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# Fano resonance in a symmetric waveguide system with different filled insulators

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ABSTRACT

Anti-symmetric waveguide mode is firstly excited in a symmetric plasmonic structure by filling different materials. This waveguide system consists of a rectangle cavity, which is divided into two parts by a silica strip. Simulation results show that by filling different materials in the two parts of the cavity, both of the symmetric and anti-symmetric waveguide modes can be excited in the cavity. The interaction of the different waveguide modes, gives rise to the Fano resonances. Because of different origins, these Fano resonances exhibit different dependence on the parameters of the structure and can be easily tuned. This has important applications in highly sensitive and multiparameter sensing in the complicated environments. The mechanism based on different filled materials paves a new route to exciting anti-symmetric waveguide mode, and the utilization of the anti-symmetric mode in the MIM waveguide provides a new possibility for inducing Fano resonances.

## 1. Introduction

Surface plasmon polaritons (SPPs) are electromagnetic waves propagating along the metal and dielectric interface [1]. Because of their tight spatial confinements and strong local field enhancements, they are considered as one of the most competitive candidates of the next generation information carriers [2]. A large number of devices based on SPPs have been investigated and analyzed theoretically and experimentally [3–6]. Moreover, with a variety of high-efficiency and ultra-small size SPPs generator structures [7–9] have been proposed, and confirmed by experiments, further improve the applicability of the SPPs devices. Fano resonance, a fundamental resonance mode, has been studied extensively in quantum systems, and is realized well in plasmonic nanostructures in recent years, such as nanoshells [10–12], rings [13–16], polymers [17–20] and metal-insulator-metal (MIM) waveguide [21–25]. Different from the Lorentzian resonance, the Fano resonance possesses a distinctly asymmetric line profile [26,27], which has great important applications in demultiplexing [21], plasmonic switches [28,29], sensors [25,30,31] and so on. In particular, metal insulator metal (MIM) waveguide has deep-subwavelength confinement of light, ultra-small size and can be easily manufactured by electron beam lithography, which make it more suitable for highly integrated optical circuits [21–25,30–33]. Therefore, the study of Fano resonance in MIM waveguide systems attracts more and more researchers' attention.

In general, both symmetric and anti-symmetric waveguide modes can be supported in MIM-based structures [34,35]. However, anti-symmetric mode was hardly used in SPPs devices due to its large propagation loss (propagation length ~10 nm) [34] and critical excitation condition [36]. In reference [37], we analyzed the basic characteristics of anti-symmetric mode, and proposed a symmetry broken structure, to achieve the anti-symmetric mode excitation. Later, in order to eliminate the impact of small baffle, we designed another asymmetric structure [38], and excited the anti-symmetric mode. However, these excitation of anti-symmetric modes were both acquired in symmetry breaking structures [37,38], whether a symmetric MIM-based structure can also excite the anti-symmetric waveguide mode?

In this paper, a MIM-based waveguide coupled with a rectangle cavity is proposed to generate Fano resonance. The cavity was divided into two parts by a silica strip. To excite the anti-symmetric waveguide mode, the two parts of the cavity are filled with different materials. Simulation results show that the anti-symmetric waveguide mode can be reflected back and forth off the walls of the cavity, constructing a Fabry-Perot resonator. Due to the interaction of the symmetric and anti-symmetric waveguide modes, the transmission spectra possesses a sharp asymmetrical profile. Because of different origins, these Fano resonances exhibit different dependence on the parameters of the structure, and can

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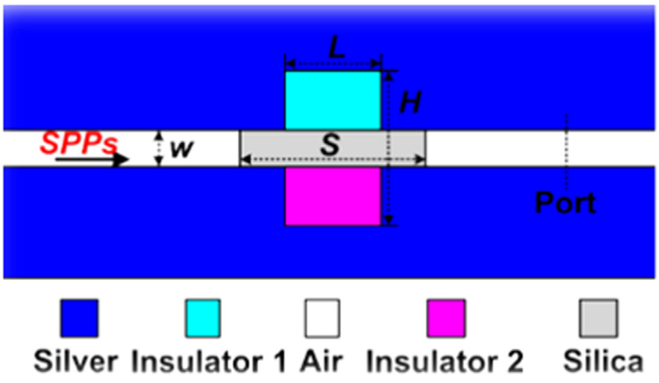

**Fig.1.** Schematic configuration and geometric parameters of the plasmonic waveguide system.

be easily tuned. Our structure provides a new way to produce anti-symmetric mode, and the utilization of the anti-symmetric mode in the MIM waveguide provides a new possibility for inducing Fano resonance.

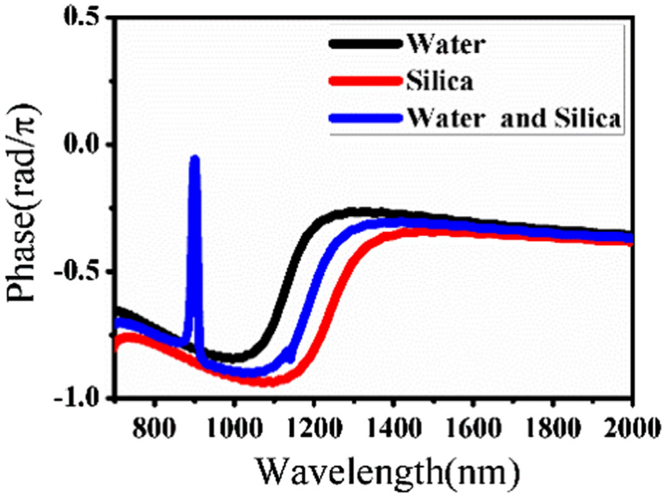

**Fig. 3.** Phase response of the system when the cavity filled with water, silica and water and silica at $L=330$ nm, $H=330$ nm.

## 2. Structure and simulations

The proposed structure is schematically shown in Fig. 1, which is composed of a MIM structure with a rectangular cavity separated by a silica strip ($\varepsilon_{sio2}=2.25$, Length $S$, denoted by the gray parts). Different materials can be filled in both sides of the silica (denoted by the green and pink parts). This system is a two-dimensional model, and the white and blue parts mean air ($\varepsilon_d=1.0$) and Ag ($\varepsilon_m$), respectively. The permittivity of Ag is described by the Drude model with ($\varepsilon_\infty$, $\omega_p$, $\gamma$)=(3.7, 9.1 eV, 0.018 eV) [25]. The length and height of the rectangular cavity are $L$ and $H$, respectively. The width of the MIM waveguide is $w$. Here, $S-L=200$ nm.

In order to investigate the optical responses of the proposed structure, its transmission spectra are numerically calculated using the finite element method (FEM) of COMSOL Multiphysics. In the simulations, the width of the MIM waveguide is set to be $w=50$ nm and is fixed throughout the paper. The length of the cavity is set to be $L=330$ nm. The two insulators are chosen to be silica ($\varepsilon_{sio2}=1.5^2$) and water ($\varepsilon_{water}=1.333^2$), and the calculated transmission spectra by varying the cavity height $H$ are displayed in Fig. 2(a)–(e). The calculated method can be seen in our previous work [37,38]. Obviously, two Fano resonances [denoted by green

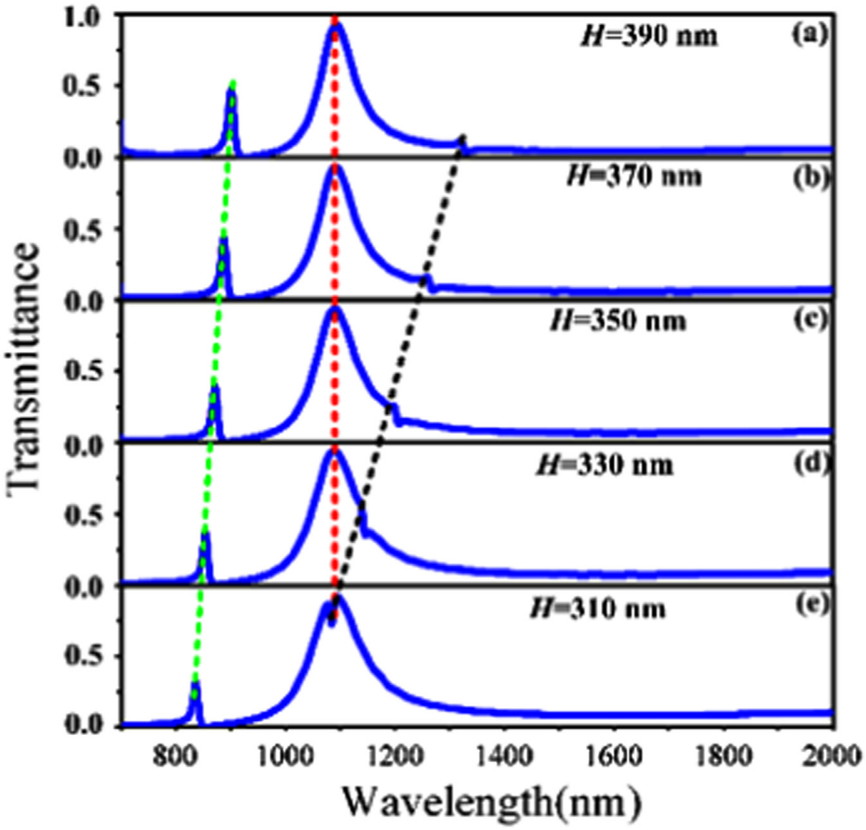

**Fig. 2.** Transmission spectra for different $H$ (a) $H=310$ nm, (b) $H=330$ nm, (c) $H=350$ nm, (d) $H=370$ nm and (e) $H=390$ nm when $L=330$ nm.