



Tunable nonreciprocal transmission system based on MIM waveguide with Kerr nonlinear material

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ABSTRACT

A novel nonreciprocal MIM waveguide with Kerr nonlinear material in near-infrared region is proposed and the corresponding transmission characteristics are investigated. In the proposed MIM waveguide, a transmission contrast ratio up to 49.2 dB can be achieved between forward and backward transmission by using the finite-difference time-domain (FDTD) method, revealing an excellent nonreciprocal effect. Moreover, the proposed nonreciprocal MIM waveguide can also be flexibly controlled as forward transmission or backward transmission at different wavelengths. Therefore, our results can offer a new possibility and important application in highly integrated optical circuits.

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1. Introduction

Recently, plasmonic devices, based on surface plasmons (SPs) propagating at metal–insulator interfaces, have shown great potential to guide and manipulate light by metallic nanostructures at deep sub-wavelength scales [1]. Among these metallic nanostructures, the metal–insulator–metal (MIM) waveguide can confine SPs in a much smaller space [2,3] and is also simple and easy to be fabricated. Thus, many MIM-based SPs devices have been motivated extensive studied, such as optical diodes, filters, couplers, splitters, and nano lens [4–22].

In particular, among these devices, the MIM-based optical diodes are important and indispensable in highly integrated optical circuits. Similar to electronic diodes, optical diodes are spatially nonreciprocal devices that provide unidirectional transmission of optical signals for specific wavelengths. Recently, several MIM-based optical diodes have been demonstrated. Hu et al. [4] theoretically studied a low-power SPs all-optical diode based on the MIM waveguide, which can achieve a high transmission contrast between forward and backward transmission. By asymmetrically inserting three coupled cavities into the MIM waveguide, Fan et al. [5] proposed a tunable plasmonic optical diode based on Fano resonance in a nonlinear plasmonic system. Gong et al. [6] demonstrated a structure of two dimensional T-shaped MIM waveguide with dual-nanocavity. It is shown that the proposed structure can effectively switch the SPs propagation between the left and right waveguides in the desired direction.

In this paper, we propose and investigate a novel nonreciprocal MIM waveguide with Kerr nonlinear material. By using the finite-difference time-domain (FDTD) method, its transmission characteristics are extensively investigated. Moreover, the results show that our structure can work as a tunable optical diode with high transmission contrast between forward and backward transmission by combining the nonreciprocal nonlinear response. Furthermore, the performance of proposed structure can be effectively tuned as forward transmission or backward transmission at different wavelengths. Thus, our tunable optical diode based on the MIM waveguide can be greatly beneficial in highly integrated optical circuits.

2. Structures and model

The schematic for the nonreciprocal MIM waveguide is illustrated in Fig. 1, consisting of two metal layers and sandwiched multiple insulator units structured by alternately stacking two insulators with different refractive indices, which can be briefly denoted by $(AB)^2 (AC_1) (AC_2) (AB)^3$. Here, A and B stand for the two insulators with different refractive indices [i.e., $n_A = 3.2$ (zircon) and $n_B = 1.6$ (boron oxide)]. Meanwhile, C represents the Kerr nonlinear material. Moreover, the permittivity of the Kerr nonlinear material depends on the intensity of the electric field, which is described by $\epsilon_k = \epsilon_l + \chi^{(3)} |E|^2$. Here, $\epsilon_l = 2.31$ is the linear permittivity and $\chi^{(3)}$ is the third-order nonlinear susceptibility. In this paper, we choose $\epsilon_l = 2.31$ and $\chi^{(3)} = 9 \times 10^{-12} \text{ m}^2/\text{V}^2$ [23,24]. In each super unit, the lengths (x direction)

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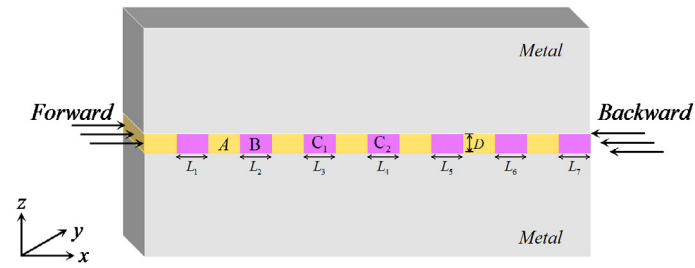


Fig. 1. Schematic diagram of the nonreciprocal MIM waveguide.

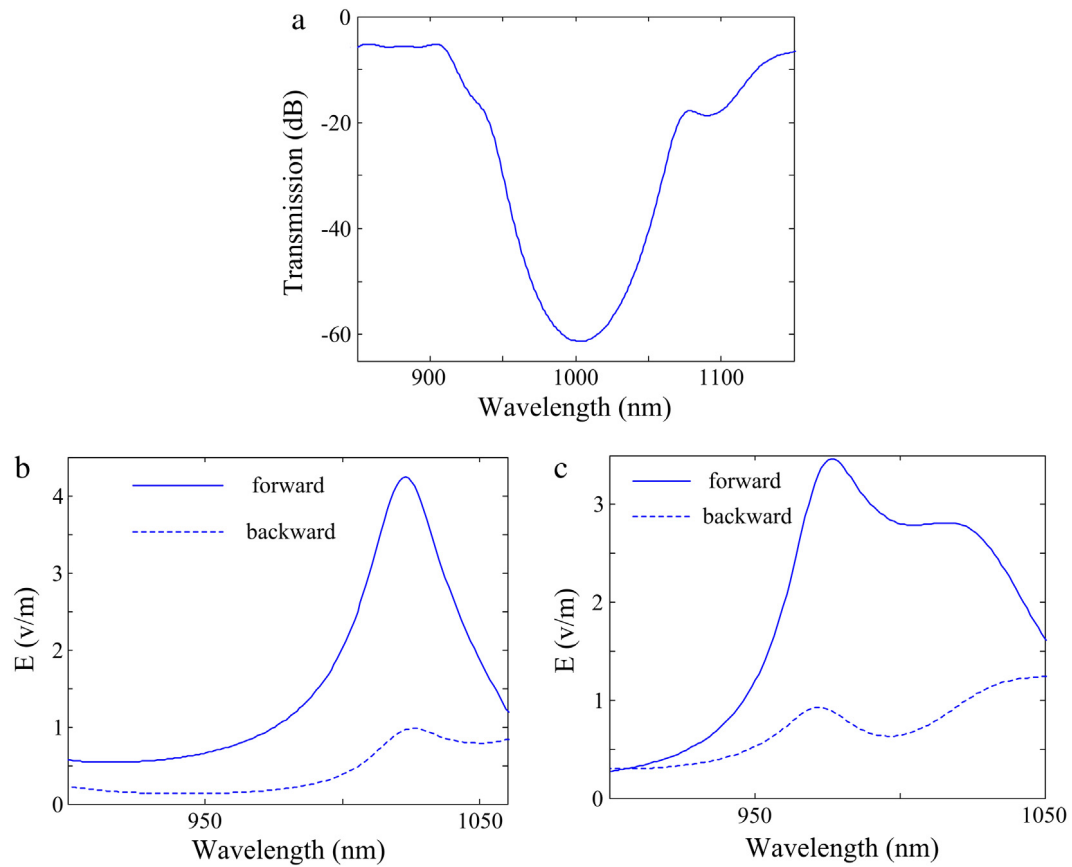


Fig. 2. (a) Transmission response of the proposed nonreciprocal MIM waveguide. Strength of the localized electric field inside the nonlinear material cavity C_1 (b) and C_2 (c) as a function of wavelength under forward (solid line) and backward (dashed line) incidence.

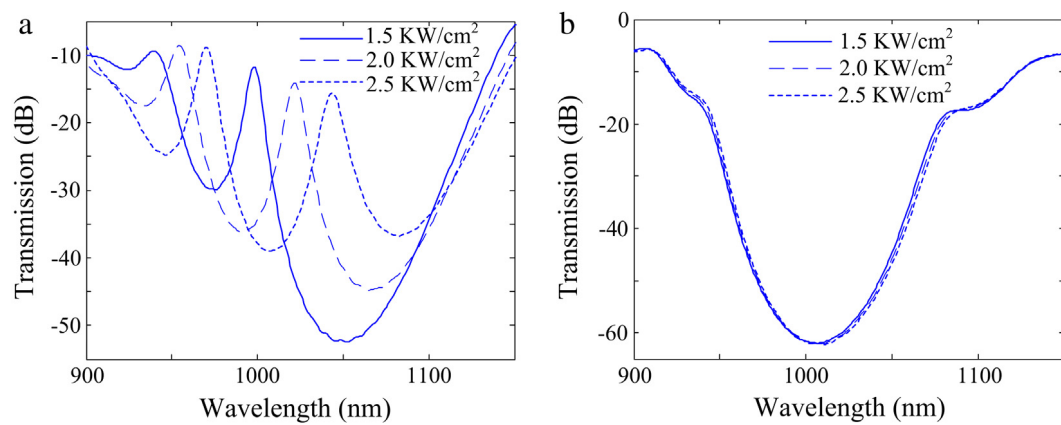


Fig. 3. (a) Forward transmission responses of the proposed nonreciprocal MIM waveguide under different input intensities. (b) backward transmission responses of the proposed MIM waveguide under different input intensities.

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