18a-A18-2

Traveling plasmon interaction with light

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1. Introduction:

One of the fundamental challenge in photonics integration, compared to electronics, is the large variety of the devices. While electronics consist mainly of two devices, i.e., transistors and interconnects, quite a few devices have to be implemented to construct circuits in photonics, such as light emitter, modulator, multiplexer/demultiplexer, photodetector, isolator and interconnect. Based on coupling the Maxwell's equations with electron motions, it has been predicted that a light mode in conductive waveguides should strongly interact with the traveling plasmons and should show amplification. Thus, this could be an important corner stone for silicon photonics. This paper briefed a couple of key interactions of light with electrons according to the electron density and its relative velocity to light.

2. Theory

An analytical solution of the coupled Maxwell's equations with traveling plasmons is shown by a secular equation and simplified to a form of $((\omega-\beta k)^2-\omega_n{}^2)((kc)^2-\omega^2+\omega_n{}^2+\omega_c{}^2)+\beta^2\omega_n{}^2\omega_c{}^2=0$. Here, ω denotes the mode frequency; k the mode propagation constant; β the ratio of velocity of the electrons and light, ω_n the plasma frequency, and ω_c the cutoff frequency of the waveguides. This equation indicates that a coupling of the traveling plasmon and the waveguide mode meditated by a term of $\beta^2\omega_n^2\omega_c^2$ generates the optical wave could travel at an apparently forbidden frequency zone $(\omega<\omega_c)$ carried by the interaction with electrons. This plasmon instability is due to perturbation by the current. No instability is found when no current is applied.

3. Calculations

A basic mode with the form of $E_\omega(x,y,z)=e^{k_i z}E_\omega(x,y)e^{-ik_r z}$ is obtained from the maxwell equation with an amplifying part of $e^{k_i z}$. While a large amplification is predicted, an extremely tiny k_r will cause huge evanescence and loss. We normalized the equation as follow to estimate the exact amplification: $((\bar{\omega}-\beta\bar{k})^2-1)((\bar{k}c)^2-\bar{\omega}^2+1+\kappa^2)+\beta^2\kappa^2=0$ β and κ as parameters. Here, ω is real and $k=k_r+ik_i$. As in Figs. 1 and 2, the real and imaginary parts linearly depend on β and κ, suggesting that higher κ and β are favorable for interaction. β is basically limited by the electron drifting velocity, while slow light using photonic structures should increase β. κ (ω_c in non-normalized case) is decisive for amplification.

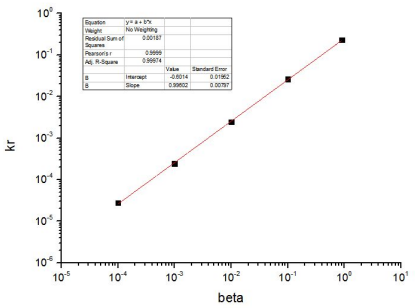

Fig. 1: Real part peak of instability wave dependence on β

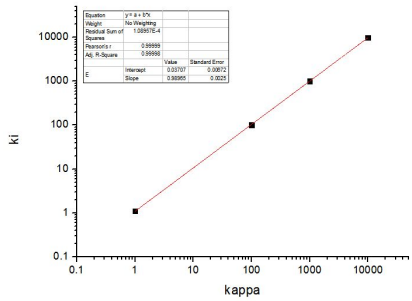

Fig. 2: Imaginary part peak of instability wave dependence on κ

4. Conclusions

Coupled Maxwell's equations with electron motion generates instability of light wave and traveling plasmons which could lead amplification of the light wave in conductive waveguide. Silicon photonics provides a fundamental test bed to understand the predictions experimentally.

参考文献

[1] Y. Mizushima, Optical Review, Vol.19-5 (2012) 290-293.

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