Plasmonic Fabry-Perot cavity for nano-optical filter and sensing platform

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***Abstract*— This work deals with the nano-optical version of a Fabry-Perot cavity. By exciting plasmon modes on the metallic nanoparticles in the cavity, optical power can be squeezed into subwavelength scale without scattering effects stemmed from diffraction. As suggested by our first results, it surges feasible to use such structure as a building block for optical resonators at nanometer dimensions. Furthermore, the enhanced near-field provided by the plasmon modes yields a high-sensitive ultra-compact area, which meets potential applications for biochemical sensing.**

Keywords*— *Plasmonics, Fabry-Perot cavity, subwavelength optical filters, optical sensors.

I. INTRODUCTION

Since the paper of Barnes *et al.* [1], overcoming the diffraction limit and leading optical systems towards nanoscale have been possible due to manipulation of surface plasmon polaritons (SPP). SPPs are excitations confined to a conductor-dielectric interface owing to the resonant interaction between incident photons and free electrons at the conducting surface. Within SPP resonance, the optical power can be confined and enhanced with an effective wavelength much smaller than that of the incident light.

As the issue of high losses provided by the conducting parts has been continuously mitigated due to advances in nanostructurization of metallic particles, the application of SPPs waves to transmit and process optical signals in subwavelength dimensions has indeed opened a new frontier in photonic networks. Since the last decade, scientific community has witnessed the emerging of many configurations for handling SPP waves. Stacks of metallic layers sandwiched by dielectric composites are the most common structures for SPP guiding [2]. However, more complex arrangements are proposed to mimetize conventional optical circuitry in nanometric size. Nanowaveguides based on trenches in metal film and coupled metal nanoparticles can be applied to the realization of optical modulators, switches and nano-filters [3]. Metal wedges have been proved a suitable tool for near-field probe [4]. Metallic-coated dielectric cylinders are designed to optimize interconnections in nanophotonic network integration [5]. All these structures are fruitful examples of the current status of plasmonics engineering and their potentials for a new generation of optical devices in communication technologies.

Within the above context, this work is devoted to investigate the impact of plasmon modes of metallic nanodisks on the resonances of a Fabry-Perot cavity. Our aim is to cast the SPP modes that arise at the nanodisk periphery and propose a building block feasible to actuate as an optical filter. Moreover, upon the attractive potentials in using network optical devices as sensing platform, as well as the high sensitivity provided by the near-field enhancement at the metal-dielectric interface [6], we assess the application of the plasmonic cavity structure as a refractive index sensor.

II. THE PLASMONIC FABRY-PEROT CAVITY

On the contrary to bulk waves in conventional dielectric optical devices, SPP excitations present an evanescent decay profile along the conducting and dielectric regions. The electromagnetic power is highly confined to the metal surface, which gives rise to an enhanced near-field mode as net effect.

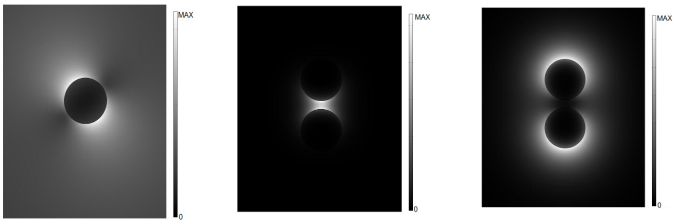
On regarding subwavelength dimensions, the first order correction to the dipole problem retained in Mie expansion can appropriately determine the SPP excited modes. Within this assumption, the electric fields inside and outside a metallic sphere of radius *r* immersed in a dielectric medium are expressed by [7]:

$$\begin{aligned} \overline{E}_{i(m)} &= \frac{3\varepsilon_m}{\varepsilon_d + \varepsilon_m}\overline{E} \\ \overline{E}_{o(m)} &= \frac{1}{4\pi\varepsilon_0\varepsilon_m}\left\{ \begin{aligned} &\left[k^2\left(\overline{n}\times\overline{p}\right)\times\overline{n}\right]\frac{e^{jkr}}{r} + \\ &\left[3\overline{n}\left(\overline{n}\cdot\overline{p}\right)-\overline{p}\right]\left(\frac{1}{r^3}-\frac{jk}{r^2}\right)e^{jkr} \end{aligned} \right\} \end{aligned} \tag{1}$$

k is the wavenumber, $\overline{n}$ is the outwardly surface normal unitary vector and ε_0, ε_m and ε_d are the permittivities of air, metal and insulator, respectively. $\overline{p}$ is the induced dipole moment. The subscripts i and o indicates the fields inside and outside the metallic particle. $\overline{E}$ is the incident electric field.

It is stated in (1) that the SPP modes at the boundaries of a subwavelength metallic spheroidal particle are equivalent to the reactive and radiative fields of a time-oscillating electric dipole.

In this work, we use the above theory as a starting point to investigate the SPP modes excited in a Fabry-Perot cavity containing metallic nanodisks. As depicted in Fig. 1, the incidence of a TM plane wave in 632 nm excites a SPP mode with typical dipolar field distribution at the boundaries of a silver nanodisk of radius r=100 nm immersed in silica. If two identical spheres are approximated to each other at distances smaller than the radius, a coupled plasmon mode can be reached. The coupling may yield an enhanced near field at the space between the nanodisks or along the total structure periphery depending on the nature of the interaction: attractive (Fig. 1(b)) or repulsive (Fig. 1(c)).



(a) (b) (c)

Fig. 1. (a) Electric field intensity of the SPP mode excited in a silver nanodisk under a TM plane wave in 632 nm. Coupled SPP modes with attractive (b) or repulsive (c) interaction.

Fig. 2(a) shows the Fabry-Perot cavity built with the two silver nanoparticles (grey color) depicted previously. The thickness of the cavity is L=500 nm and the nanodisks are distant from each other by 50 nm. The clad (blue color) in which the particles are immersed is silica glass (n=1.45) and the overall cavity is surrounded by air.

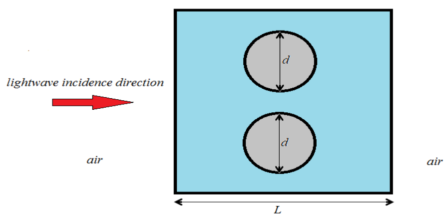


Fig. 2. Geometry of the plasmonic Fabry-Perot nanocavity.

Whether a lightwave normally incides onto the cavity, reflectance deeps arises in the optical domain. Fig. 3 shows that such resonances are dependent on the radius r of the metallic particles. One can obtain sharply resonant deeps and red-shift them upon decreasing r, indicating that the cavity may be tailored to operate from the near infrared to the visible spectrum.

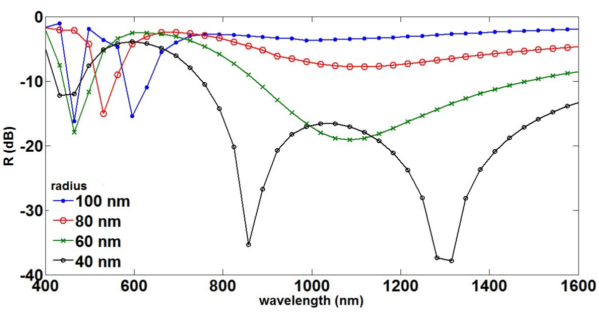


Fig. 3. Reflectance spectrum obtained for distinct particle radius.

According to Fig. 1(b)-(c), the high field intensity at the vicinity of the metallic particles suggests that the structure is also reliable to actuate as a nano-optical sensor. The corresponding sensitivity, which was estimated in terms of the reflectance deep power (in dB), reaches nearly -16 dB/RIU within the refractive index of the clad varying from 1.45 up to 1.50, which is typically the values for specimens used in biochemical industry (Fig. 4). Due to the local field enhancement in a rather narrow area, the cavity allows detecting diminute quantities of such composites, which means a further degree in the resolution level of optical sensing platforms.

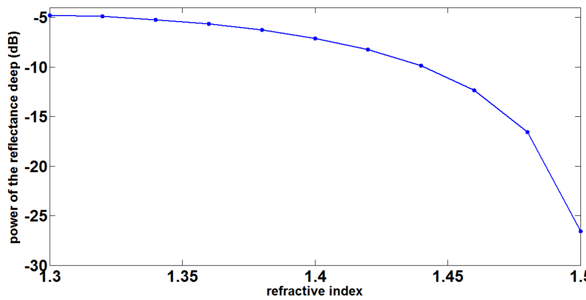


Fig. 4. Dependence of the reflectance deep power on the refractive index of the clad.

III. CONCLUSIONS

This work reports the feasibility to use plasmonic effects for compacting optical devices at subwavelength scales. It is addressed that a Fabry-Perot nanocavity composed by silver nanodisks surrounded by silica glass offers attractive features to be applied as a building block for implementing nano-optical filters. Moreover, accompanying the current trends in optical sensors, our results indicates that the same structure provides high sensitivity with a ultrathin effective sensing area for biochemical composites, which is expected to be an optimizing component for a broader variety of optical sensors, as those based on coated optical fibers and fiber tips.

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