A CMOS-Compatible, low-energy consumption Franz-Keldysh effect Plasmonic Modulator Active Region

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Abstract

In this abstract we report on the design of a low energy consumption CMOS-compatible Franz-Keldysh effect plasmonic modulator. The main characteristics of the modulator were determined using integrated electro-optical simulations. A 3.3 dB extinction ratio for a 30 µm long modulator was demonstrated under 3 V bias voltage at an operation wavelength of 1647 nm. The estimated energy consumption was as low as 20 fJ/bit. This is the lowest energy consumption reported with photonic Franz-Keldysh effect modulators.

The structure of the modulator proposed is presented in Fig. 1. It consists in a classical vertical MIS plasmonic slot waveguide formed by Copper (Cu), Silicon Nitride (Si_3N_4) and Germanium (Ge). The Si_3N_4 diffusion barrier has a thickness h_{Slot} and the Ge core has a width w and a height h. Such a structure stands on a p-doped Ge (p-Ge) layer of height h_{Bot} which is over a p-doped Si layer (p-Si) of height h_{Buf}. Everything is encapsulated by SiO_2. The structure has two electrical contacts: one in the top Cu material and the other in the p-Ge and p-Si. Such a structure is CMOS-compatible, as it can be fabricated on a SOI substrate using microelectronics tools.

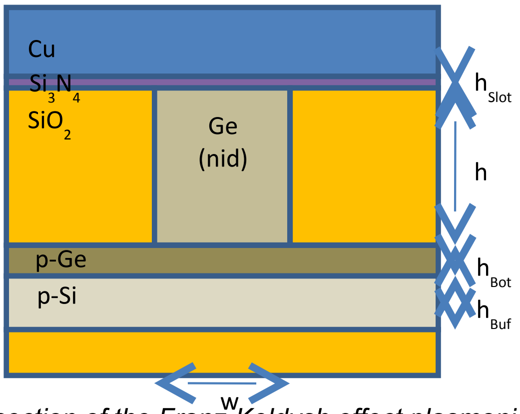

Fig. 1: Cross section of the Franz-Keldysh effect plasmonic modulator

The active principle of the modulator is to use the Franz-Keldysh (FK) effect [1,2] in order to modulate the plasmonic mode supported by the slot waveguide. The FK effect is the change in absorption that a material experiences under the influence of a static electric field. The change in the absorption occurs close to the band-edge energy of the material, i.e. at the wavelength of 1647 nm in strained Ge grown on silicon.

This slot waveguide supports a plasmonic mode whose electric field is concentrated mainly in the Si_3N_4 slot and in the Ge core. When a voltage V is applied between the contacts, a static electric field appears in the Ge core. This static electric field changes the absorption of the material Ge present in the core, due to the FK effect. As a consequence, the effective loss of the plasmonic mode is also changed, thus producing the intensity modulation at the output of the waveguide.

In this work, we performed an integrated electro-optical simulation in order to deduce the characteristics (modulation depth, insertion losses, etc.) of the plasmonic modulator of Fig. 1. For this purpose, we used a commercial electrical simulator ISE-DESSIS in order to calculate the static electric field distribution when a voltage V is applied between the two contacts. Knowing the static electric field in the Ge core, the change in the absorption of the material due to the FK effect can be calculated using a known theoretical model [3]. Finally, using a Finite Difference Method (FDM) optical mode solver with the absorption distribution, we are able to calculate the effective propagation losses of the plasmonic mode. From this value we can calculate the modulation depth of the device for a given length. Using this method we optimized the device in order to increase the modulation depth, reduce the insertion losses and the energy consumption.

Regarding the energy consumption, we used the model described in [4]. In this model the energy consumption of the dynamic modulation is given by the formula $E_{bit}=1/4CV_{DD}^2$ where C is the capacitance of the device and V_{DD} is the driving voltage. Using the electrical simulator ISE-DESSIS we found a capacitance of around C=9 fF for a device length of 30 µm. Using this value, the energy per bit is found around 20 fJ/bit, which is lower than for state-of-the-art photonic FK effect modulators [5-10]. This makes plasmon-assisted Franz-Keldysh modulators promising candidates for future optical links.

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