Nano Scale Disruptive Silicon-Plasmonic Platform for Chip-to-Chip Interconnection

Decision on plasmonic waveguide couplers with less than 3 dB coupling loss

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List of Partners concerned

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Deliverable Responsible

Organization: Karlsruhe Institute of Technology
Contact Person: Argishti Melikyan
Address: Institute of Microstructure Technology
Hermann-von-Helmholtz-Platz 1,
76344 Eggenstein-Leopoldshafen
Germany
Phone: +49 (0)721 – 608 42496
E-mail: argishti.melikyan@kit.edu

Executive Summary

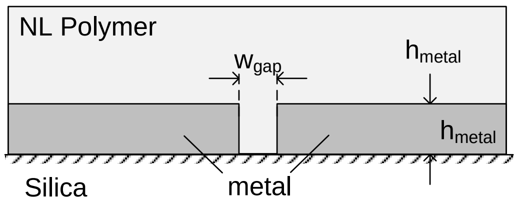
This document shall incorporate (all) rules procedures concerning the technical and administrative management of the project and is therefore to be updated on a regular basis. Please look at www.navolchi.eu regularly for the latest version.

Change Records

Version	Date	Changes	Author
0.1 (draft)	2013-03-10	Start	Argishti Melikyan
1 (submission)	2013-03-13		Argishti Melikyan

Introduction

NAVOLCHI milestone "*Decision on an optimized structure for plasmonic modulator*" shows that the figure of merit of the modulator increases with reducing the size of the metal slot. Based on the above milestone, the targeting dimensions for metal slot structures are



Slot opening (w_{gap}) - 50-100nm
Metal thickness (h_{metal}) - 100-200nm

Figure 1 Vertical metal structure studied in MS9 and the targeted dimensions.

Technological challenge in fabricating such vertical slot metal structure is the large aspect ratio of the slot. It has been experimentally seen that fabricating vertical slot structure is challenging even for the slot with aspect ratio of 1:1. Therefore, in addition to vertical slots we have also studied horizontal metal slot structures because of it several advantageous over vertical slot structure which is summarized in Table 1.

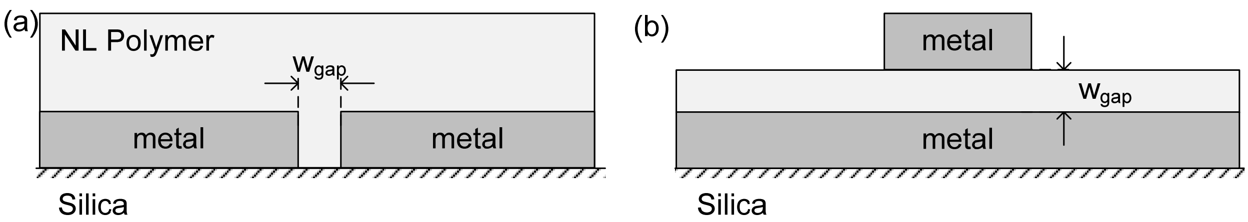


Table 1 Summary of advantages and disadvantages of two metal slot structures

Vertical Slot Structure		**Horizontal Slot Structure**	
Easy coupling	☺	Difficult coupling	☹
Easy fabrication	☹	Easy fabrication	☺
Strong roughness	☹	Low roughness	☺

The bottleneck of horizontal metal slot structure is the difficulty of excitation of SPP at such a structure. The horizontal metal slot structure sustains fundamental SPP mode having a dominant electric field perpendicular to the substrate i.e. being orthogonal to the SPP mode at vertical slot structure. Consequently, SPP at horizontal slot structure can be excited with the quasi-TM mode of silicon nanowire waveguide unlike to the SPP at vertical slot structure which has been excited employing quasi –TE mode of silicon nanowire and metal taper couplers (*studied and reported in NAVOLCHI Milestone 25*). Therefore, the coupling scheme has to be developed for excitation of SPP at horizontal metal slot structure.

Design

Here we propose and investigate directional coupling configuration between silicon nanowire and horizontal metal structure. In this coupling scheme, the quasi-TM photonic mode of silicon nanowire is brought into phase matching with the SPP at the horizontal metal slot structure. Light guided through silicon nanowire then excites the SPP at horizontal metal structure at the coupling section with exact length of L. SPP then is guided at the horizontal metal structure and can be converted back to photonic mode with the identical coupler. The geometrical parameters that need to be optimized for the highest coupling efficiency are follows:

- Silicon nanowire width h_{Si}
- Silicon nanowire height w_{Si}
- The length of coupling section L
- Separation of silicon nanowire and horizontal metal structure d
- Top metal width w_{metal}

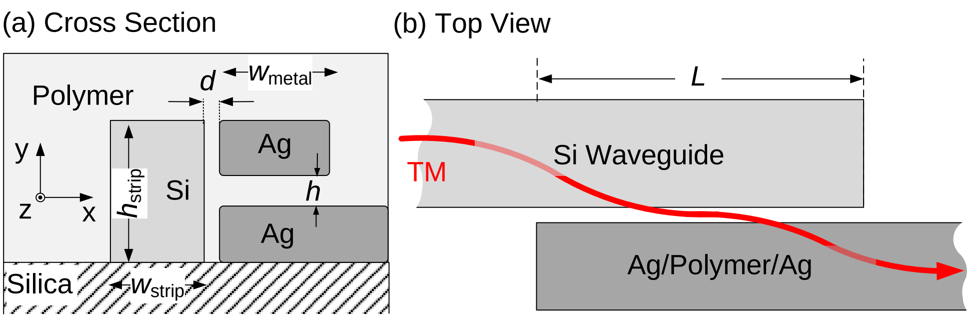


Figure 2 The coupling scheme for converting the photonic mode to SPP at horizontal slot structure. (a) The cross section of the coupling section consisting of silicon nanowire and horizontal metal slot separated with a distance d. The top view of the mode converter with the length of L. Photonic mode guided through silicon nanowire excited the SPP at the coupling section.

Methods and Results

We have used eigenmode expansion method to find the geometrical parameters leading to the highest coupling efficiency of the SPP at the horizontal slot structure. The eigenmodes at silicon nanowire, coupling sections and horizontal metal slot are simulated with COMSOL Multiphysics. The coupling efficiency of the SPP is then calculated in Matlab applying to eigenmode expansion method.

The example of the electric field distribution at the coupling section is given in Fig. 3. It can be seen that photonic mode launched from silicon nanowire waveguide can very efficiently excite the SPP at the coupler with a length of 2.4μm.

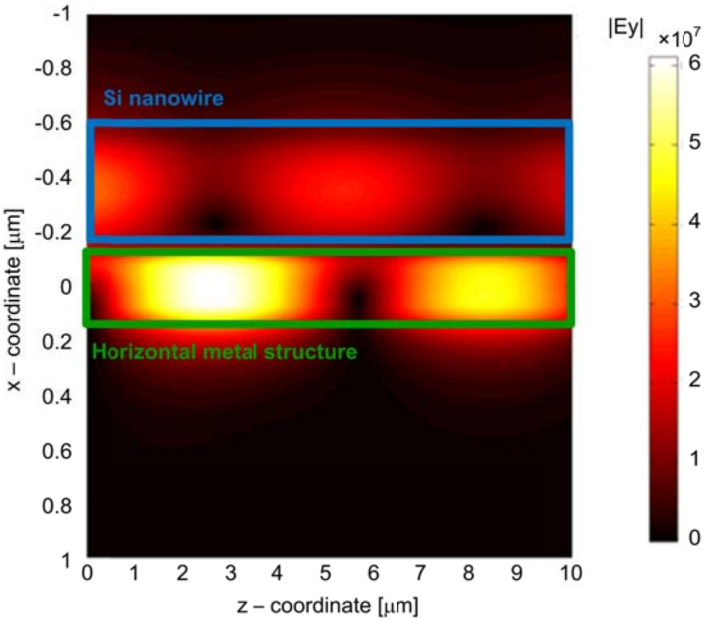


Figure 3 Electric field distribution at the x-z plane cut in the centre of the horizontal slot. Light launched from the silicon nanowire excites the SPP at the horizontal metal slot at the position of 2.5μm.

Coupling coefficient versus separation d and slot size w_{gap} are given in Fig. 4. Other geometrical parameters are fixed:

Fixed Parameter Name	**Value**
h_{strip}	340nm
w_{strip}	300nm
w_{metal}	200nm

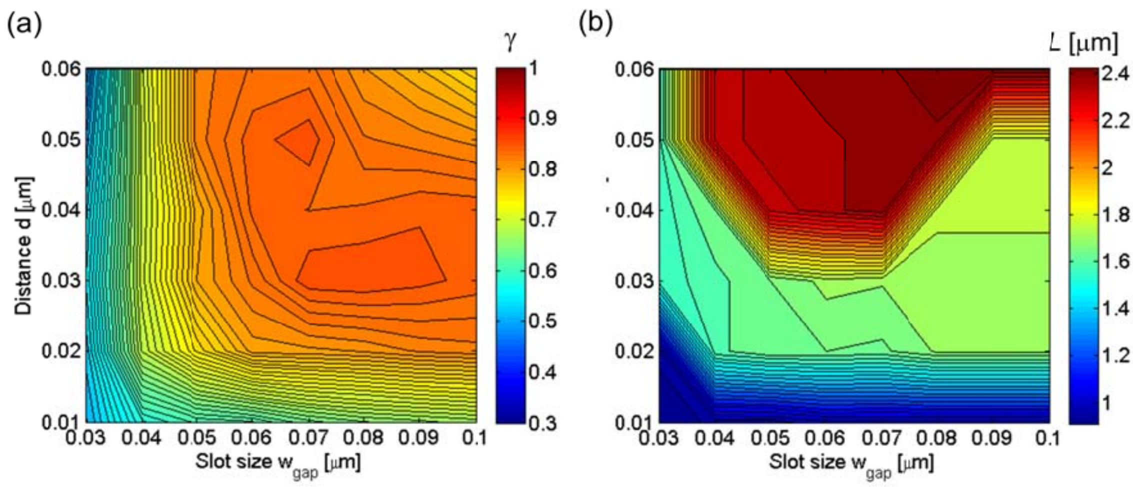


Figure 4 SPP Coupling Efficiency and the necessary coupling length *L*. (a) The coupling efficiency of the SPP for various slot size w_{gap} and distance d. SPP at the horizontal slot with a size larger than 60nm can be excited with more than 85%. (b) The length of the coupler leading to the maximum SPP excitation efficiency.

It can be seen that more than 85% coupling efficiency is possible for the metal slots larger than 60nm, see Fig. 4(a). We also calculated the necessary length of coupling section leading to the maximum SPP excitation efficiency which is given in Fig. 4(b). This coupling scheme not only provides good coupling coefficient but also is compact with maximum length of 2.4μm. Such compact couplers are necessary in order to keep the size of the modulator small.