# Broadband and Large-Area Field Enhancement for SERS via Hybrid Plasmonic-Dielectric Cavity Coupling

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## Abstract

By integrating a $TiO_2$ cavity layer beneath a hexagonally arranged gold nanoparticle array, we show modulation of LSPR characteristics without requiring sub-nanometer control over nanoparticle morphology. Finite-difference time-domain (FDTD) simulations, supported by experimental results from surface-enhanced Raman spectroscopy, confirm the performance of this design. While the primary LSPR exhibits a modest red shift as the $TiO_2$ thickness increases from 110 nm to 160 nm, a secondary broadband resonance emerges near 1300 nm. This cavity-induced enhancement spans a broad spectral window ranging from 900 nm to 1500 nm.

## Hypothesis

A high-index dielectric spacer between nanoparticles and a gold film forms a hybrid cavity-plasmon mode through Fabry–Pérot cavity-like field distributions.

## Introduction

Subwavelength confinement of electromagnetic energy of plasmonic nanostructures amplifies light-matter interaction via localized surface plasmon resonance (LSPR), enabling advances in sensing, photonics, and more. We take inspiration from a Fabry-Perot cavity, where optical waves are confined between two parallel reflectors and pass through under resonance. Varying cavity thicknesses provides scalable resonance tuning and near-field enhancement. Raman enhancement is proportional to $10^4$ of the electric field intensity.

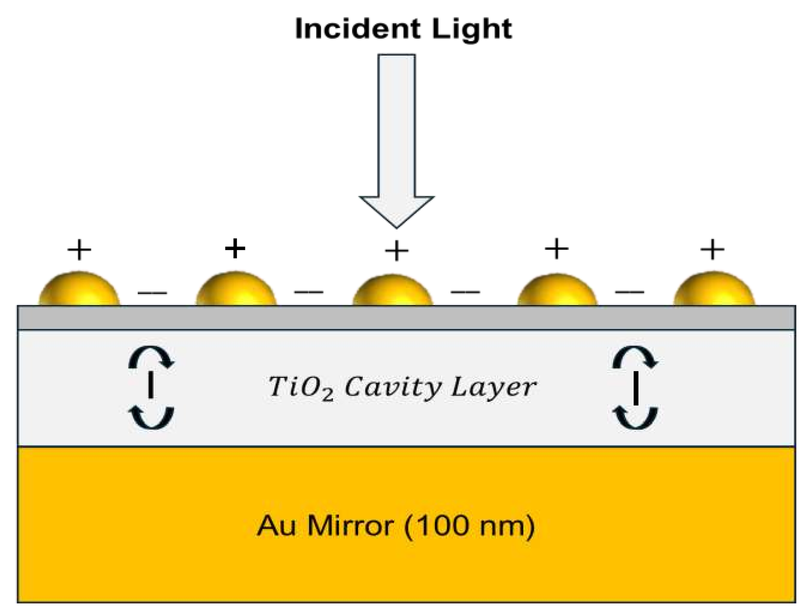
## Methodology

**FDTD/Surface Enhanced Raman Spectroscopy (SERS):**

$$\phi_{prop} = \frac{2\pi n(2d)}{\lambda} = 2\pi \rightarrow d = \frac{\lambda}{2n}$$

- FDTD simulations to field distribution at cavity thicknesses of 110nm, 130nm, and 160nm
- Raman spectroscopy with 785nm excitation wavelength normal incident onto top surface at 1% and 5% laser power
- Range of 0-2500 $cm^{-1}$

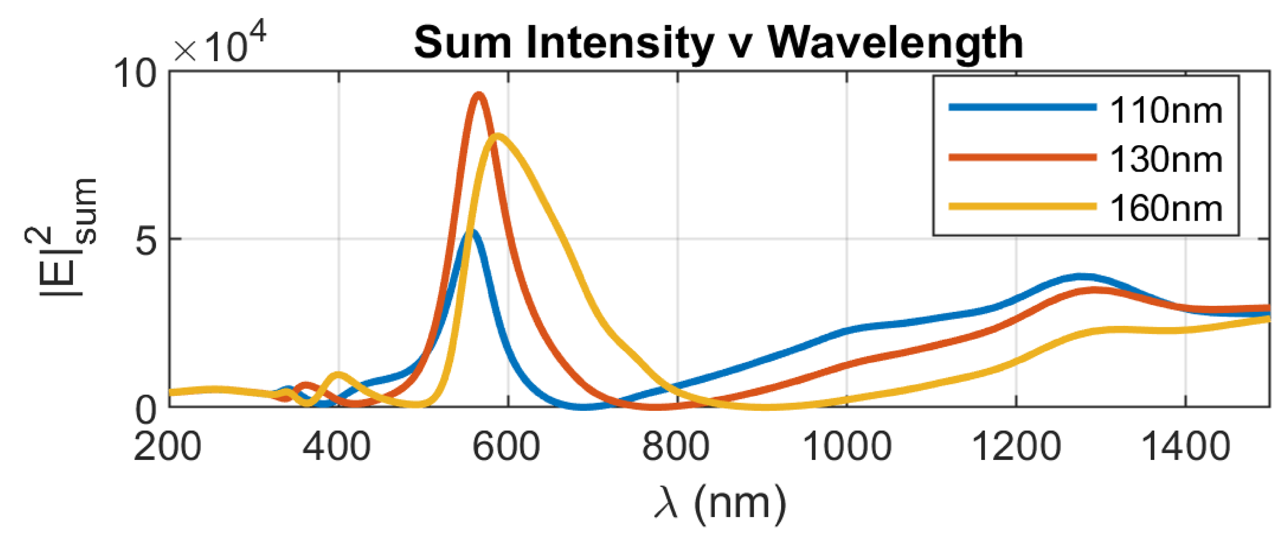
## Simulation/Experimental Results

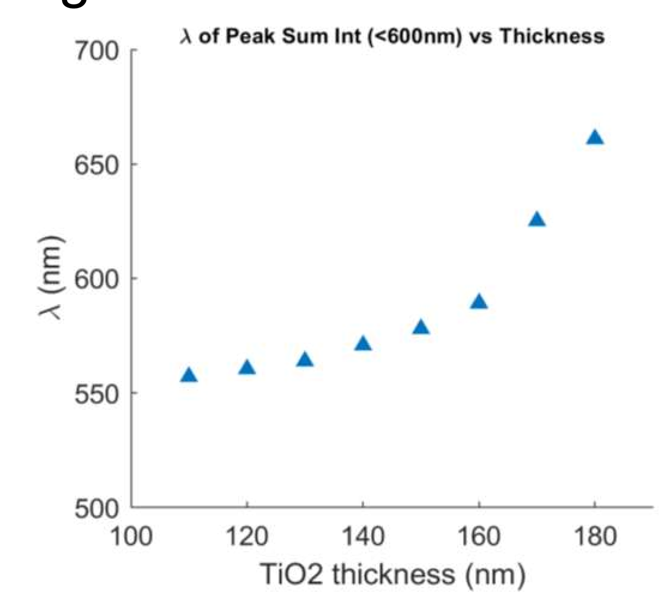



- $TiO_2$ layer functions as a Fabry–Pérot cavity
- 100nm Au film acts as a mirror while AuNPs partially reflect and transmit light
- Field confinement and constructive interference within cavity layer form hybrid cavity-plasmon mode where near field intensity is greatly amplified and localized at resonance

**FDTD Sum Intensity Results and Analysis**

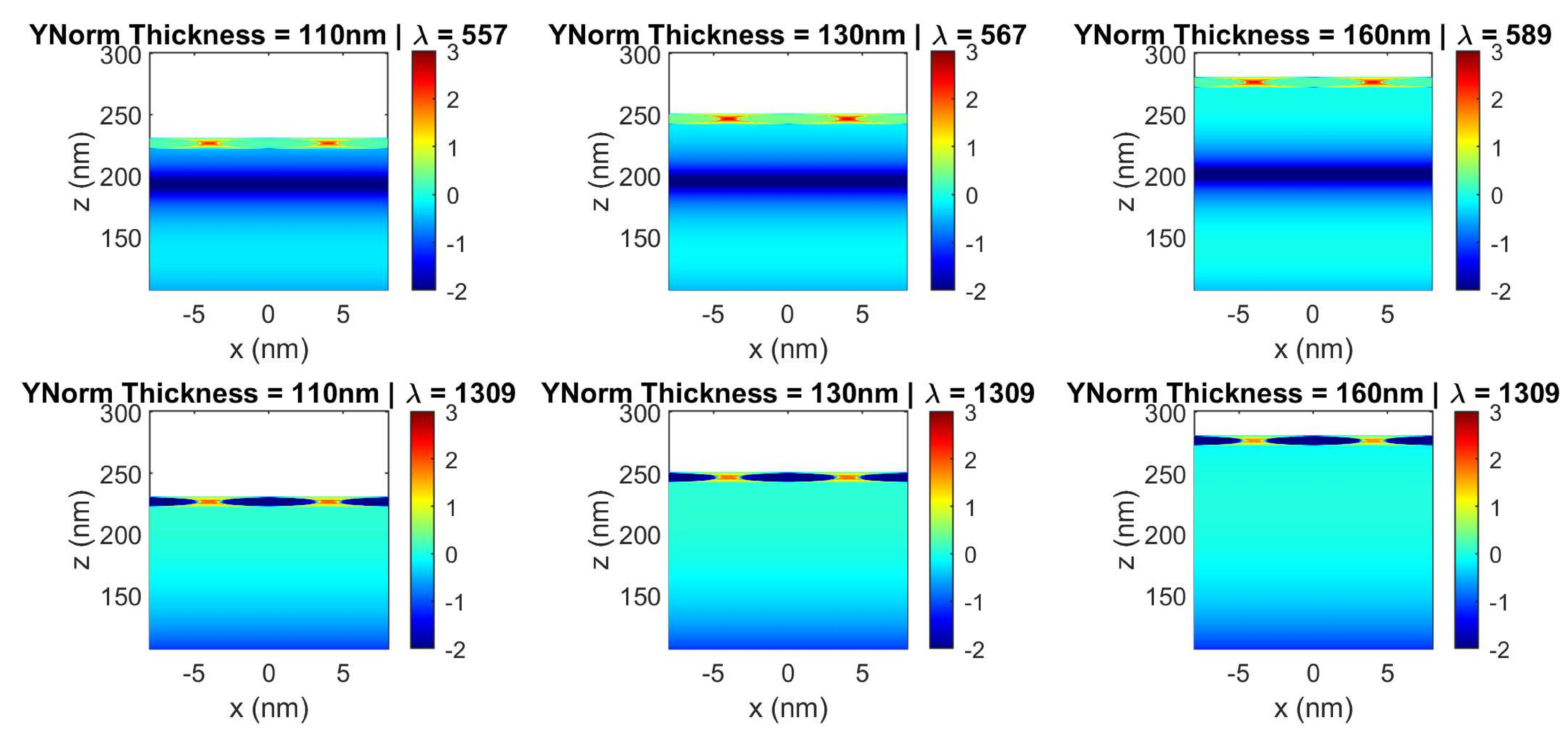
- Increasing thickness corresponds to red-shifted peak wavelength
- 160nm cavity provides largest electric field intensity at 785nm
- Broadband resonance peak appears in the NIR region



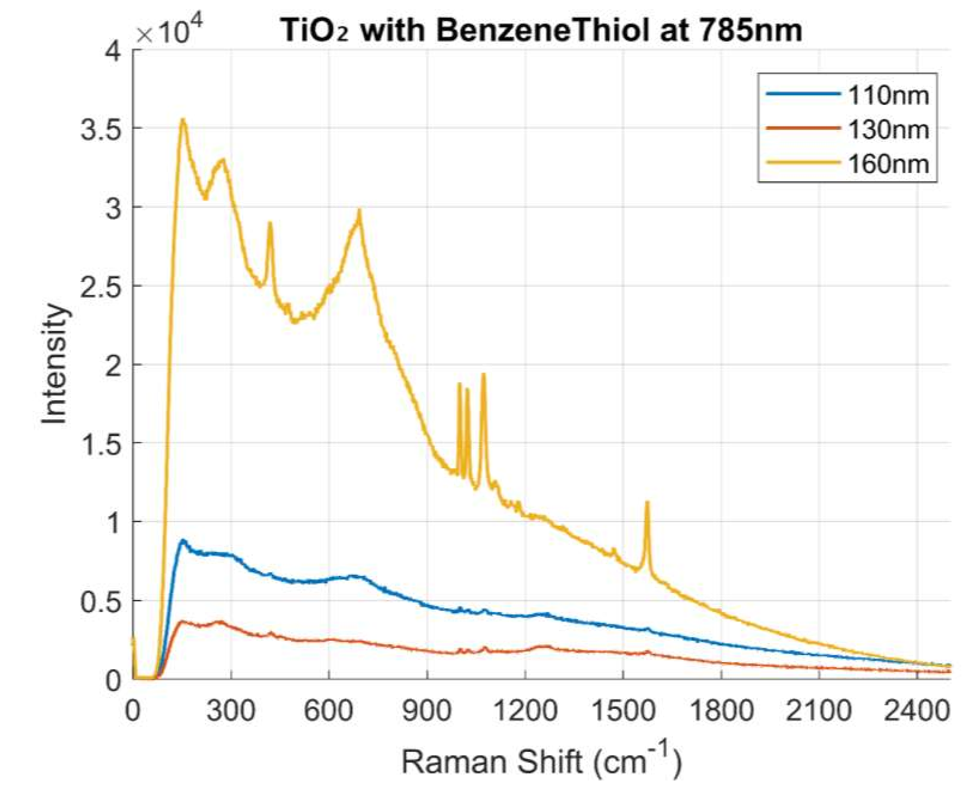




**FDTD Field Profile Results and Analysis**

- Field profiles demonstrate the tunability of the resonance mode by varying the thickness of the dielectric layer
- 130nm thickness corresponds with the largest field enhancement due to resonance alignment with LSPR from the gold nanoparticle layer
- Second mode resonance at shorter wavelength (~660nm)
- Fundamental mode at the longer wavelength (~1300nm)




## SERS Experiment Results




- 160nm cavity shows largest Raman enhancement for 785nm laser line
- Raman peaks of Benzenethiol identified at ~420, 1020-1060, and 1600 $cm^{-1}$
- Peaks differ in oscillation strength due to different excitation frequencies at 785nm laser line

## Conclusions/Future Work

**Conclusions:**

$TiO_2$ cavity layer offers resonance tunability and electromagnetic field enhancement. Varied dielectric thicknesses corresponded to different excitation wavelengths and near-field intensities. Raman peaks of Benzenethiol showed considerable Raman enhancement. 160nm cavity thickness offers ~$10^4$ Raman enhancement compared to no cavity layer at off-resonance wavelength

**Future Work:**

Simulate/test thinner $TiO_2$ thicknesses for resonance tunability. Take Raman measurements at 532nm and 633nm to verify resonance effects at different excitation wavelengths.

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