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E-3-2

Optimization of Gold Line and Space Antenna for Silicon-On-Insulator Metal-Oxide-Semiconductor Photodetector

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1. Introduction

For photodetectors, silicon-on-insulator (SOI) has advantages of high-speed operation and large voltage gain per electric charge because of the small parasitic capacitances. However, due to the small volume for light absorption, the sensitivity of SOI photodetector is usually not high. Recently, it is reported that optical near-field caused by surface plasmon (SP) around a noble metal structure can be utilized to enhance the light absorption in nanometer-scale Schottky photodiode [1]. We have proposed to apply the SP antenna with gold (Au) line and space (L/S) grating to SOI metal-oxide-semiconductor (MOS) photodetector, which features much smaller dark current and parasitic capacitances [2]. In this report, conditions for high absorption efficiency, single-peaked spectroscopic characteristics, etc. are investigated with electromagnetic simulations using the finite difference-time domain (FDTD) method [3].

2. Device Structure

Figure 1 shows the schematic of the proposed MOS p-i-n photodiode with Au L/S grating on SOI substrate, and a two-dimensional (2D) analysis model of a unit period structure for electromagnetic simulation. As for permittivities of Au and silicon (Si), Drude-type and Lorentz-type dispersion properties, respectively are adopted. When the photodiode is illuminated, a part of the incident light is converted to an optical near-field by SP around the Au L/S grating. By utilizing such optical near-field, sufficient light absorption can be expected even if SOI layer is thin.

3. Results and Discussion

Figure 2 shows the positions of integral paths and the equations for power calculations. Power through each integral path is obtained by integration of Poynting vectors toward vertical direction. The most important power in this analysis is Si absorption (i.e. absorption efficiency). The other ones such as reflection, transmission, and Au loss are also calculated here. If these powers are shown in the stack as in Fig. 3, the fraction of each power converted from the incident light can be recognized. In this example, major SP resonance occurs and the reflection decreases at λ = 547 nm. There, the incident power is efficiently absorbed in Si, but the Au loss also becomes high simultaneously.

Figure 4 shows the dependence of absorption efficiencies on wavelength with the thicker Au thickness t_2 as a parameter. This figure includes the absorption efficiency in the case without Au L/S grating for comparison. The maximum value of the absorption efficiency is 37% at λ = 547 nm when t_2 = 80 nm. This is 14 times larger than the 2.6% in the case without the grating. It is interesting to note that the thin Au does not necessarily lead to higher absorption in Si.

Figure 5 shows the binary distributions of the absorption efficiency in the wavelength and the Si thickness t_{SOI} for the cases with and without the Au L/S grating. White area corresponds to the absorption efficiency exceeding 20 %. Without the grating [Fig. 6(a)], the white area is located at shorter wavelength and thicker Si thickness. Note that the stripes appear due to the light interferences in the Si layer. On the other hand, with the grating [Fig. 6(b)], the white stripes are extended to the longer wavelength and the thinner Si thickness region. The number of absorption peaks along the wavelength increases with the t_{SOI}. For the photodetector with the single-peaked absorption characteristics, the t_{SOI} should be thinner than 110 nm.

Figure 6 shows the absorption efficiency for various grating periods p. The ratio of grating period and width is fixed at w/p = 0.7. The thicker Au thickness t_2 and the Si thickness t_{SOI} are 80 nm and 100 nm, respectively to realize high absorption efficiency and single-peaked characteristics. We can see that the peak wavelength can be varied from 490 to 610 nm by changing p. In other words, the Au L/S grating works as a filter whose peak wavelength can be tailored.

4. Conclusions

This paper has described the optimization of SOI-MOS photodetector with Au L/S grating especially for high absorption efficiency and single-peaked spectroscopic characteristics. The grating does not only enhance the light absorption up to 37 % for 100-nm thick Si at the wavelength of 547 nm, but also works as a filter whose peak wavelength can be tailored from 490 to 610 nm by changing its period. The latter result suggests that photodetectors with different absorption wavelengths can be integrated in a chip just by preparing Au L/S gratings with different periods. Furthermore, it has been shown that the Si layer thinner than 110 nm is needed for single-peaked absorption characteristics.

References

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[2] H. Satoh and H. Inokawa, *2008 IEEE Silicon Nanoelectronics Workshop* (Honolulu, June 15-16, 2008) to be presented.
[3] A. Taflove and S. C. Hagness, *Computational Electrodynamics –Finite Difference-Time Domain Method–*, 3rd ed., Artech House, MA, 2005.

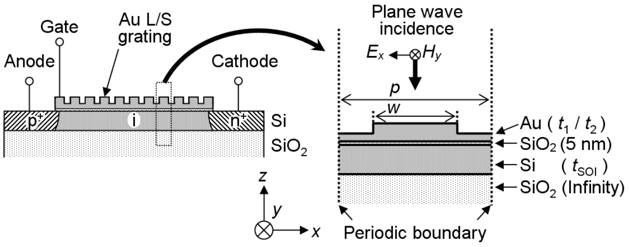


Fig.1: A p-i-n photodiode with Au L/S grating on SOI substrate and 2D analysis model of a unit period structure for electromagnetic simulations. It is assumed that the structure is periodic infinitely in x-direction. Incident light is polarized as indicated by magnetic field H_y and electric field E_x.

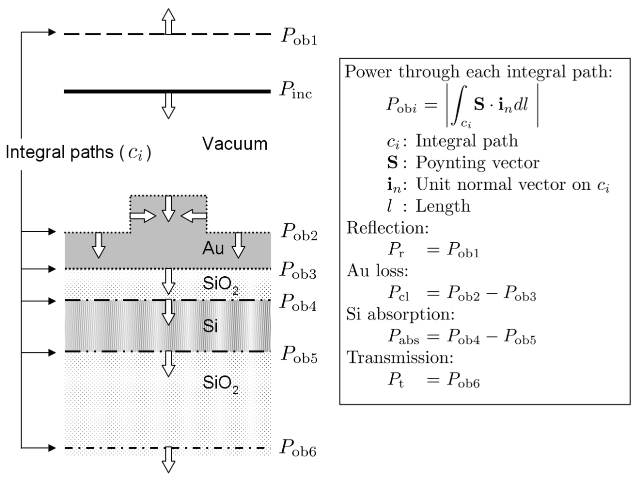


Fig. 2: Definition of integral paths in the model structure and equations for obtaining power components.

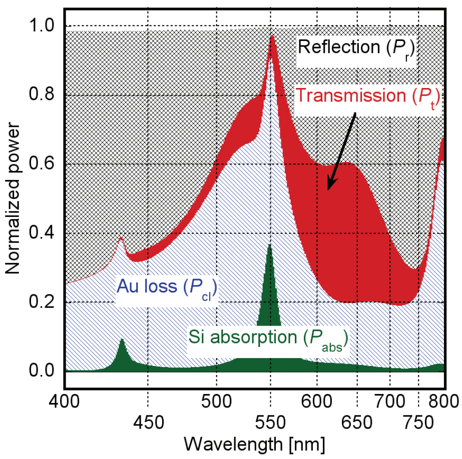


Fig. 3: Stacked area chart of power components as a function of incident wavelength. Grating period and width are p = 200 nm and w = 140 nm, respectively. Au thicknesses are t_1 = 30 nm and t_2 = 80 nm. Si thickness is t_{SOI} = 100 nm.

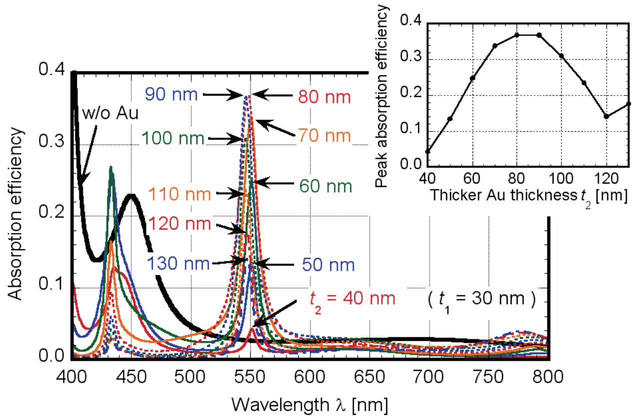
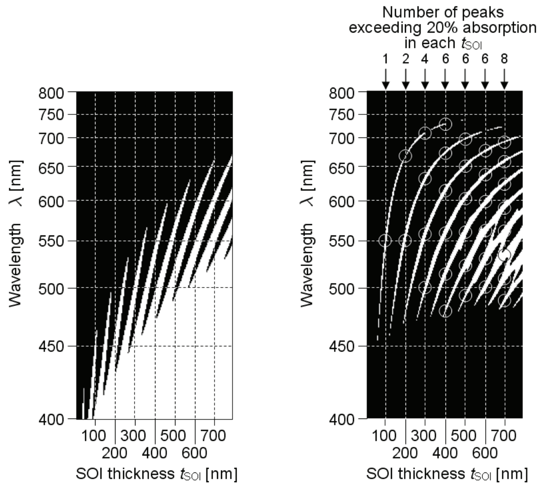


Fig. 4: Absorption efficiency with thicker Au thickness t_2 as a parameter. Thinner Au thickness is t_1 = 30 nm. Grating period and width are p = 200 nm and w = 140 nm, respectively. Si thickness is t_{SOI} = 100 nm.



(a) without Au (b) with Au

Fig. 5: Binary distribution of absorption efficiency for incident wavelength and SOI thickness t_{SOI}. White area corresponds to the absorption exceeding 20 %. Grating period and width are p = 200 nm and w = 140 nm, respectively. Au thicknesses are t_1 = 30 nm and t_2 = 80 nm.

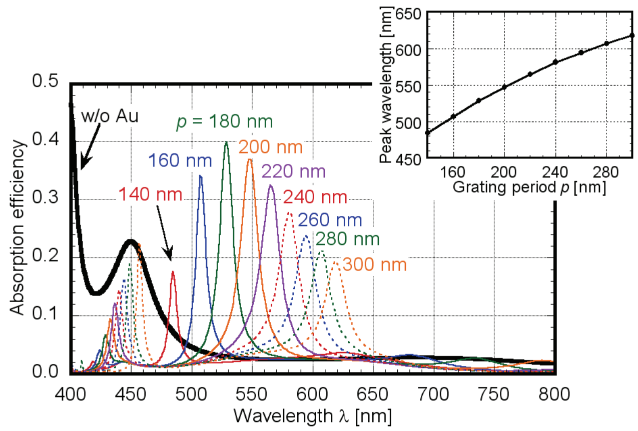


Fig. 6: Absorption efficiency for various grating periods p. The ratio between grating period and width is fixed at w/p = 0.7. Au thicknesses are t_1 = 30 nm and t_2 = 80 nm. Si thickness is t_{SOI} = 100 nm.