Squeezing the Local Density of States (LDOS) for Ultrasensitive Plasmonic Sensing

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Introduction

It is generally accepted that localized plasmonic resonance (LPR) based nanosensor inevitably suffers from a broad LPR linewidth because of the large intrinsic absorption of metal and hence the quality factors of nanoparticles (NPs) are usually quite small. To overcome this obstacle, we propose a hybrid structure for efficient plasmonic sensing. When a resonant plasmonic nanoparticle is placed inside a microcavity with high Q-factor, sensitivity is enhanced in the far-field extinction. Ultrasensitive detection of nano-sized targets are able to realized when the system is active namely with optical gain in the cavity. Such particle-microcavity system opens up a new hybrid plasmonic sensing device platform based on that the local density of state (LDOS) is squeezed.

Passive system[1]

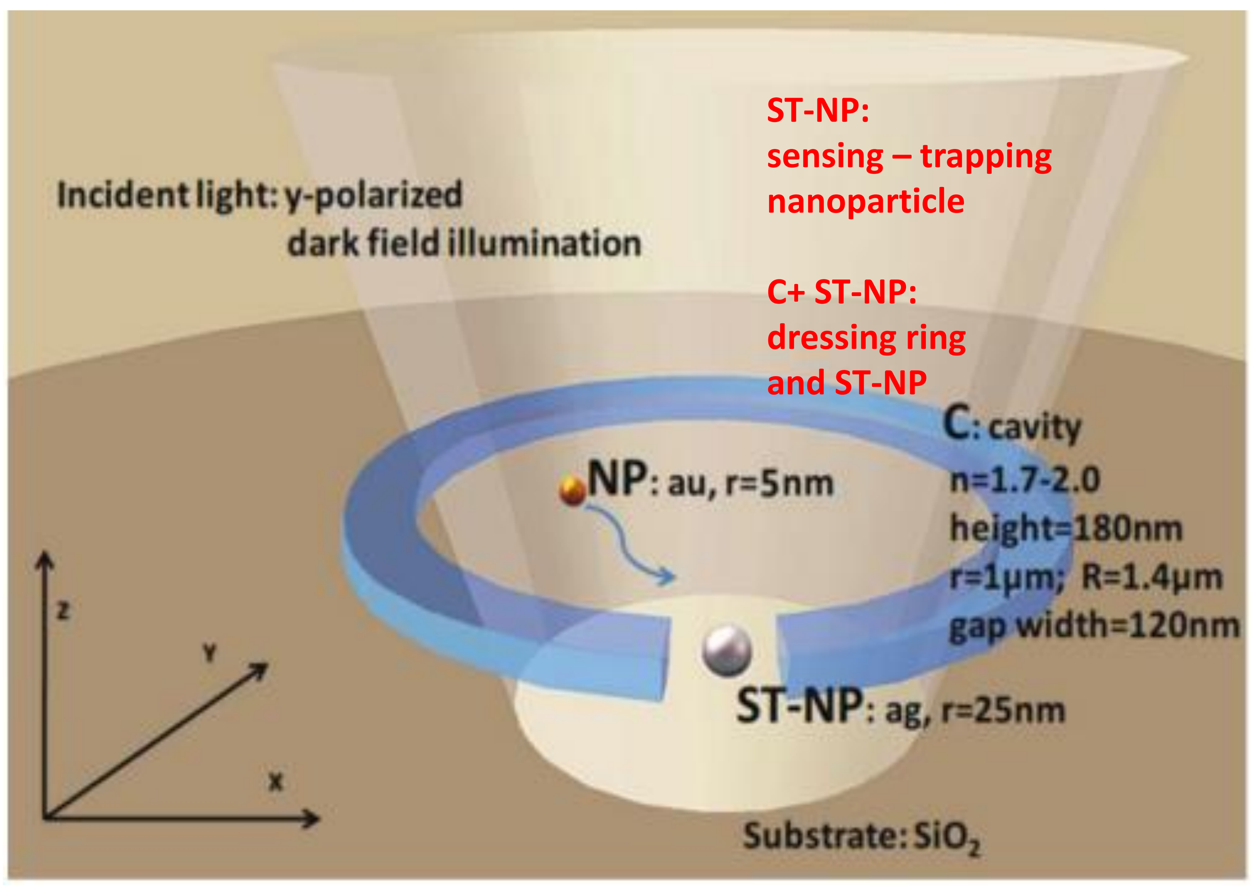
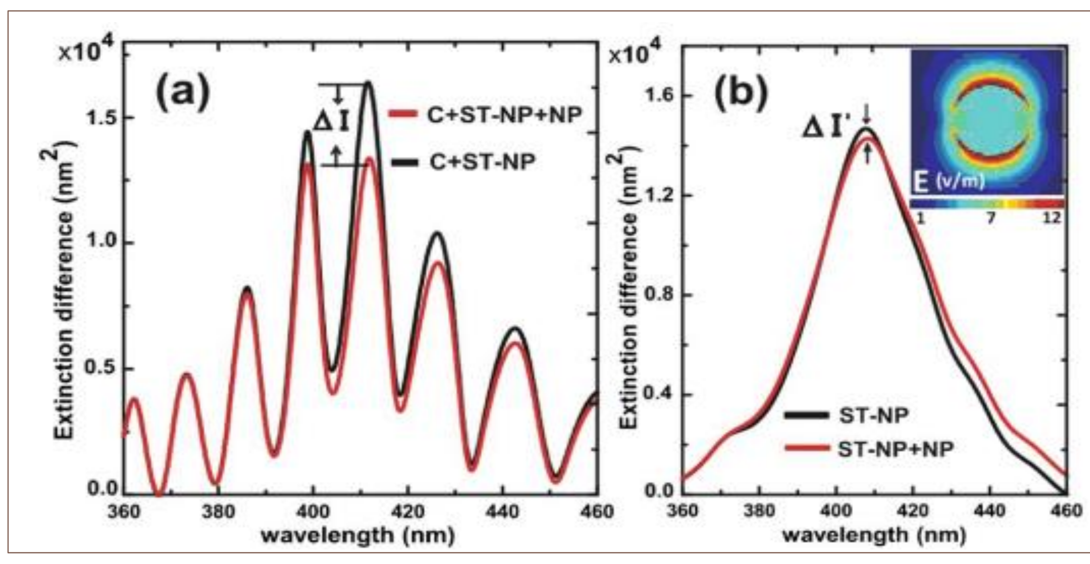
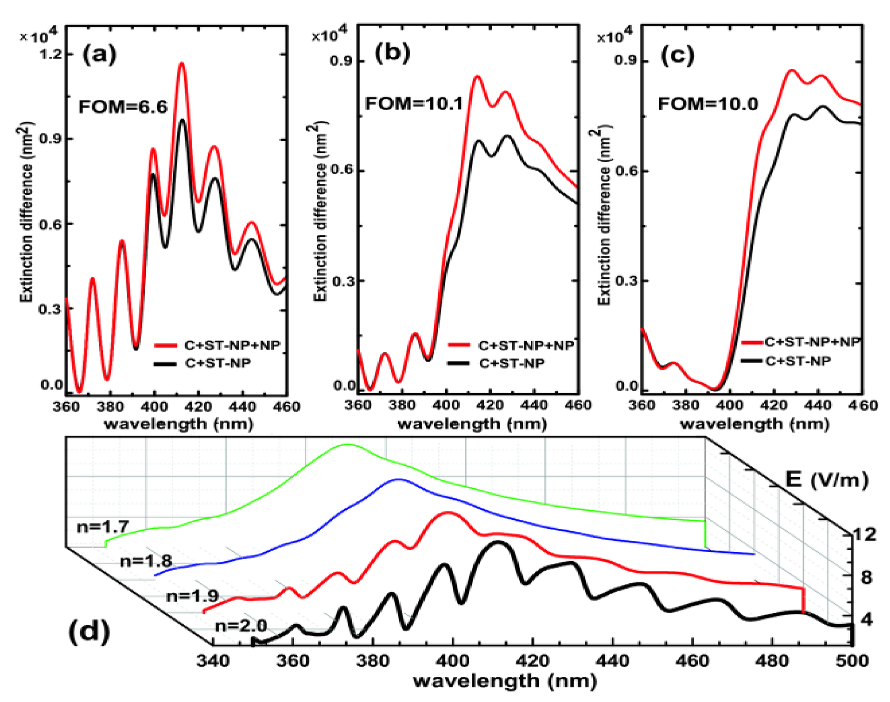


Fig.1.Schematic of the hybrid ST-NP configuration. The micro-ring has a height of 180 nm, a gap width of 120 nm and an outer and inner radius of 0.9μm and 0.5μm respectively. The silver ST-NP has a radius of 25 nm. The incident cone of light is used for dark-field spectroscopy.



(a) Extinction spectra of the C+ST-NP+NP and C+ST-NP systems with the dressing ring index n=2.0.
(b) Extinction spectra of the ST-NP and ST-NP+NP systems; inset shows the ST-NP's near-field distribution in the equatorial plane parallel with the substrate.



Evolution of extinction spectra of the C+ST-NP+NP and C+ST-NP systems with the refractive index of the dressing ring (a) 1.9; (b) 1.8; (c) 1.7; (d) near-field amplitude of the C+ST-NP system (data recorded by the point monitor).
The LDOS is proportional to the power emitted by the source (ST-NP).
For certain wavelength the extinction variation is inversely proportional to n_{eff} (effective index of the optical configuration around the scattering object) but proportional to the factor Q/V.

Active system[2] (with gain in the cavity)

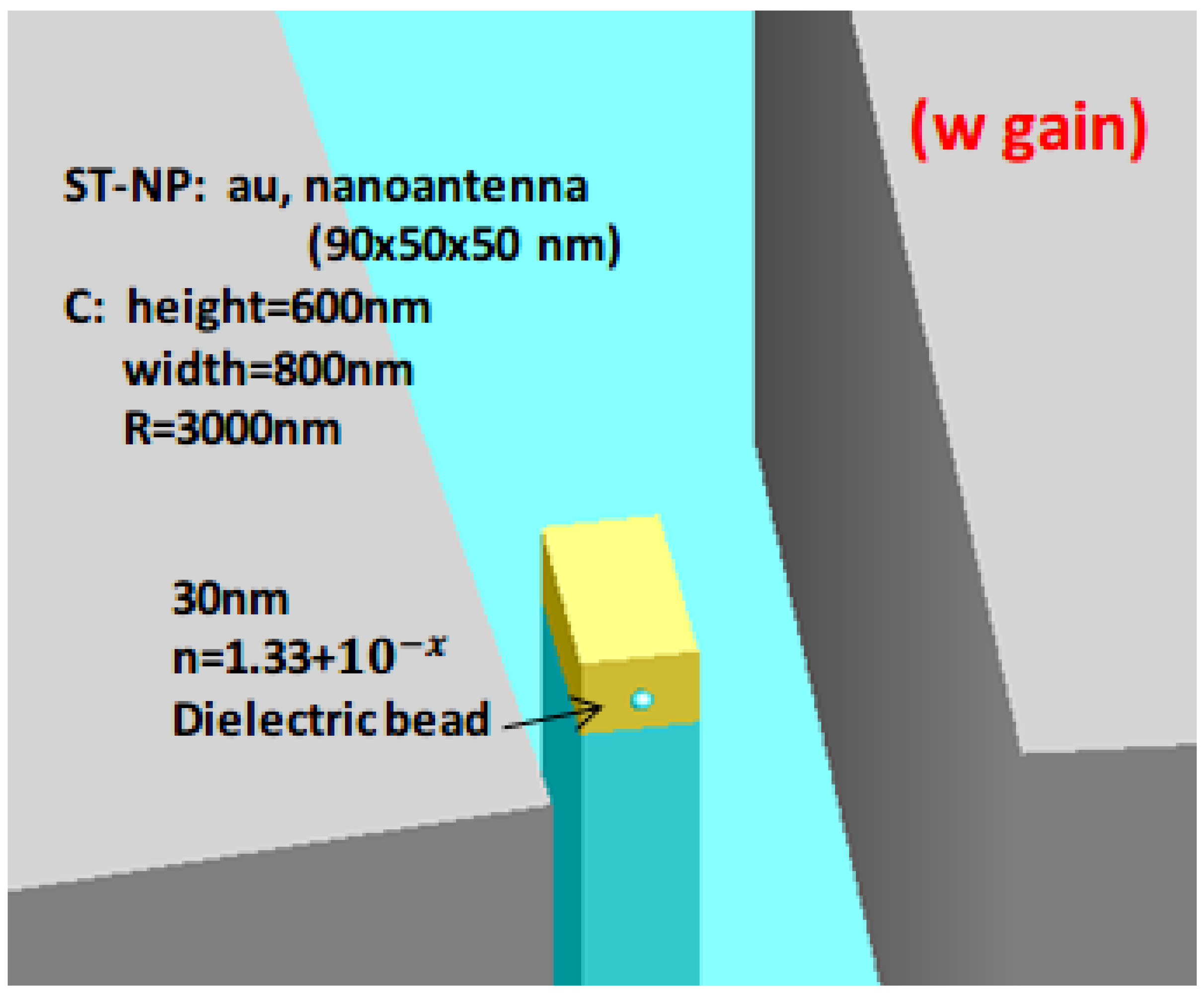
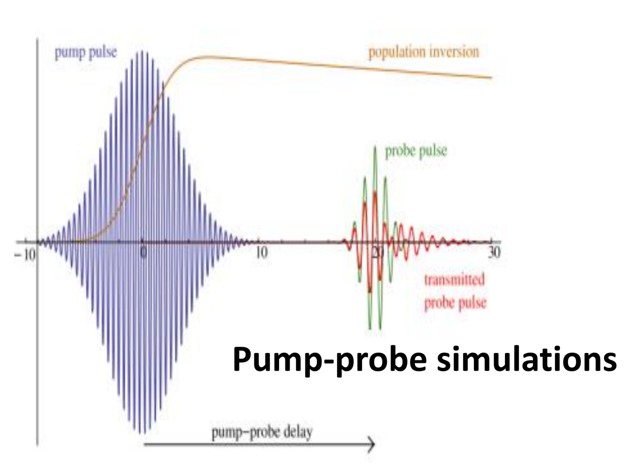
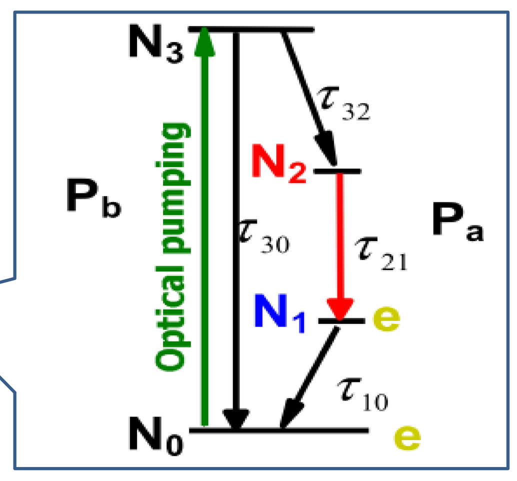
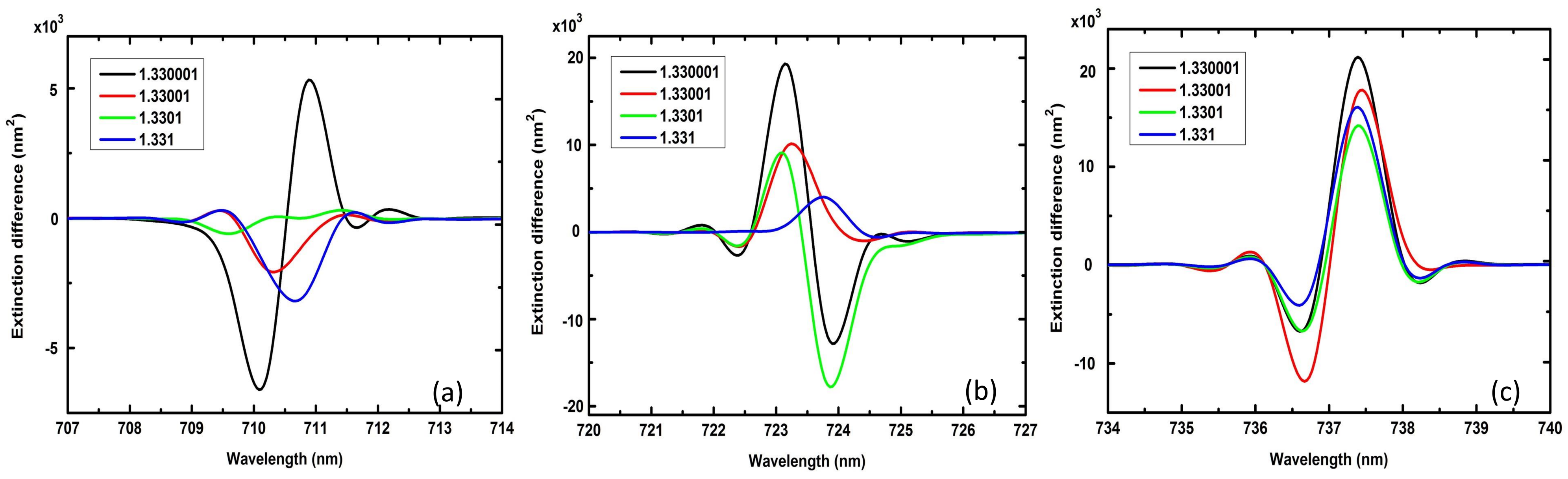


Fig. 2. Schematic of the active configuration. The micro-ring has a height of 600 nm, a gap width of 120 nm and an radius of 3μm. The gold ST-NP is a nanoantenna. The detection is also dark-field spectroscopy in our simulation. The cavity is of optical gain doped. The environment is water (n=1.33), and the target to sense is dielectric bead with n=1.33+10^{-x}



With gain in the ring, we use four-level two-electron model to simulate the solid Rh800 dye in epoxy.
The gain level : about 400 cm^{-1} peak@723nm.
We do pump-probe simulations via FDTD method.





Extinction difference spectra (C+ST-NP+NP minus C+ST-NP) with the dressing ring of optical gain (Rh800). The target bead is of index varies from 1.331 to 1.330001.

$$P=\frac{\pi\omega^2}{12\varepsilon_0}\left|P^2\right|LDOS(r,\omega)$$

$$P=\alpha E$$

$$\alpha=\frac{V}{(1/(\varepsilon_r-1))+N-i(4\pi^2V/3\lambda^3)}$$

P: dipole moment
r: location
α : polarizability of ST-NP
N: shape-dependent depolarization factor

Conclusion

In conclusion, we propose and investigate an ultrasensitive plasmonic configuration. The introduction of an external cavity will greatly enhance the sensing performance in terms of far field radiation modulation. The cavity offers a sensitivity FOM, defined as ΔI/I, of 10 after trapping a target NP for passive system. While for active system that with optical gain in the cavity, our calculation shows that the critical detection limit is at n=1.330001. The amplification ability for this index variation level is able to do single molecular detection.

References
[1] H.X.Zhang,Y.Y.Zhou,X.Yu.F.Luan,J.B.Xu,H.C.Ong,and H.P.Ho, Opt. Lett. 39, 873 (2014)
[2] H.X.Zhang and H.P.Ho, Squeezing the local density of state (LDOS) for ultrasensitive plasmonic sensing, (in preparation)

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