Ultra-Fast Compact Plasmonic Modulator based on Adiabatic Coupled Waveguides

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Abstract: Compact plasmonic modulator based on adiabatic coupled waveguides obtains insertion loss as low as <0.1 dB with the extinction ratio exceeding 40 dB. In addition the speed of 400 GHz with footprint of 2.7 µm² is expected. © 2018 The Author(s)
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1. Introduction
In this work, we propose an atto-joule, low-loss; high-speed plasmonic optical modulator based on tunability of three adiabatically coupled waveguides (ACW). The optical power in the middle waveguide oscillates much faster in comparison to the other waveguides leading in no significant build up due to the large detuning between nearby waveguides despite the large coupling strength [1]. TM mode injected through one of the outer waveguides propagates merely in the other outer waveguide. Figure 1(b) confirms the adiabatic coupling condition, where the center plasmonic waveguide is in “dark state”. The two identical outer waveguides are 350 nm-wide. 110 nm-wide intermediate waveguide is 50 nm away and consists of a metallic Au-pad with a gate oxide of 20 nm-thick SiO2 and an active Indium-Tin-Oxide (ITO) with the thickness of 10 nm sandwiched between them. The effective coupling strength between the two outer waveguides is $\kappa_{eff} = \kappa_{13} - (\kappa_{12} \kappa_{23})/(\Delta \beta_{21})$ [1-2].

![Fig.1.](image)

2. Simulation and discussion
Figure 2 shows the optical absorption in the middle waveguide enlarges with the increasing of device length and applied bias voltage. However due to the phase detuning of the ON state from (2N+1)$\pi$ in the output port, the overlap of optical power with the center waveguide reduces with the longer device length and higher bias voltage. As a result, insertion loss for longer device length first become smaller and then larger. For instance at driving bias voltage of 0.9 V, device length of 125 µm provides insertion loss of 0.9 dB, which is increasing with the larger length. In contrast, conventional ITO modulators [3] cannot provide sub-volt operation with a reasonable insertion loss. For instance as shown in figure 2 (c), even at driving bias voltage of 0.9 V a 16 dB insertion loss is expected to obtain a 10 dB extinction ratio. However, as shown in figure 2(a) our ACW modulator provides extinction ratio of exceeding 40 dB at driving bias voltage of as low as 0.1 V. Conventional ITO modulator at the bias voltage of 2.5 V provides extinction ratio of 10 dB with the insertion loss of 0.6 dB. In the other hand, in ACW modulator, with applied bias voltage of to 2.5 V, insertion loss of 0.04 dB corresponding to the device lengths of 3.5 µm is expected. Next, we explored the limit of modulation speed caused by parasitic elements. To this end, a full-wave three-dimensional simulation is performed via “Ansys Electronics Desktop”. We modeled parasitic responses caused by both active region and RF pads. Dimensions of RF pads are optimized for a 50 Ω and 100 µm-pitch ground-signal-ground probe.
tuning a plasmonic mode via carrier modulation of an active ITO layer of the compact silicon nanophotonic modulator with broadband response,”

...of an adiabatic elimination scheme,” Applied Physics Letters, 2015. The other contact is provided through the extension of the center waveguide of the modulator, we show that tunability in and out of an adiabatic elimination region in the index-design space enables dramatic modulation depth of 40 dB for just 100 mV of applied bias. This modulator opens a new era for electro-optic modulation in silicon photonics.

3. Conclusion
In conclusion, we have developed a new concept for an energy-efficient, high-speed and low-loss ITO plasmonic modulator. The underlying operation principle is based on the altering the coupling strength of an adiabatically coupled three-waveguide system. By voltage-tunin...of an adiabatic elimination scheme,” Applied Physics Letter 111, 033105 (2017).
