AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Engineering Physics and Mathematics Department

Novel on-chip plasmonic devices

A ThesisSubmitted in partial fulfillment of the requirements of the degree of Master of science in Engineering Physics

Submitted by:

Aya Osama Kamal Zaki Ibrahim

B.Sc. in Electrical Engineering

(Electronics and Communications Engineering)

Ain Shams University, 2012

Supervised By

Prof. Khaled Abdelwahab Kirah
Associate Prof. Mohamed Abdel Azim Swillam

Cairo, 2017

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STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Engineering Physics.

The work included in this thesis was carried out by the author at the Engineering Physics Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis was submitted for a degree or a qualification at any other university or institution.

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Abstract

Surface plasmon polaritons (SPP) – shortly called plasmonics – have recently attracted a lot of researchers due to their potential applications in a wide range of fields including physics, biology and engineering. However, there are severe limitations to the utilization of plasmonics in practical applications due the high propagation losses of SPP. Additionally, the extremely short skin-depth of the metal used in guiding the SPP reduces the coupling efficiency between plasmonic waveguides.

In this dissertation we propose novel devices that adopt engineering mechanisms to address the drawbacks of plasmonic guided waves. Compatibility with the widely spread silicon photonic platform is also investigated. The proposed devices rely on the exceptional capabilities of plasmonics to confine light beyond the diffraction limit. Contrary to conventional dielectric waveguides, the light is concentrated inside the lower refractive index medium in plasmonic waveguide. This effect is extremely useful in applications of electro-optical modulation or sensing where the active medium is of low refractive index. Thus, we focus on these applications introducing two high performance electro-optical modulators and a gas sensor.

An electro-optical modulator based on an asymmetric hybrid plasmonic waveguide is introduced. The proposed modulator consists of two non-identical hybrid plasmonic waveguides (HPW) vertically coupled through an ultra-thin metal spacer. Each HPW has three main layers in a metal-oxide-semiconductor structure. The lower HPW employs an additional layer of conducting oxide that acts as the active material for electro-optical modulation. A detailed analysis is performed to study the supported modes in the on and off states of the modulator. It is established that the low loss symmetric super-mode guided by the modulator is easily excited by butt coupling to a standard silicon waveguide. The switching mechanism proposed is based on breaking the symmetry of the waveguide and introducing losses resulting in a high extinction ratio while keeping the insertion loss ultra-low.

A square plasmonic hybridly-coupled sensor is proposed and the effects of various parameters on the device performance are analyzed in detail. In this device, we overcome the challenge of coupling light into metal-insulator-metal (MIM) cavities and use this to obtain a compact sensor of high sensitivity. This structure offers low fabrication cost since the minimum feature size is larger than similar cavity-based sensors published prior to this work. Possible applications of this structure in temperature sensing are also investigated.

In an effort to introduce a high speed electro-optical modulator that has a small footprint, we investigated the performance of HPW bends and designed an indium-tin-oxide HPW ring modulator compatible with the complementary metal-oxide-semiconductor (CMOS) process. Unlike conventional silicon-on-insulator (SOI) ring modulators whose speed is limited by their extremely small resonance linewidth and driving capacitance, our device offers high speed operation by adopting a low quality resonator of compact size. The proposed device outperforms previously reported electro-absorption modulators and ring modulators.

Keywords:**plasmonics, waveguide, electro-optical modulator, silicon photonics.**

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