



Integration of plasmonics into nanoelectronic circuits

Ping Bai^{*}, Hong Son Chu, Mingxia Gu, Oka Kurniawan, Erping Li

Computational Electronics and Photonics, Institute of High Performance Computing, 1 Fusionopolis Way #16-16 Connexis, Singapore 138632, Singapore

ARTICLE INFO

Keywords:

Plasmonics
Subwavelength waveguide
Plasmonic converter
Nanoantenna

ABSTRACT

Plasmonic waveguides are proposed to transmit information optically from one electronic component to another in integrated nanoelectronic circuits. A metal–insulator–metal (MIM) plasmonic waveguide, rather than a traditional dielectric waveguide or an electric wire, is used for data transmission. The MIM plasmonic waveguide confines plasmonic (electromagnetic) waves to a dielectric slot with a cross-section of 50 nm × 50 nm, and propagates them close to the speed of light. Two nanorods that form a nanoantenna are employed to receive the optical power from the waveguide, and localize as well as concentrate the received power in the proximity around the two nanorods. The localized optical power is converted to electric signals by a nanoscale plasmonics-to-electronics converter, which has a nanosized active volume and a bandwidth of up to 1 THz. Both the plasmonic waveguide and the converter have nanoscale dimensions comparable to those of modern nanoelectronic counterparts. The proposed method could be used to improve the performance of existing nanoelectronic systems by exploiting the strength of optics.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Integration of optical and electronic circuits leads to remarkable benefit in data transmission and processing by combining the advantages of the large bandwidth of optics and the compactness of electronics [1]. Continuous reduction in size of electronic components has resulted in better, faster, and smaller electronic everyday products for society. However, interconnects on a chip have become a bottle-neck preventing further improvement of the performance of electronic products due to the increasing signal delay and power consumption associated with the interconnects [2]. Optical interconnects are superior to the electronic interconnects by virtue of their large operational bandwidth, and huge data transmission capability. However, the dimensions of a traditional optical device are fundamentally limited by the law of diffraction. The large mismatch in size prevents integrating optics with electronics for a better performance.

Plasmonics allows manipulating the flow of light in a nanometer scale well below the diffraction limit, by exploiting the unique optical properties of metallic structures [3]. Much attention has been attracted to the study of plasmonics, from the fundamentals to applications in recent years [4–8], including nanoscale optical waveguides [4], perfect lenses, subwavelength lithography, highly sensitive biosensors and ultra-fast modulators [5]. Plasmonics could provide a new way for optical data transmission near light speed requiring a size well below the

free-space wavelength, with efficient power delivery. Plasmonics will be the potential technology to achieve information transmission between nanoscale electronic devices at optical frequencies, and bridge the gap between photonics and electronics in the nanoscale regime [9].

We explore the convergence of optics and electronics by using plasmonic waveguides for on-chip nanoscale optical interconnects. To optically transmit data between electronic devices, we need to develop a number of plasmonic devices, including plasmonic sources, modulators, waveguides, switches, filters and detectors. As a first step, we focus on the waveguide and detector. We use plasmonic subwavelength waveguides as optical interconnects. The plasmonic waves carry information, and propagate along the waveguide close to the speed of light. At the end of the waveguide, the plasmonic waves are converted into electronic signals through a plasmonic converter. Fig. 1 shows a schematic diagram of a metal–insulator–metal subwavelength waveguide coupled to a plasmonic converter.

2. Subwavelength waveguides

The major challenge for the on-chip optical data transmission is to confine the electromagnetic waves in a waveguide of nanometer size compatible with that of the electric components. Previous studies show that plasmonics could be confined in, and propagated along, a waveguide with dimensions below one-tenth of the free-space wavelength [4]. Different plasmonic waveguides have been studied, including metal–insulator–metal (MIM),

^{*} Corresponding author. Tel.: +65 64191242; fax: +65 64635176.
E-mail address: baiping@ihpc.a-star.edu.sg (P. Bai).

insulator-metal-insulator, and dielectric-loaded structures. The MIM waveguide is most suitable for the on-chip data transmission as it provides a better trade-off between the lateral confinement and the propagation loss [10].

For the purpose of this paper we have considered a subwavelength MIM waveguide. Fig. 2a shows the schematics of the MIM waveguide, which consists of a dielectric slot between two thin metallic films. The width and the thickness of each metal film are $1\ \mu\text{m}$ and $50\ \text{nm}$, respectively. The gap between the two metal films is $50\ \text{nm}$. Fig. 2b shows the electric field propagating along the Ag-air-Ag waveguide at a free-space wavelength of $1.55\ \mu\text{m}$, simulated with CST Microwave Studio [11]. Plasmonic waves are well confined within the nanoscale slot. The distribution of the electric field in the xz -plane across the center of the waveguide is shown in Fig. 2c. We notice that the magnitude of the electric field decreases along the waveguide. Fig. 3 shows the relationship between the propagation distance and the wavelength. It shows that the propagation distance increases when the free-space wavelength of the input field is increased. This can be attributed to the fact that the metal becomes less lossy at lower frequency. That is why the metal can be treated as a perfect conductor in microwave regime. Therefore, shorter free-space wavelength corresponds to a larger propagation loss.

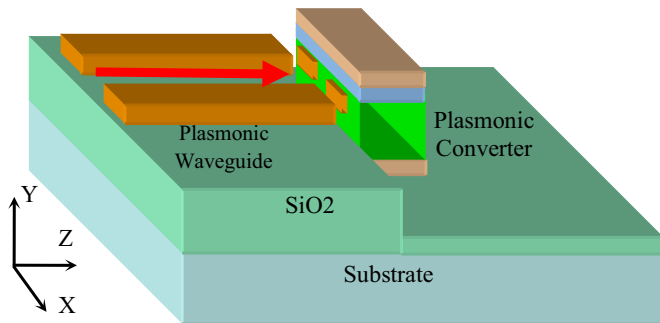


Fig. 1. Schematic illustration shows plasmonic waves propagating along a metal-insulator-metal subwavelength waveguide and detected by a plasmonics-to-electronics converter.

The length of an on-chip interconnect can range from sub-micrometers (local interconnects) to centimeters (global interconnects) in an advanced electronic chip. However, the MIM plasmonic waveguide is very lossy due to high absorption of light in the optical frequency regime. The propagation distance in the MIM waveguide can only reach a distance of deca-micrometers with the field being reasonably confined. The performance of existing plasmonic waveguides is not good enough for on-chip interconnect applications yet. There is urgent need to increase the propagation distance of plasmonic waveguides while maintain a high confinement in order to integrate them into semiconductor-based electronic circuits. Fortunately, studies on novel materials, such as gain materials, plasmonic metamaterials and epsilon-near-zero materials, and on novel structures have shown a very promising future for the implementation of subwavelength waveguides with ultra-low propagation loss [8].

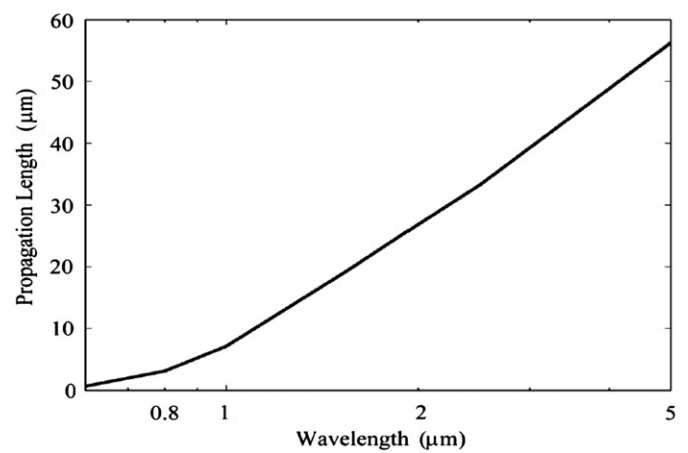


Fig. 3. Propagation distance of the Ag-air-Ag waveguide (slot cross-section of $50\ \text{nm}$ by $50\ \text{nm}$) as a function of free-space wavelength.

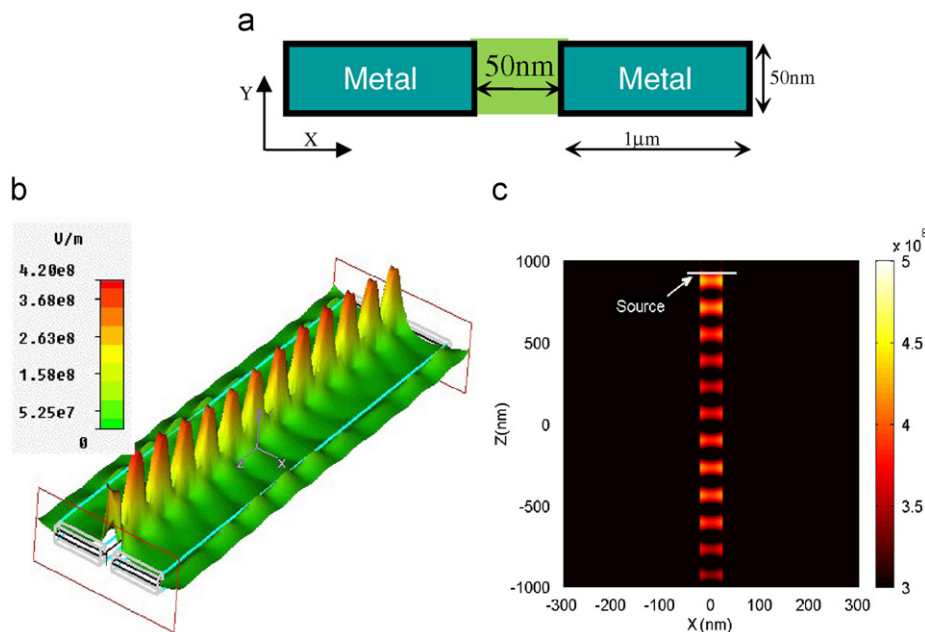


Fig. 2. Plasmonic waves propagating along an MIM waveguide: (a) 2-D illustration of the MIM waveguide, (b) 3-D electric fields propagating along the Ag-air-Ag waveguide with a cross-section of $50\ \text{nm} \times 50\ \text{nm}$ and at a free-space wavelength of $1.55\ \mu\text{m}$ and (c) the distribution of the electric fields in the xz -plane across the center of the waveguide.

Download English Version:

<https://daneshyari.com/en/article/1812939>

Download Persian Version:

<https://daneshyari.com/article/1812939>

[Daneshyari.com](https://daneshyari.com)