Plasmonics for sensor applications

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Abstract We demonstrated the quantum efficiency (QE) of silicon-on-insulator (SOI) photodiode was enhanced in visible wavelength region by using gold (Au) nanoparticles. The photons plasmonically scattered by Au nanoparticles couples with the waveguide mode in SOI, and are absorbed efficiently. Optimum size and density of Au nanoparticles have been investigated by 3-D FDTD simulations for sensitivity improvement. The highest enhancement factor of the absorption efficiency in 100-nm-thick SOI is obtained by periodically attaching Au nanoparticles of about 140 nm in diameter and 1.7×109 particles/cm2 in density.

1. Introduction

Silicon-on-insulator (SOI) photodiodes have a feature of high charge sensitivity and high operation speed due to the low parasitic capacitance [1, 2]. However, its light absorption efficiency is usually low because of the small volume for the absorption. In order to improve the absorption efficiency, we propose an SOI photodiodes with Au nanoparticles. Incident light is efficiently coupled to the waveguide modes in SOI induced by metallic nanoparticles to enhance the light absorption in SOI.

Previously, we have developed SOI lateral pn-junction photodiodes for improved quantum efficiency (QE) by Au line-and-space grating [3]. The diffracted light from the grating efficiently couples with the waveguide mode in SOI, leading to the resonant peak which shows an external quantum efficiency QE one order of magnitude higher than that without the grating. The resonant peak wavelength is controlled by the grating period, which can be explained that is caused by the coupling between the diffracted light from the Au line-and-space grating and the waveguide mode in SOI.

Here, we would like to present the demonstration of the enhanced quantum efficiency QE of silicon-on-insulator (SOI) photodiode by using randomly arranged Au nanoparticles.

2. Structure optimization of SOI photodiode with periodically arranged Au nanoparticles

We have performed 3-D FDTD simulations for the characteristics of absorption efficiencies in SOI photodiode with Au nanoparticles varying with the structural parameters such as the diameter of Au nanoparticles d, and the period of Au nanoparticles array p. Fig. 1 shows the cross-sectional view of the simulated SOI photodiode with Au nanoparticles. In the simulations, we fixed the thickness of the SOI absorbing layer to 100 nm and the buried oxide (BOX) layer to 400 nm. Periodic boundary conditions are set to the width and depth sides of SOI structure, and the normal incident light of impulse is irradiated from the top. The power spectra at the both interfaces of SOI are ob-tained using the fast Fourier

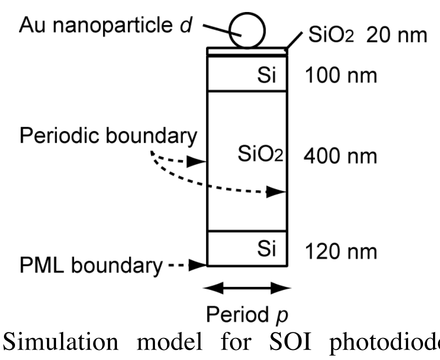

Fig. 1 Simulation model for SOI photodiode with Au nanoparticles

transform. Figs. 2(a), 2(b), and 2(c) show the typical simulation results of enhancement spectra varying with the Au nanoparticle diameter d (50 -200 nm) and the period p (200, 240, and 280 nm). The resonant peak wavelength respectively appears in 585, 636, and 682 nm depending on the period that is corresponding to the waveguide mode of TM_0 in SOI as shown in Fig. 2(d). It is found that the enhancement factor of 29 is achieved in the optimized structural parameters of d =140 nm and p =240 nm. The resonant wavelength in these optimized conditions is 682 nm.

Figures 4(a), 4(b) show the corresponding steady state field distributions of absolute intensities of Ex and Hy. Enhanced Ex distributions were observed in the near-field of Au nanoparticle due to the excitation of local surface plasmon resonance. In SOI region of $|Hy|^2$, enhanced

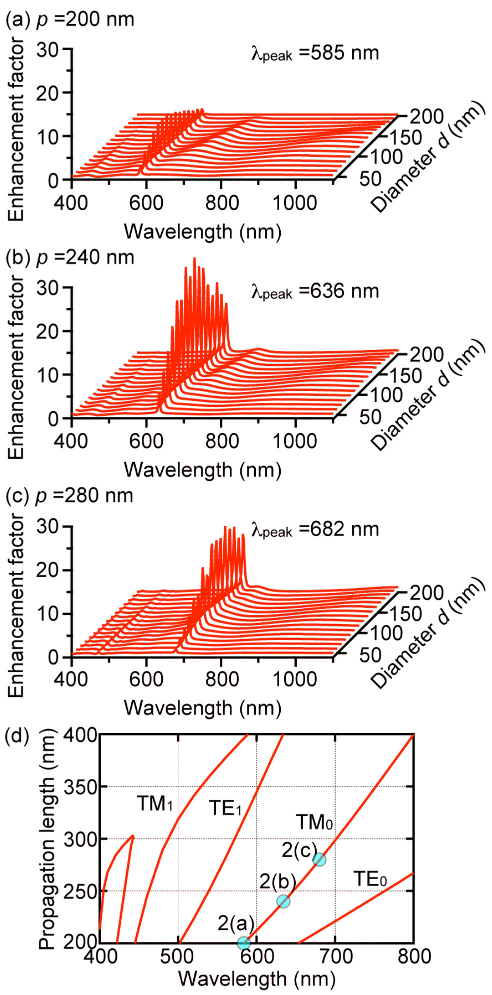

Fig. 2 Enhancement spectra varying with Au nanoparticle diameter and the period (a) 200, (b) 240, (c) 280 nm. (d) Waveguide mode spectra in SOI.

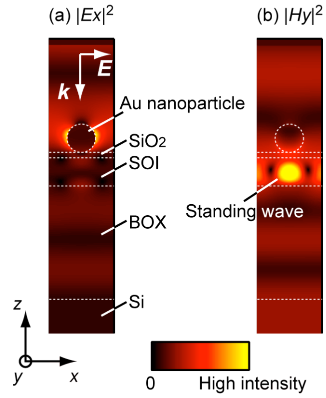

Fig. 4 Field distributions for electro-magnetic components of (a) Ex and (b) Hy.

standing wave is observed, which can be attributed to the coupling to SOI waveguide mode.

3. Conclusions

The structural parameters of Au nanoparticles attached to the SOI photodiode have been optimized by 3-D FDTD simulation.

The particle diameter of 140 nm arranged with the period of 240 nm exhibited 29-fold enhancement at the wavelength of 682 nm.

8. References

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