Evanescent Excitation of Plasmonic Nanodisks using Hybrid Guided Wave Silicon Nitride Structures

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Abstract: We propose a hybrid scheme in which light is coupled into gold nanodisks from a silicon nitride waveguide or travelling wave resonator. Large field enhancements in the vicinity of the nanodisk resonator can be achieved.

OCIS codes: (130.3130) Integrated optics materials; (240.6680) Surface plasmons, (240.6695) Surface-enhanced Raman scattering.

1. Introduction

Plasmonic nanoparticles exhibit very large field enhancement at the localized surface plasmon resonance wavelength [1,2] and have been extensively used for nonlinear applications, especially for surface enhanced Raman spectroscopy (SERS) where a very large field enhancement is required [3]. Conventionally, metallic nanoparticles in different shapes are prepared on a substrate or in a solution and the input pump light is coupled using a lens and free space optics. In this paper, we introduce a hybrid scheme in which a planar guided wave structure such as a waveguide is used to evanescently couple light into the resonance mode of nanoparticles which are lithographically defined on top of the guided wave structure. The waveguide can be designed to efficiently couple the light into the nanoparticle resonance mode. On the other hand, the proposed hybrid scheme can be implemented in an integrated platform on a chip. This eliminates the bulky free space optics for coupling the light into plasmonic nanoparticles and brings about new potentials for a compact lab-on-a-chip sensing device where compact, low cost, and integrated devices are required.

2. Analysis and design of the hybrid structure

The schematic of the device consisting of a silicon nitride (Si_3N_4) ridge waveguide on a Silicon Dioxide (SiO_2) substrate and a gold nanodisk on top is shown in Figure 1(a). The side view is shown in Fig. 1 (b). The coupled light at the input propagates along the ridge waveguide and the evanescent tail of the waveguide mode excites the resonance mode of the plasmonic nanoparticle. The mode profile of the waveguide and the plasmonic nanodisk at the resonant wavelength of the nanodisk (λ = 652nm) are shown in Figure 1(c) for a 200nm×400nm waveguide and a gold nanodisk with a diameter of 50nm and a height of 20nm. The inset shows the amplitude of the electric field in the vicinity of the gold nanodisk, where the large field enhancement can be seen around the nanodisk. Three dimensional Finite Element Method (FEM) time harmonic analysis is used to analyze the structure.

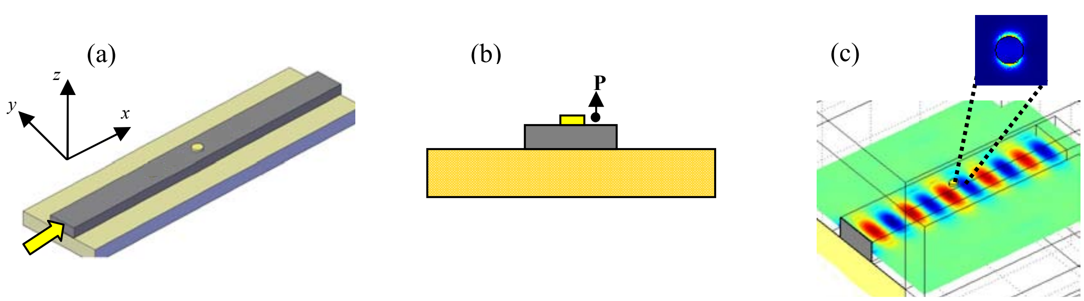

Fig. 1. (a) Schematic of Hybrid structure consisting of a Si_3N_4 ridge waveguide and a gold nanodisk on top. (b) Side view of the structure (c) Mode profile (Electric field) at a cross section in the middle of the waveguide. Inset: enlarged electric field amplitude around the nanodisk.

The electric field amplitude spectrum (normalized to the electric field of the waveguide without nanoparticle) probed at point P (1nm from the edge of the nanodisk) in Figure 1(b) is shown in Figure 2 for three different nanodisk sizes, i.e. 50nm, 60nm, and 80nm. It can be seen that the plasmon resonance wavelengths for these

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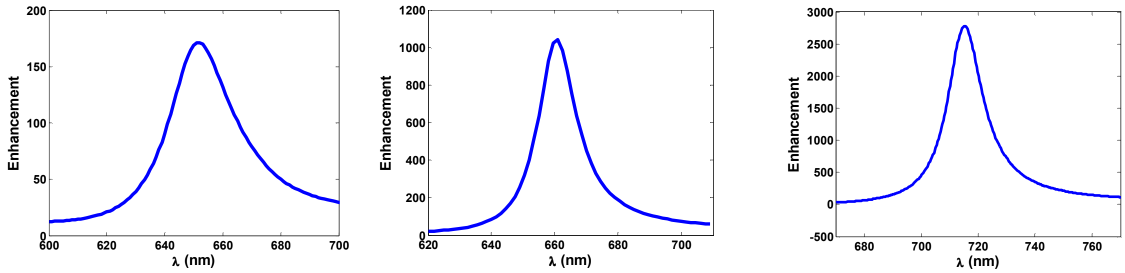
nanodisks are 652nm, 661nm, and 715.2nm respectively. The field enhancements is defined as the ratio of the electric field amplitude probed at point P to the field amplitude probed at the same location when there is no nanoparticle. It can be seen that a field enhancement of 171 fold (for 50nm nanodisk), 1043 fold (for 60nm nanodisk), and 2775 (for 80nm nanodisk) can be achieved.

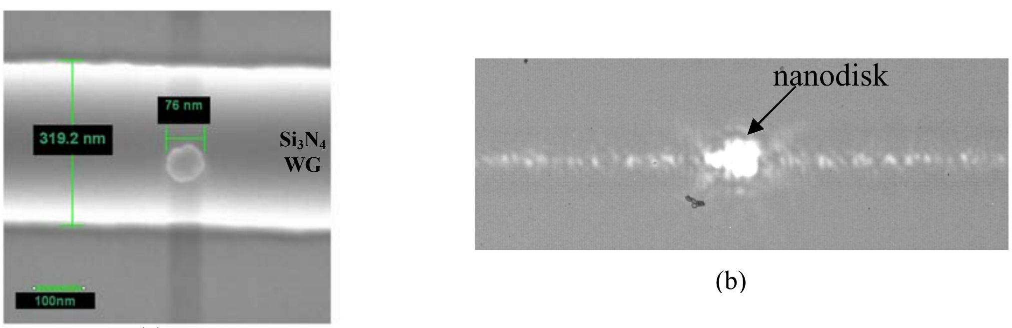


(a) (b) (c)

Fig. 2. Electric field enhancement for the field probed at point P in Figure 1 (b) which is 1nm from the edge of the nanodisk along the *y* direction and at a height of 10nm for a nanodisk with a diameter of (a) 50nm, (b) 60nm, and (c) 80nm.

3. Fabrication and Characterization

The fabrication involves two steps of nanolithography. In the first step, the substrate is cleaned and spin coated with 100nm thickness of 950 PMMA A2, then electron beam lithography (EBL) is used to define the metallic patterns. After developing the pattern, 1 nm of Ti and subsequently 20nm of Au is deposited using electron beam metal evaporator. Then a lift off process is carried out and metallic nanoparticles are left. The Ti layer is used to enhance the adhesion of Au to Si_3N_4 surface. The sample is coated with 540nm of ZEP 520A and then second step nanolithography is carried out where the patterns of the guided wave structures are aligned to nanoparticles and transferred to the resist. The pattern is then etched into Si_3N_4 layer using ICP. Then the remaining resist is stripped and the sample is cleaned in O_2 plasma. The scanning electron micrograph of the device is shown in Figure 3 (a) where the nanoparticle can be seen on top of the waveguide.



(a) (b)

Fig. 3. (a) Scanning electron micrograph of the device (top view). (b) Snapshot of the scattering from the nanoparticle on top of the waveguide

The device is characterized by coupling the light from a tunable laser source into the waveguide and measuring the top scattering using a microscope and CCD camera. Since light propagates in the core of the ridge waveguide and evanescently couples into the nanoparticle, scattering from each individual nanoparticle can be captured using this method. The dark field snapshot of the scattering from the top of the structure is shown in Figure 3 (b), where it can be seen that the nanodisk with a size of 76nm exhibits a very bright scattering near the resonance. We will demonstrate the results for various nanodisk sizes and will show that very large field enhancements can be achieved by efficiently coupling the light from the waveguide to the nanoparticles. Further details of design and experimental characterization will be discussed in the presentation. We will show that other guided wave structures such as travelling wave microresonators can be used in the proposed hybrid scheme.

4. References

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