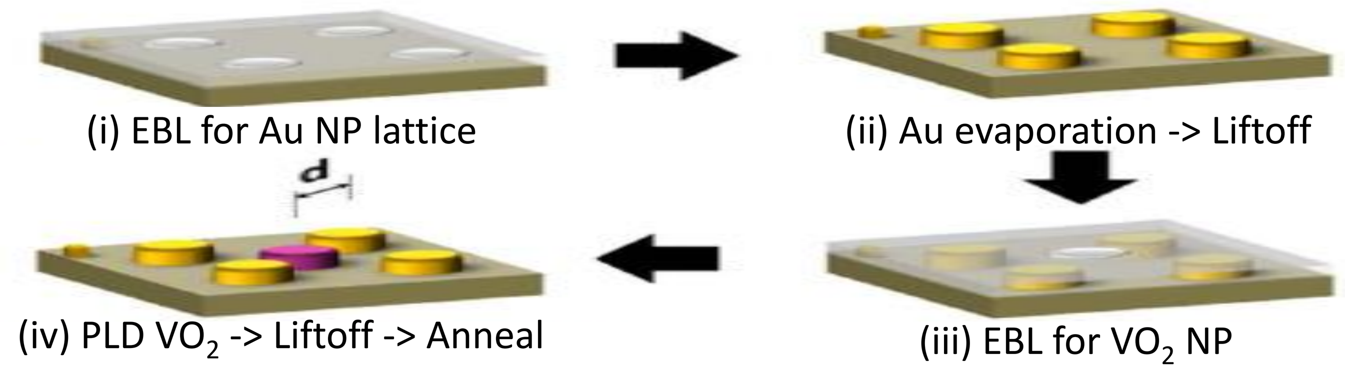


Figure 7: Our results after repeating the FDTD model. Same conditions as in Figure 6.

Future work

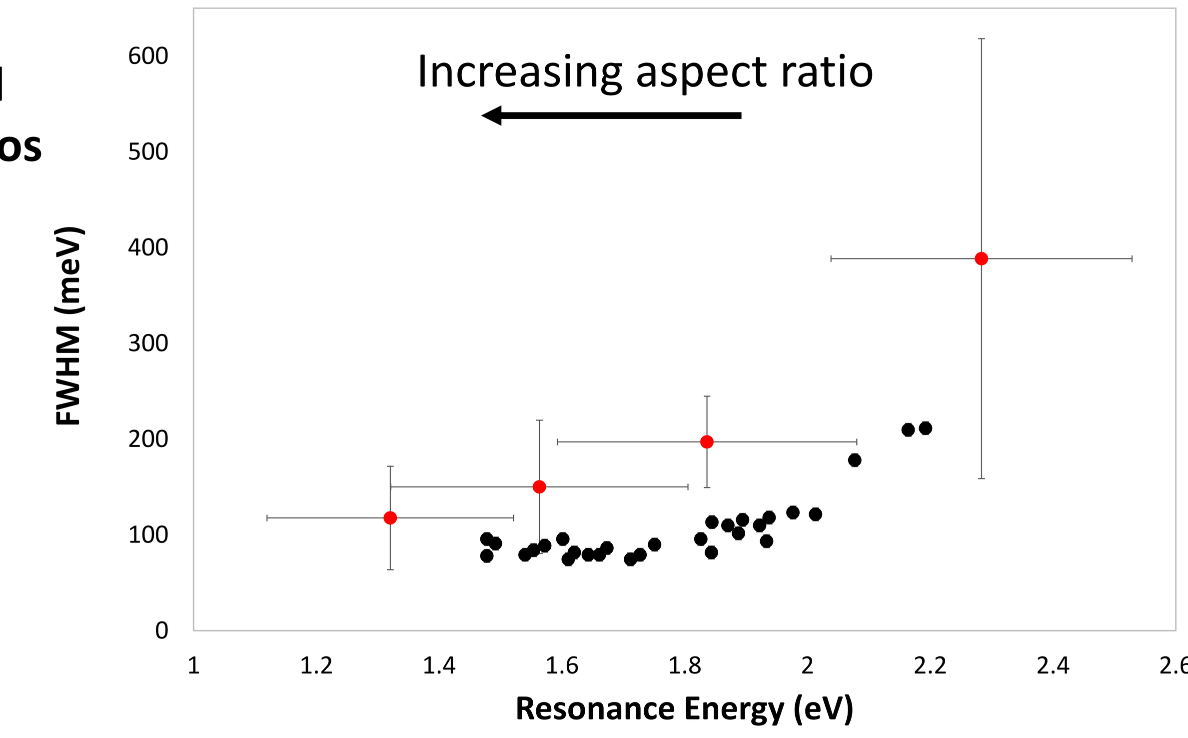
- Test gap dependence on resonance shift for high aspect ratio Au particles
- Shift resonance to telecommunications regime for enhanced switching
- Fabrication of optimal hybrid Au:VO_2 nanomodulators



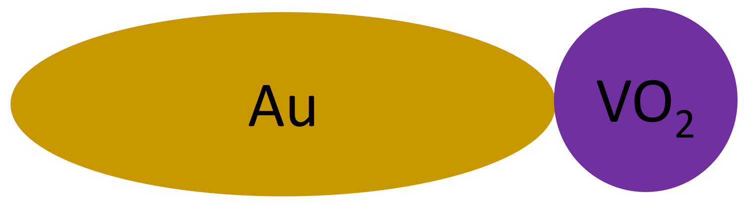
Consistency check with experiment

- Calculated average full-width-half-maximum for each aspect ratio
- Compared to Sönnichsen *et al.* measurement (2002)[2]
- Error bars reflect variance in material volume for given aspect ratio
- Acceptable correlation found for both magnitude and trend

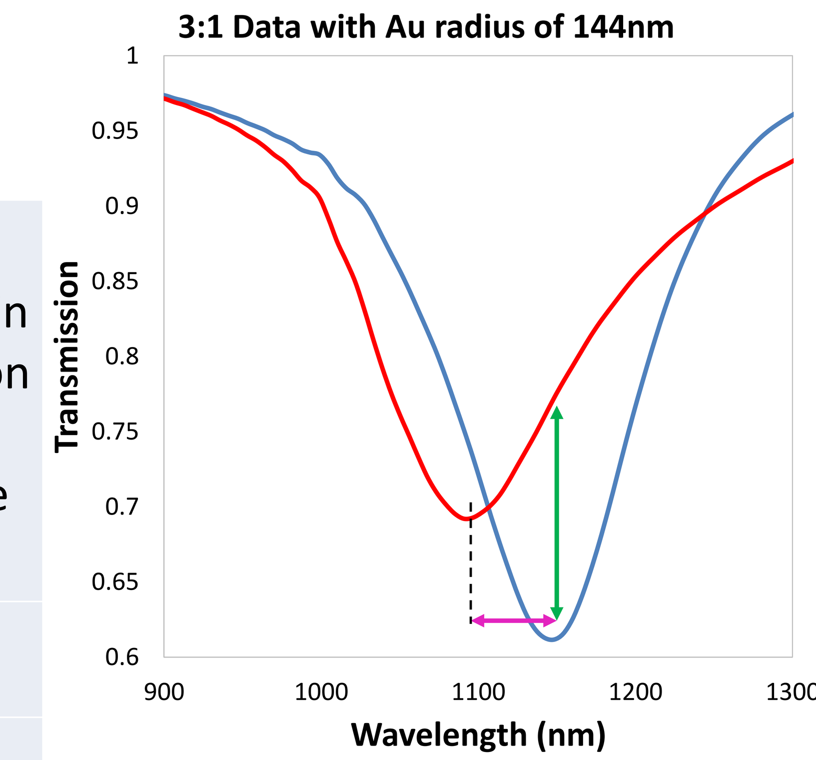
Figure 8: Calculated **average aspect ratios** for nanorods (red) compared to Sönnichsen's **experimental** nanorod averages[2] (black).



Results from Au:VO_2 Lumerical simulations



Sample Geometry (0nm gap)	Resonance Shift (nm)	Difference in Transmission at Cold Resonance
1:1 ratio, 48nm radius	23	0.02
2:1 ratio, 96nm radius	36	0.26
3:1 ratio, 144nm radius	58	0.16
4:1 ratio, 192nm radius	35	0.2



Purple Arrow: Resonance Shift (nm)
Green Arrow: Difference in Hot and Cold Transmission

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References

1. Appavoo, K. and Haglund, R. F., "Polarization selective phase-change nanomodulator," Scientific Reports 4, 6771 (2014).
2. Sönnichsen C, Franzl T, Wilk T, von Plessen G, Feldmann J. " Drastic reduction of plasmon damping in gold nanorods," Phys Rev Lett 2002, 88:077402.
3. Ferrara, Davon Wayne. "Calculations and Simulations." *Plasmonic Interactions in Gold::Vanadium Dioxide Hybrid Nanostructures*. Ph.D.dissertation, Vanderbilt University, 2011 Unpublished. Pages 71-77.