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CLEMSON INSTITUTE FOR BIOLOGICAL INTERFACES OF ENGINEERING

Improving Detection Sensitivity for Nanoscale Targets through Combined Photonic and Plasmonic Techniques

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Optical techniques to detect small particles (bacteria and virus)

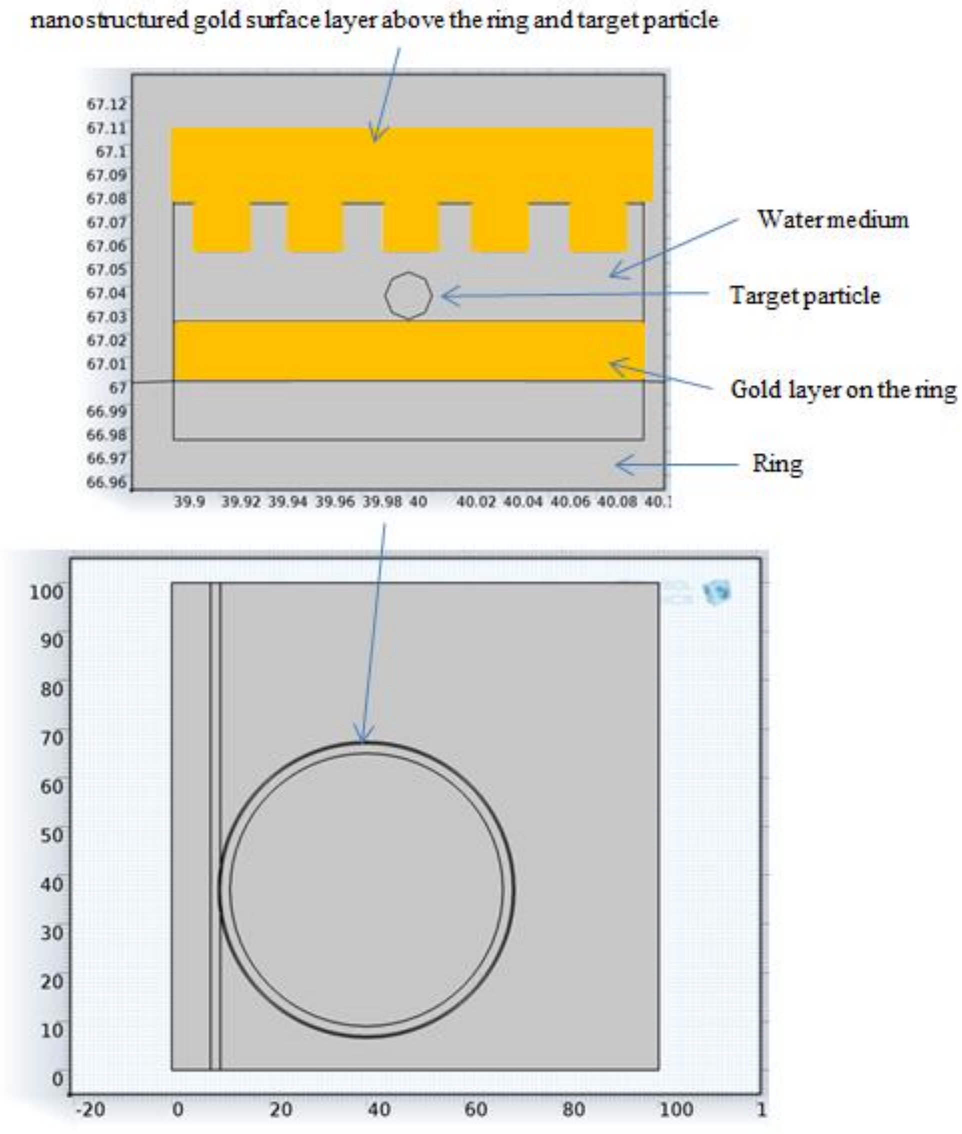
- Photonic technique:
  Whispering Gallery Mode (WGM)

- Plasmonic technique:
  Surface Resonance Plasmon (SPR)
  Surface Enhanced Raman Scattering (SERS)

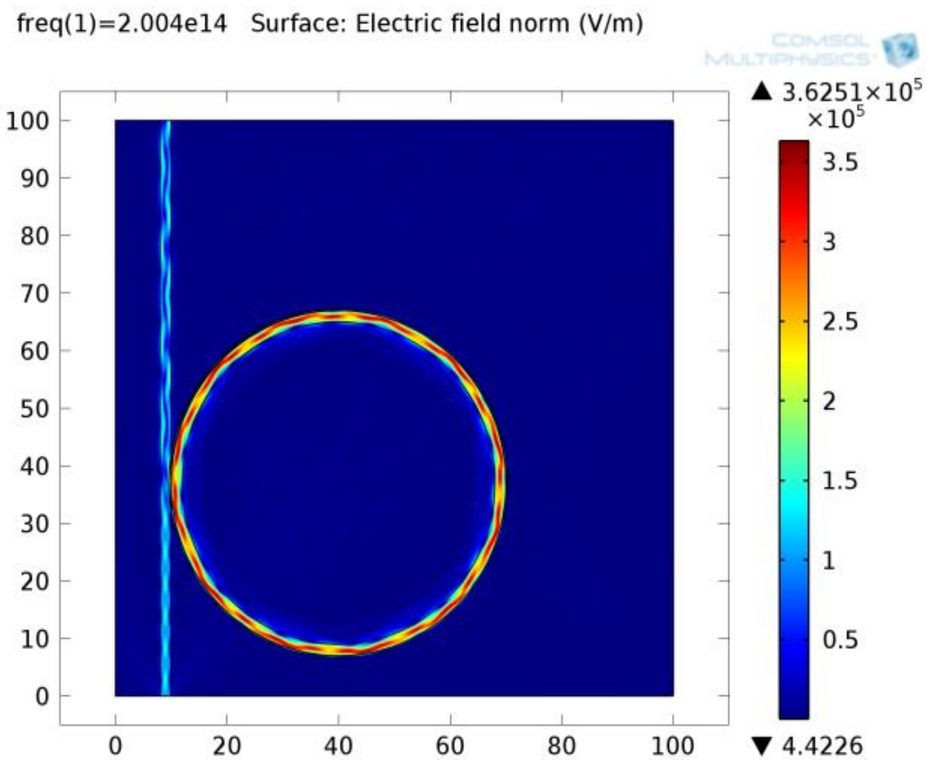
We hypothesize that if these techniques are combined in one setting, detection sensitivity can increase by several orders of magnitude

Modeling geometry

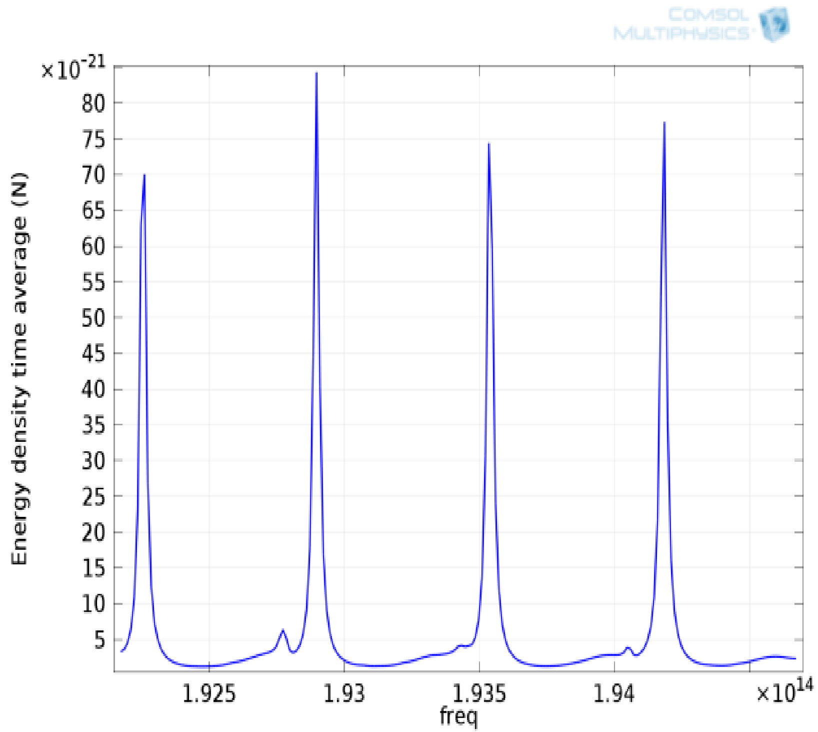
- Straight waveguide with thickness of 2um
- Ring waveguide with diameter of 60um
- Channel formed by smooth and rough gold layer



Simulation of WGM



The resonance pattern of light in the ring at approximately 200×10^12 Hz

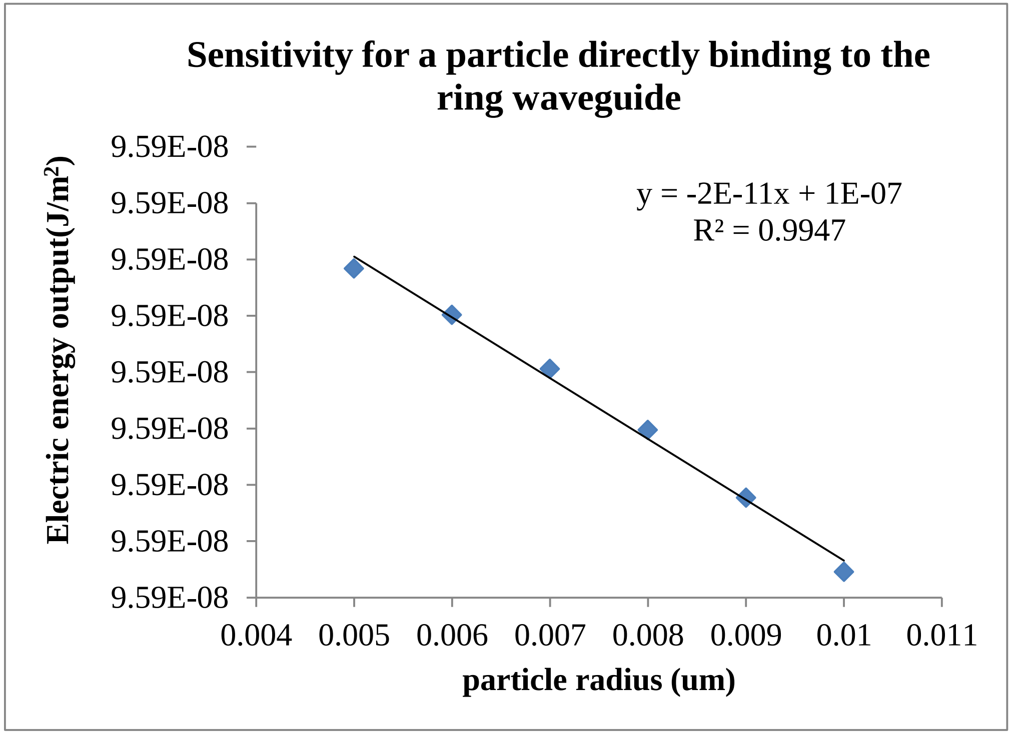


Resonance peak of energy in the ring waveguide

Refractive index of straight waveguide: 1.4682;
Refractive index of ring waveguide: 1.52

If a particle directly binds to the ring:

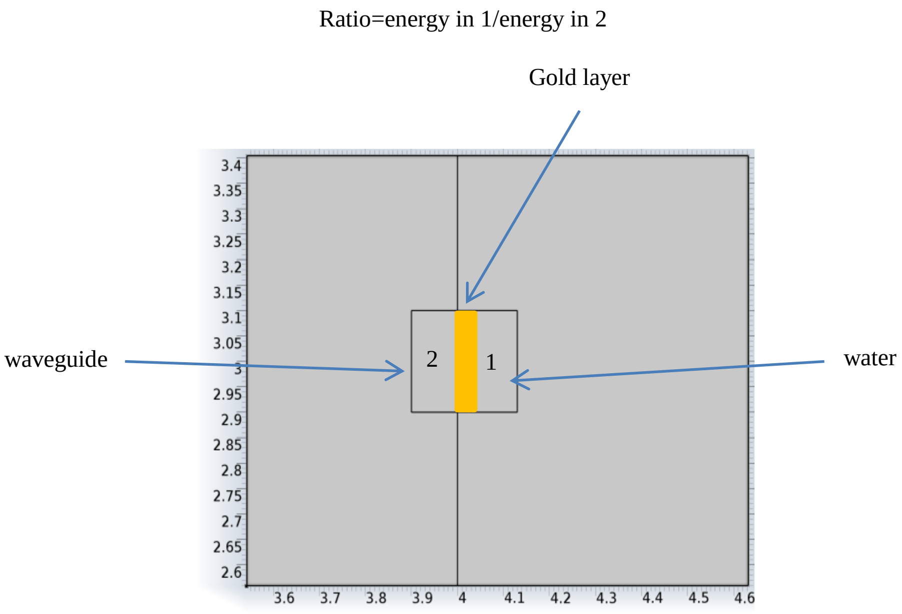
- The output at resonance frequency is calculated
- The output changes with the particle radius
- The slope represents the detection sensitivity

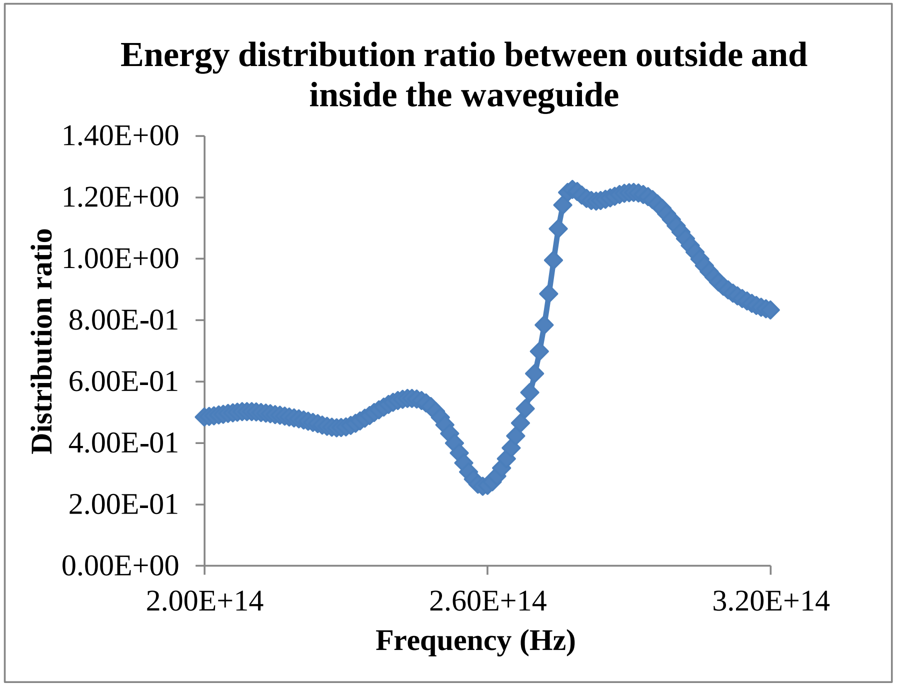


Sensitivity is 2×10^{-11} J/m^2*um

Flat gold layer is used to excite SPR

The SPR behavior is studied using structure shown below:

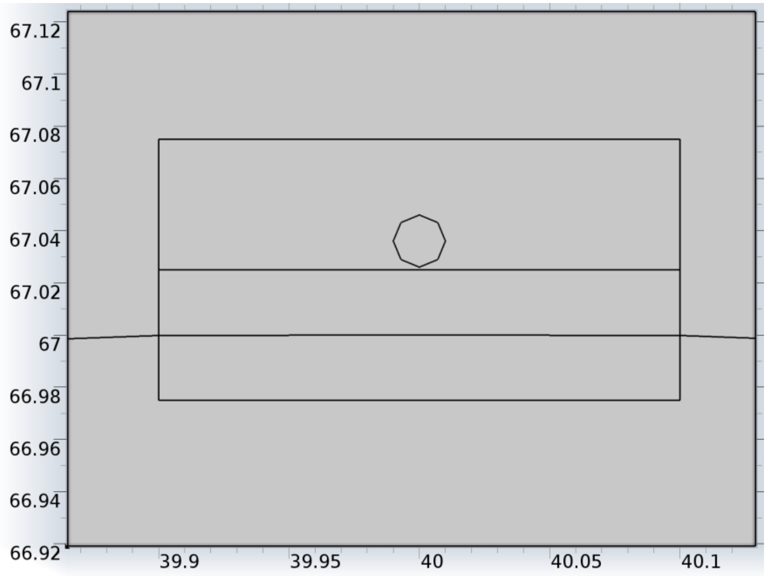


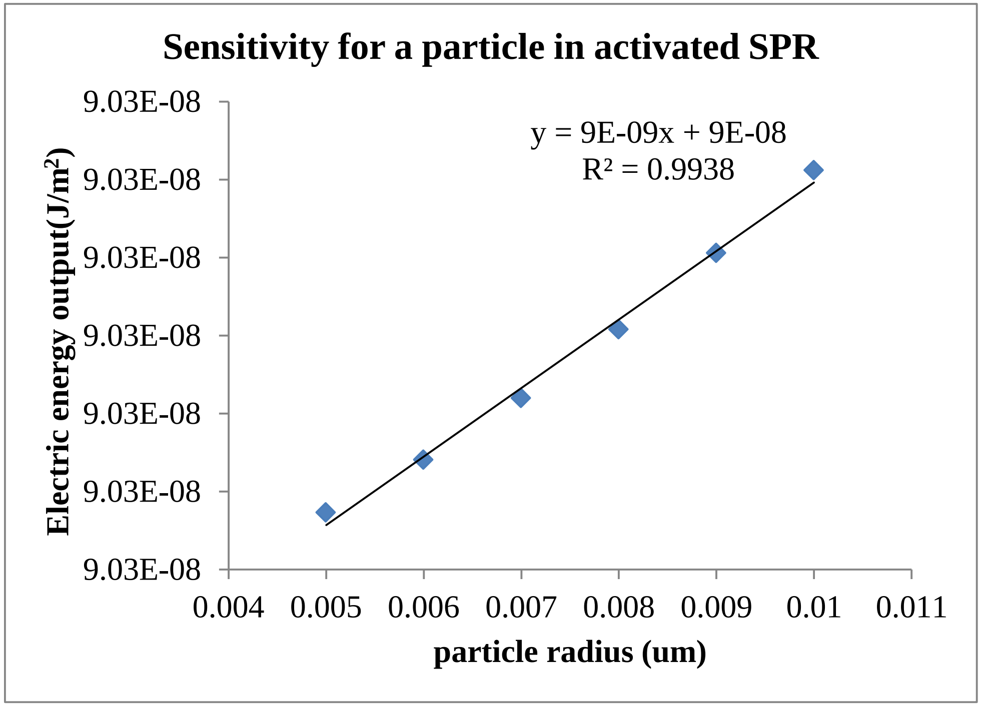


The frequency range where energy distribution ratio changes drastically indicates excitation of SPR

The simulation result shows that detection sensitivity is highest at the resonance frequency where the energy ratio peaks (around 279×10^{12} Hz in this case)

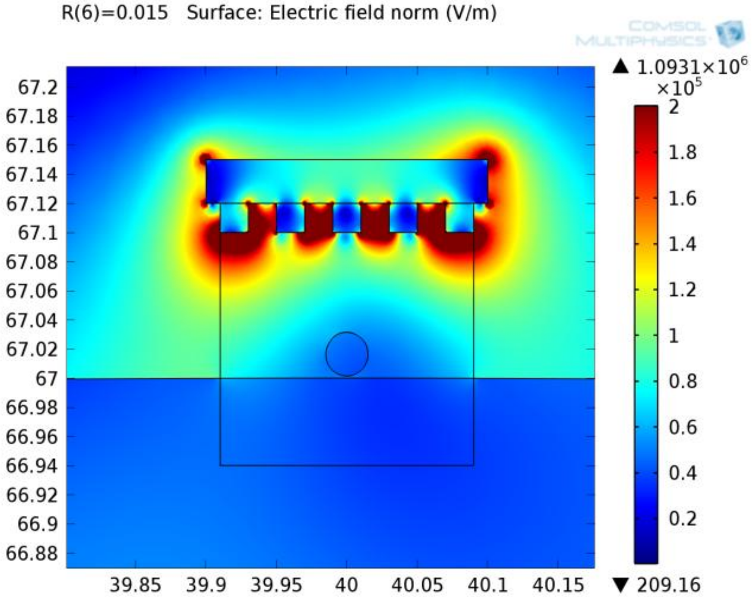
Geometry:



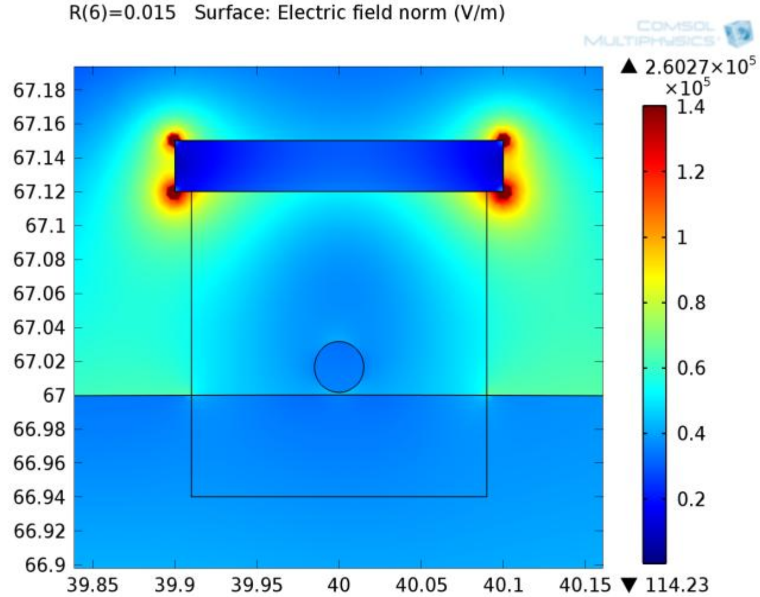


Sensitivity is 9×10^{-9} J/m^2*um, 400 times improvement

A gold sheet with rough surface is needed to excite SERS

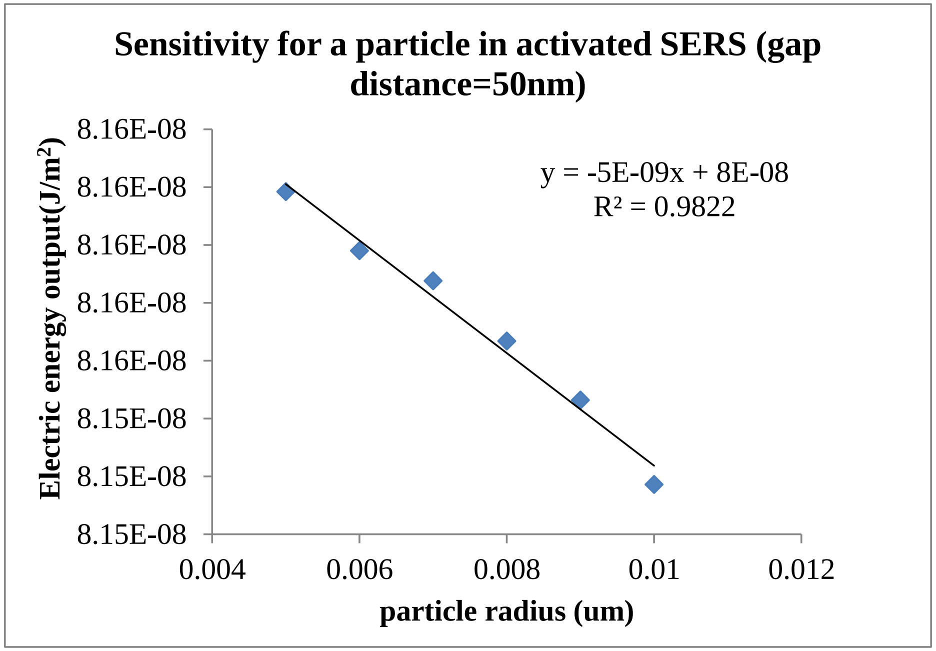


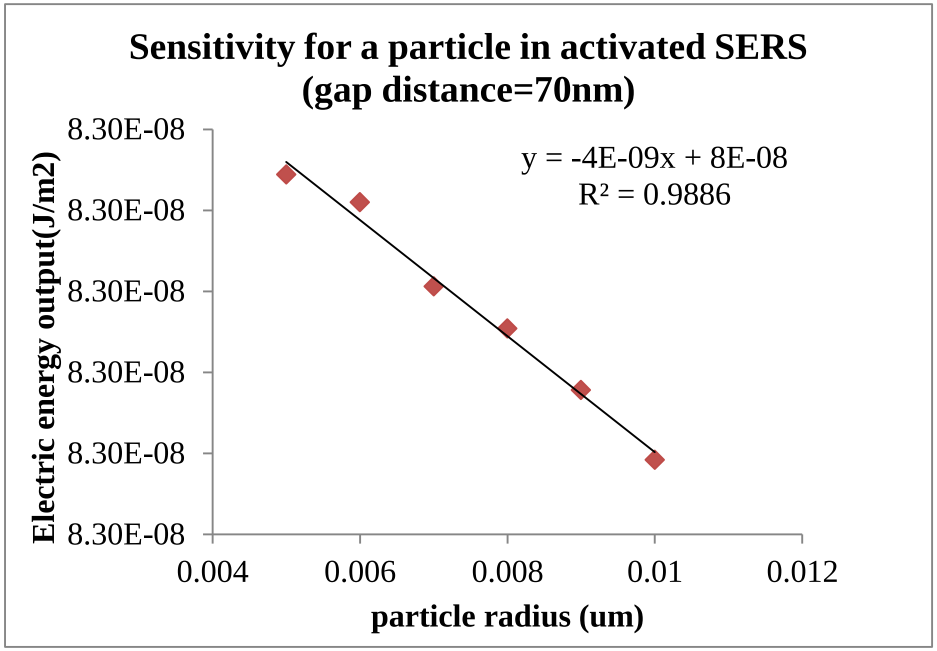
A nanostructured surface generates strong local electric field



A flat surface generates a much uniform electric field

The detection sensitivity is affected by the gap distance between nanostructured gold surface and top of the ring



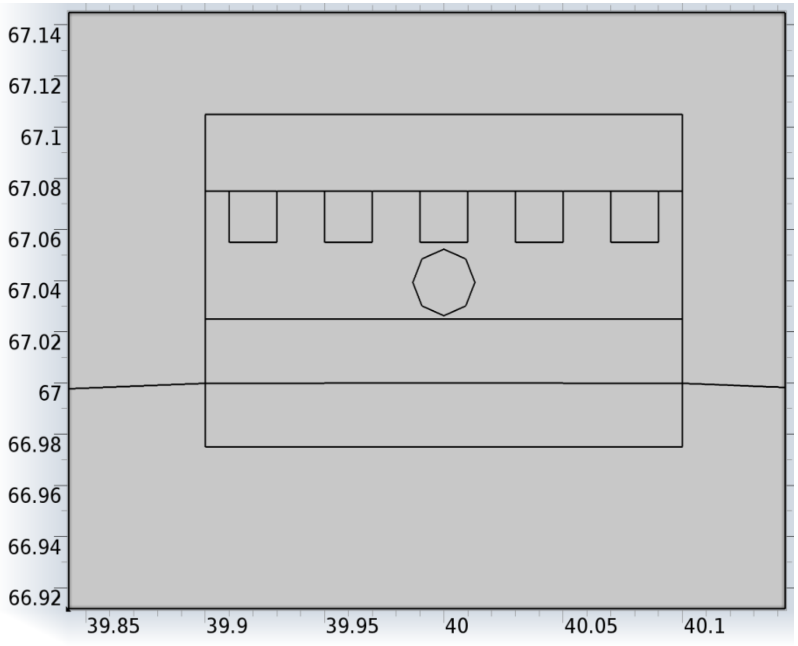


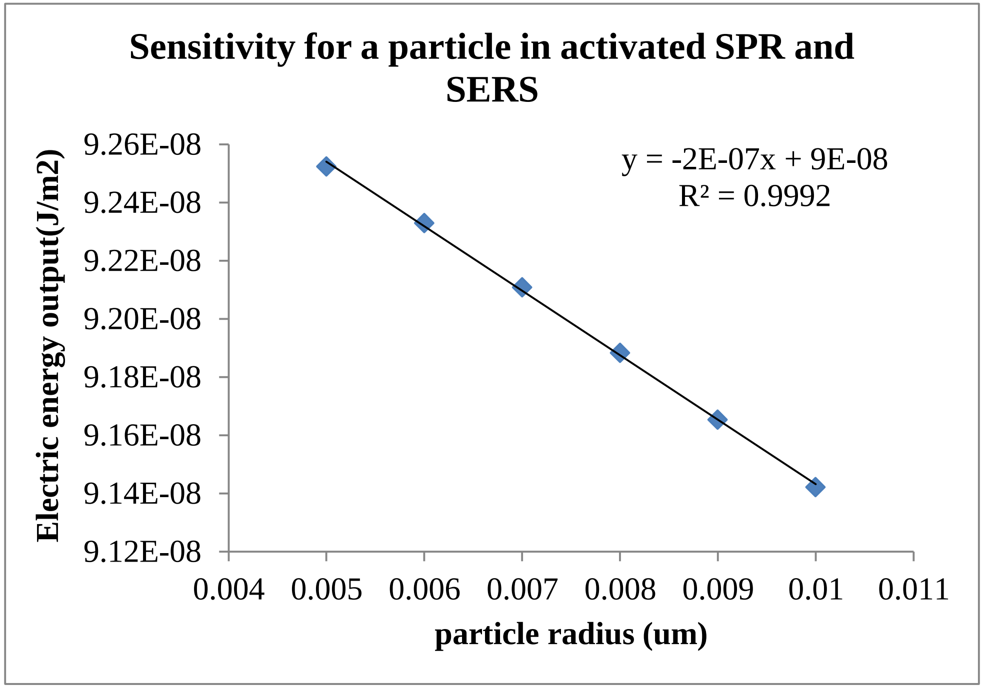
200 times improvement compared to direct binding

The detection sensitivity will decrease as the nanostructured gold layer is moved farther away from the ring

Once SPR and SERS are combined:

Geometry:

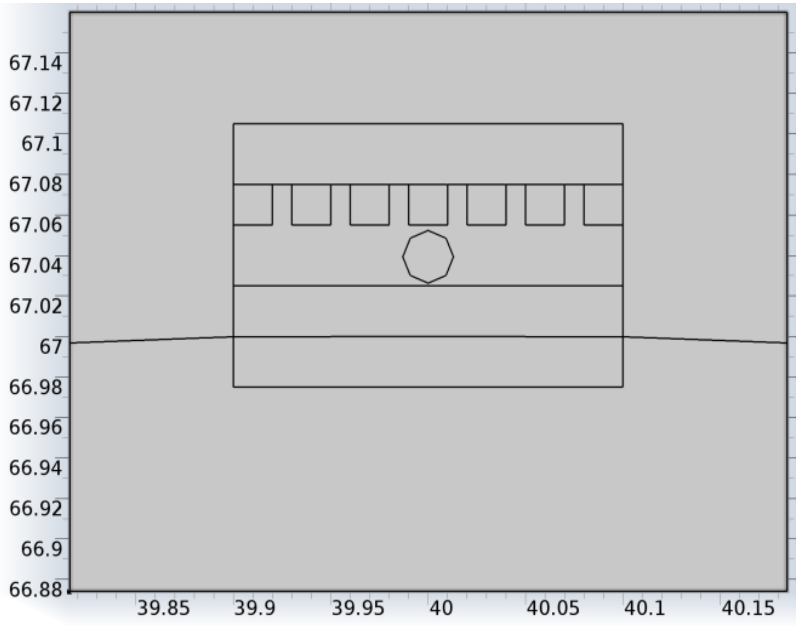


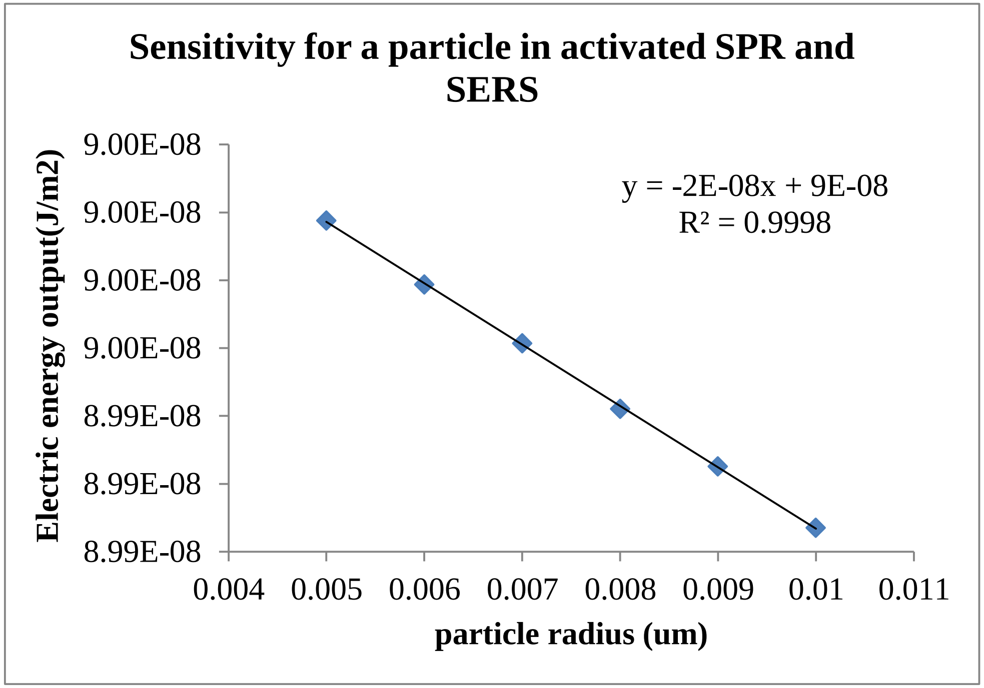


Sensitivity is 2×10^{-7} J/m^2*um, 10^4 times improvement

More compact nanostructured gold layer may reduce detection sensitivity

Geometry:





Sensitivity will only be 1/10

Conclusion:

- For the first time, WGM, SPR and SERS techniques are successfully combined in a single device by using COMSOL multiphysics modeling.

- The simulation results show that the three techniques work in synergy and contribute to the improvement of detection sensitivity significantly.

- This work provides new insight into how the distribution of energy in the photonic ring structure and the surrounding medium can affect the resonant behavior of a combined WGM/SPR/SERS detection device.

Acknowledgement:

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