Optik 159 (2018) 254–260

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

# Plasmon-induced absorption and its applications for fast light and sensing based on double-stub resonators

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ARTICLE INFO

*Article history:*
Received 26 October 2017
Received in revised form 23 January 2018
Accepted 24 January 2018

*Keywords:*
Surface plasmon
Resonator
Plasmonic-induced absorption
Finite-difference time-domain
Fast light
Sensing

ABSTRACT

We propose a double-stub resonator (DSR) end-coupled two metal–insulator–metal waveguides. The plasmon-induced absorption (PIA) effect, in which transmission characteristics completely differ from those of a plasmon-induced transparency system, is demonstrated in the DSR system. The performance of the proposed structure is investigated using the finite-difference time-domain method. A transmission dip occurs at the former peak wavelength of the DSR, whereas two transmission peaks appear around the window. The influences of coupling distance and stub length on PIA peaks are investigated and analyzed in detail. Abnormal dispersions can be achieved with the windows based on the analysis of phase responses. Such dispersions can be used for fast light applications in a plasmonic waveguide. Furthermore, sensitivities of 560 nm/refractive index unit (RIU) and 615 nm/RIU, with a sensing medium filling in the double-stub cavity, can be achieved for the two PIA peaks. Result approximates twice as much as the sensing medium filling in one stub of the double-stub cavity. In addition, PIA also manifests in the triple-stub resonator. The results indicate the potential applications of DSR in filtering and sensing.


## 1. Introduction

Plasmon-induced transparency (PIT), which is a type of electromagnetically induced transparency (EIT) (an analogue of EIT or EIT-like), is an interesting phenomenon that occurs in a specific medium. Theoretical analyses and experimental observations have shown that an EIT-like phenomenon, known as coupled resonator-induced transparency, can also manifest in dielectric photonic resonator systems [1,2]. PIT is similar to classical EIT because the slow light effect is stronger in a transparent window and can significantly increase the interaction between light and matter. Accordingly, PIT has a long history of investigation due to the important applications to nonlinear optics and integrated photonic devices. In 2003, a waveguide-plasmon polaritons with strong coupling of photonic and electronic resonances in a metallic photonic crystal slab were demonstrated firstly [3]. An ultra-narrow band plasmon induced transparency is reported based on hybrid plasmon-waveguide systems [4,5]. Extremely narrow hybrid plasmon-guided resonances at telecomunication wavelengths are investigated [6,7]. Among different plasmonic devices, metal–insulator–metal (MIM) plasmonic waveguides are of particular interest [8–11] because they support modes with a deep wavelength scale and provide an acceptable length for surface plasmon polaritons (SPPs). MIM waveguides are important metallic nanostructures used to guide SPPs at

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https://doi.org/10.1016/j.ijleo.2018.01.085
0030-4026/

the nanoscale [12–16]. Thus, MIM waveguides can provide an interface between conventional optics and sub-wavelength electronic and optoelectronic devices. MIM waveguides based on waveguide–cavity coupling systems have been extensively studied on various platforms, including photonic crystal waveguides coupled with micro-cavity systems [17] and whispering-gallery micro-resonators [18,19] as well as self-coupled optical waveguide resonators [20,21]. The plasmonic analogue of EIT observed in nanoscale plasmonic resonator systems has been theoretically predicted and experimentally demonstrated based on the unique feature of MIM waveguides [22–25]. Recently, novel plasmon-induced absorption (PIA) effects have been reported to manifest in MIM structure [26–28]. Transmission characteristics completely differ from those of a PIT system. Such PIA system is assumed to be useful for fast light applications due to the significant abnormal dispersion at the PIA window [29,30].

This study proposes an end-coupled double-stub resonator (DSR) based on MIM waveguides. The performance of the proposed structure is analyzed and investigated using the finite-difference time-domain (FDTD) method. The PIA effect will manifest as a result of mode interference between two stub cavities. Abnormal dispersions are also observed at windows by analyzing phase responses. Furthermore, refractive index sensing characteristics with filling in one or both stubs of double-stub resonator are studied. Final, PIA in a triple-stub resonator (TSR) also is investigated in detail.

## 2. Model

Fig. 1(a) shows that the structure consists of two slits and a vertical stub resonator end-coupled two MIM waveguides. This structure is presented as a 2D model in this paper. In the model, $d$ is the width of the MIM waveguides; $w$ is the coupling distance between the vertical stub resonator and the MIM waveguides; and $L_1$ and $L_2$ indicate the length and width of the stub cavity, respectively. Refractive index of the white area is set as 1.45 (e.g. fused silica), and the medium in the blue area accounts for silver. The dispersion equation of SPPs in the MIM structure can be described as [31]:

$$\frac{\varepsilon_0 P}{\varepsilon_m k} = \frac{1-\exp(kd)}{1+\exp(kd)},$$
$$k = (\beta^2 - \varepsilon_0 k_0^2)^{1/2} \tag{1}$$
$$p = (\beta^2 - \varepsilon_m k_0^2)^{1/2}$$

where $\beta$ indicates the propagation constant of SPPs [32]; $k_0 = \frac{2\pi}{\lambda}$ is the wave number of light in air; $\lambda$ is the wavelength of incident light; and $\varepsilon_0$ and $\varepsilon_m$ account for the dielectric constant of the insulator and the silver, respectively. The frequency-dependent complex relative permittivity of silver is characterized by the Drude model [33] as follows:

$$\varepsilon_m = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\gamma\omega}, \tag{2}$$

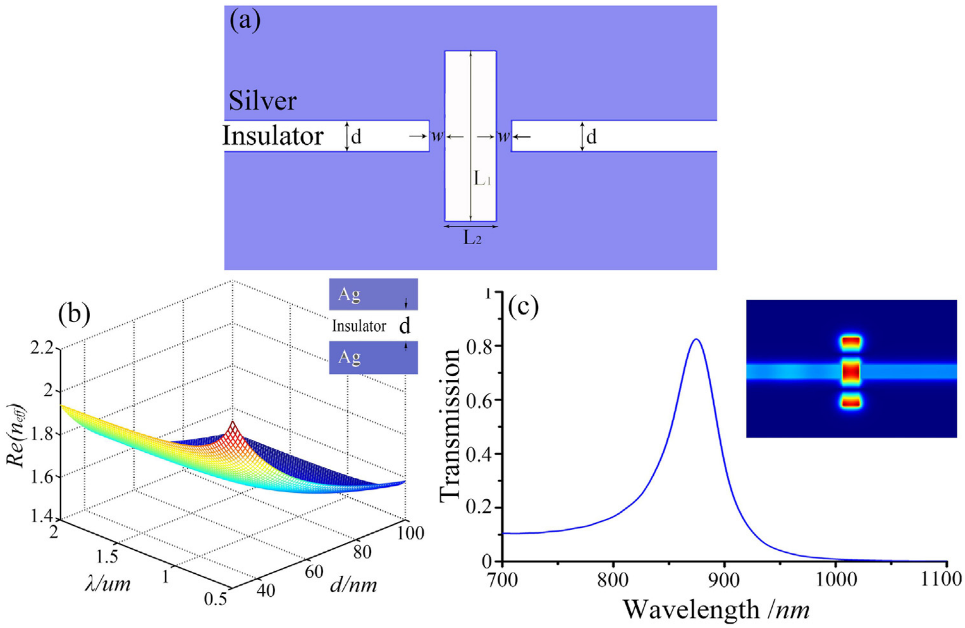


**Fig. 1.** (a) Structure schematic of single stub resonator; (b) Dependence of$Re(n_{eff})$ of MIM structure on the wavelength of incident light and width $d$; (c) Transmission spectrum of single stub resonator, and the magnetic field distributions of resonant peak at 875 nm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).