IRANIAN JOURNAL OF
PHYSICS
RESEARCH

Iranian Journal of Physics Research, Vol. 14, No. 3, 2014

Research note

Low loss coupler to interface silicon waveguide and hybrid plasmonic waveguide

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(Received 7 November 2013 , in final from 29 August 2014)

Abstract

A metallic coupler is proposed to interface a silicon on insulator (SOI) waveguide with a narrow hybrid plasmonic waveguide (200× 200 nm). The device operation is investigated and optimized to attain the best tradeoff between the mode confinement and the propagation loss. Calculations reveal that a high confinement and low loss of the energy is achieved from a silicon slab waveguide into the dielectric slot of area 200×200 nm^2 and a coupling efficiency of 70% (0.8 dB) at the 1.55 μm telecommunication wavelength can be achieved.

Keywords: surface plasmon, waveguide, coupler

1. Introduction

Guiding and confining of light waves at the sub-wavelength scale beyond the diffraction limit can be realized at optical frequencies by exploiting surface Plasmon polaritons (SPPs) [1]. Numerous kinds of plasmonic waveguides have been proposed that include metallic strips and nano-wires [2], metallic suspended waveguides [3], metallic grooves [4], and dielectric loaded plasmonic waveguides [5]. Among various SPP waveguides, silicon based plasmonic waveguides have attracted particular attention because of some unique properties such as their high compatibility with the standard CMOS technology and potential for further on-chip integration [6].

Plasmonic waveguides are important in achieving miniaturized devices. Among them, silver (Ag) waveguides is considered as an excellent one due to high SPP excitation efficiency and low propagation dissipation. However, the propagation loss of plasmonic waveguides is still a concern. One method for loss reduction is to use a low-index strip sandwiched between a high-index nano-wire and metal film [7]. The hybrid plasmonic mode is formed with more confinement and low propagation loss for a broad range of optical wavelength.

One serious problem is that, a large mode mismatch among different waveguides causes coupling losses. Thus the device with various dimensions encounter poor coupling efficiency in to the waveguide, therefore it is highly desired to investigate coupling issue among different components. Various coupling devices have been investigated. For example, a taper coupler has been investigated both theoretically and experimentally for conductor gap silicon waveguide [8]. There was also an experimental demonstration of the coupling between a silicon waveguide and a dielectric loaded plasmonic waveguide through a long silicon taper [9]. The directional coupler with plasmonic slot waveguides has been investigated for some particular structures [10]. For dielectric loaded surface Plasmon polariton (DLAPP) waveguides, a dielectric coupling using a single-mode optical fiber has been demonstrated [11].

The aim of this paper is to conduct a numerical investigation of a metallic taper coupler to transfer a photonic mode in silicon waveguide in to plasmonic mode. To calculate the propagation constant of the guided modes, we use finite difference time domain (FDTD) method.

2. Coupler

The coupler structure is shown in figure. 1(a). It consist of a low refractive index SiO_2 –gap strip (n=1.44 at λ=1.55μm) sandwiched between a rectangular high refractive index Si- nano wire (n=3.48) and a silver film (n=0.145+11.359i [12]). The slot width between Si-nano wire and Ag film is considered 40 nm and 30 nm. The

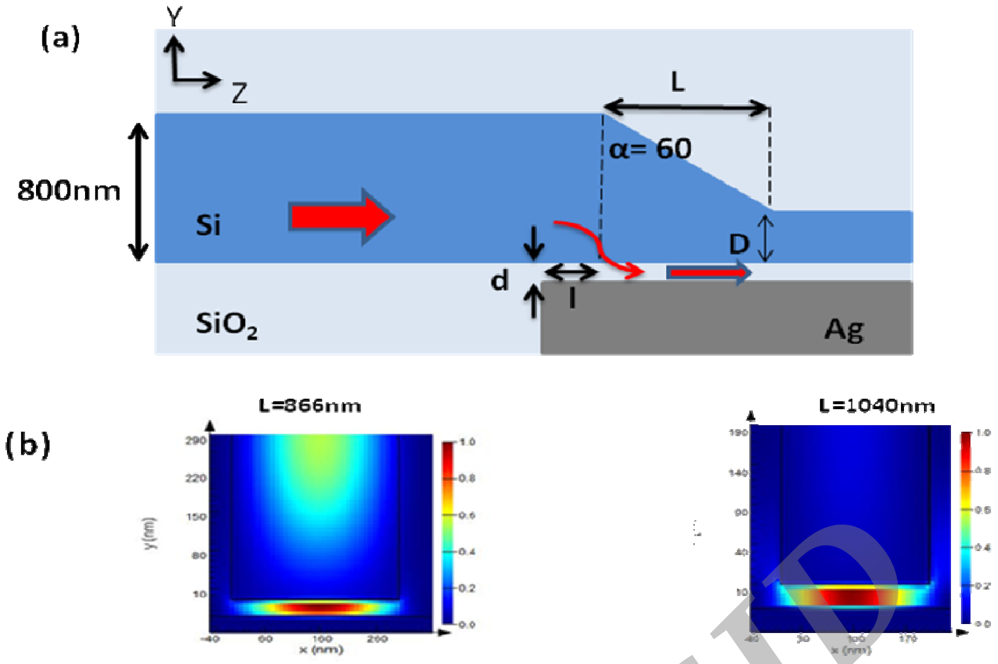

Figure 1. (a) Schematic diagram for the dielectric to hybrid plasmonic waveguide. (b) The electric-field distribution in the cross section XY-plane at two cross sections of L=1040 nm and 866 nm when α is set as 60^0 and d=40 nm and l=300 nm when λ=1550 nm.

thickness of silver film is selected larger than 100nm. The propagation constants of the structure, including the effective index, propagation loss and confinement factor are calculated by solving the eigen modes of the structure at a given wavelength λ using full vectorial finite difference method.

We note that the geometrical dimensions have a significant impact on the propagation characteristics of the guided modes. Figure 1 (b) shows the electric field distributions at two different cross sections of L=1040 nm and 866 nm when α is set as 60^0 and d=40 nm and l=300 nm when λ=1550 nm.

The coupling loss is caused by the interface reflection and the mismatch between the dielectric and hybrid plasmonic waveguide. Our numerical simulations shows that the interface reflection is less than 6%, therefore the main loss is caused by mode mismatch.

Our FDTD calculation shows that the coupling efficiency for direct coupler, when l=0 and for taper length L=0 is about 20%. In our structure, we have used the tapered configuration to couple the power from the silicon waveguide to hybrid plasmonic waveguide. However, one can couple the power without a taper waveguide, but this type of coupling is not efficient due to strong mode mismatch between photonic and plasmonic mode, More details of this effect can be seen in [13, 14]. Figure 2 shows the coupling efficiency and propagation loss as a function of taper length for two slot thickness values.

From figure 2 it can be seen for shorter taper lengths a poor confinement is observed due to back reflections associated with steep tapered. Most efficient coupling is observed when taper length is about 1 μm and slot thickness value d=40 nm. Further increase in the taper length makes the coupling efficiency decrease, which is due to the attenuation of strip losses along the taper length. This is an important observation from the fabrication point of view. With the state-of-the-art CMOS facilities, the fabrication of a lateral taper is much easier than the fabrication of a vertical taper. This is because fabricating vertical tapers demand gray-scale lithography or variation e-beam doses, which is otherwise difficult to control.

It would be interesting to investigate the effect of Ag film extension along the tapered region of the coupler. If Ag film is not extended along the tapered region, no improvement in the power confinement is observed. Figure 3 shows the dependence of Ag metal on coupling efficiency when the tapered length is set as 1μm.

From figure 3, it can be seen that even a very short Ag extension into silicon waveguide can improve significantly the coupling efficiency and the poor confinement is observed when the structure is used without Ag film over the coupler taper region (l=0). When l increases, the coupling efficiency increases rapidly from 20% to 70%, and most efficient coupling is observed for l=300 nm. When l increases further, the coupling efficiency starts to decrease.

3. Conclusion

In conclusion, a highly-efficient and compact coupler has been proposed based on a plasmonic taper waveguide which can be used for coupling between a standard silicon on insulator (SOI) waveguide and a narrow hybrid plasmonic waveguide (200×200). The structure has been optimized to achive the best

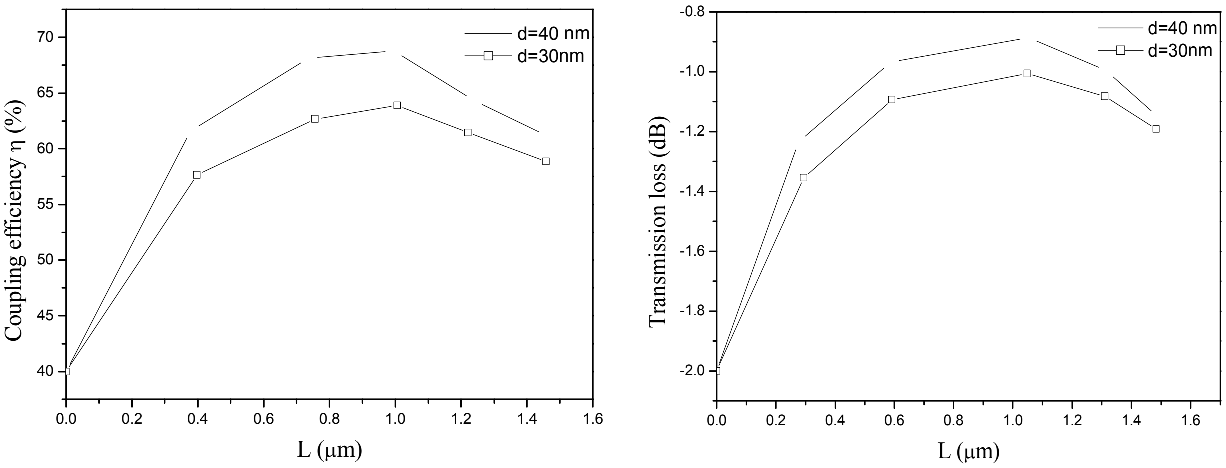

Figure 2. (a) Coupling efficiency (b) Transmission loss as a function of taper length when *α* is set as 60^0 and *l*=300nm for two slot thickness values of *d*=30 nm and *d*=40 nm.

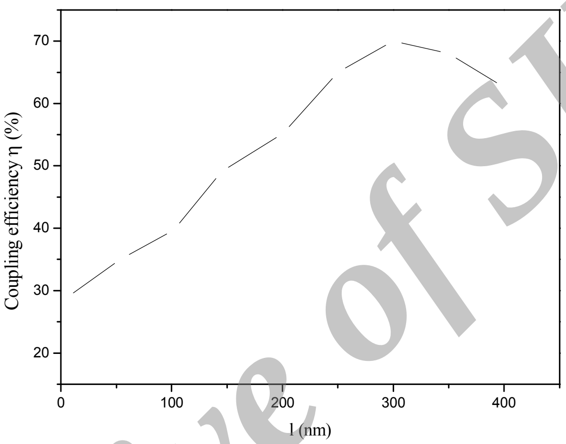

Figure 3. The dependence of Ag metal extension along the tapered region (*l*), on coupling efficiency, when the tapered length is set as *L*=1 μm and *d*=40 nm.

confinement and reasonable propagation loss. The designed coupler can take advantage of both the low-loss nature of silicon waveguide and the sub-wavelength confinement of plasmonic waveguides. The proposed device has potential applications in nano-scale electronic integrated circuits for data communication and data processing.

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