Integration of High-Speed Photodetectors on Si LSI

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1. Introduction

The increase of delay time due to the metal interconnect is one of the big problems with increasing the speed of the transistors [1]. Especially, the delay due to the global interconnect on LSI chips limits the clock frequency. So, more speed up is desired. One of the solutions to solve this problem is optical interconnection. Figure 1 shows the schematic of the optical interconnection integrated on Si wafer. Today, various photodetectors are studied and fabricated experimentally, but there is difficulty to integrate high-speed photodetectors on Si LSI monolithically [2]. Then we study the high-speed photodetectors which can be integrated on Si LSI.

2. Experiments

Figures 2(a) and 2(b) show the structure of photodetector. The reason we adopt this structure (*pin* photodetector) is that the *pin* structure is suitable for high-speed response. The concentration of impurity diffused layer (n^+ and p^+) is 10^{20} cm^{-3}. Table 1 shows parameters of this structure. The sizes of W are 22 μm and 100 μm, and x_j are 0.5 μm and 0.7 μm. But we measured only W = 22 μm and x_j = 0.5 μm. W is changed to measure the change in photocurrent by controlling the incident photon number. This research is designed to find out the effect of x_j and y to the cut off frequency. Penetration depth of the incident light (λ = 532 nm) to Si is estimated to be1 μm.

Figures 3 and 4 show the simulation result of cut off frequency when x_j and y are changed. These simulations are carried out using 2-D device simulator "MEDICI". These results show that x_j becomes deeper, cut off frequency becomes higher. This is because for the carriers generated at deep region from surface it takes time to reach impurity diffused layer because the electric field in the deep region is weak. So, this decreases cut off frequency. And y becomes smaller, the cut off frequency becomes lower. This is because for the carriers generated at impurity diffused layer by illuminated light, it takes time to reach the electrode, and the cut off frequency becomes low.

3. Results and Discussion

3.1 *pin* junction

Figure 5 shows the current-voltage (I-V) characteristics of the fabricated *pin* junction. This measurement is to check the photodetectors operate normally or not. These *pin* junctions indicate rectification characteristics but the forward I-V curve has two humps, which shows the incomplete junction property. The dark current is 10^{-2} A/cm^2 at -5 V.

3.2 Measurement of photocurrent

Next, we measured the photocurrent of the photodetector. Figure 6 shows the measurement system. The photocurrent is measured with triggering the pulse signals at reverse bias of -5 V by using oscilloscope. And we used the nanosecond pulse laser which wavelength is 532 nm. Figure 7 shows the measured photocurrent. The FWHM (Full Width at Half Maximum) of output photocurrent is 3 ns when illuminating 1 ns pulse laser. It is found from Fig. 3 and 4 that the illuminated light enters the impurity diffused layer and generates the carriers, and for x_j less than 0.5 μm it is difficult to apply the electric field to the generated carriers. These things make the response time of the photocurrent slow. We are now checking out the reason why the response speed is slow.

4. Conclusion

We fabricated *pin* photodetectors for the optical interconnection. And we measured photocurrent by using nanosecond pulse laser with the wavelength of 532 nm. We would like to see the effect of y to the cut off frequency. At present, it is far from the target of high speed response. This may be because the light illuminates the impurity diffused layer and the fabricated device is not good. We will check out this reason. And we will fabricate high speed and high sensitive photodetectors.

References

[1] T.Kikkawa, IEICE C, Vol. J83-C(2000), pp.105-117
[2] Zhihong Huang, Jungwoo Oh, and Joe C.Campbell, APL, Vol.85, Number 15, 11 Oct. 2004

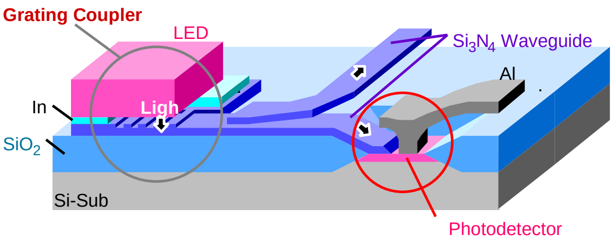

Fig. 1 LSI with optical interconnection in which photodetectors are integrated.

Table Ⅰ The parameter of photodetector structure fabricated.

y (μm)	L_j (μm)
0.05	0.2 – 2.0 (ΔL_j = 0.2) , 4.0
0.1	0.4 – 2.0 (ΔL_j = 0.2) , 4.0
0.3	0.8 – 2.0 (ΔL_j = 0.2) , 4.0

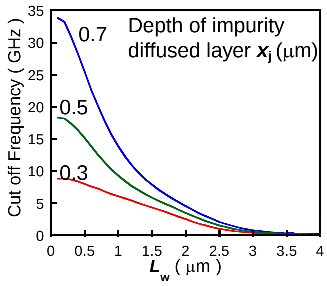

Fig. 3 Simulation result of cut off frequency as a function of x_j and L_j.

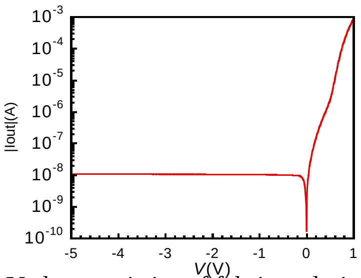

Fig. 5 I-V characteristics of fabricated *pin* junction.

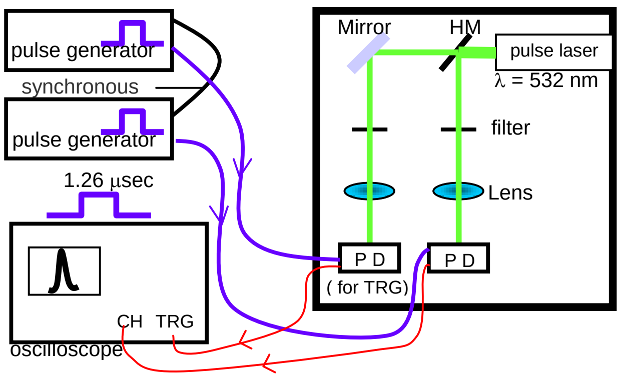

Fig. 6 Measurement system for optical response of photodetectors.

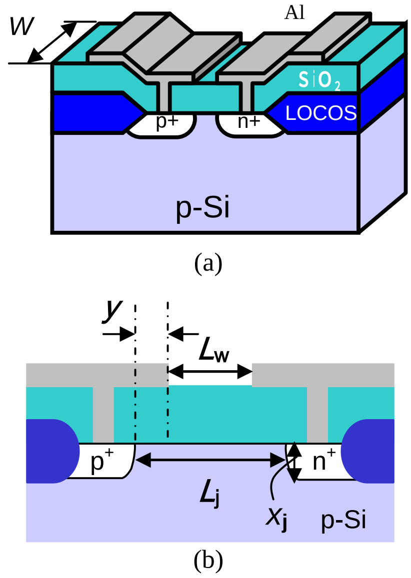

Fig. 2 Structure of the fabricated *pin* photodetector, (a) bird's-eye view and (b) cross-section.

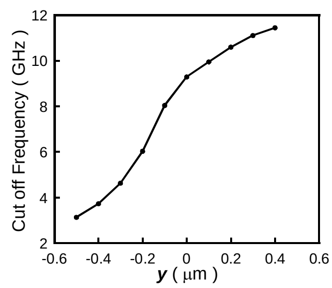

Fig. 4 Simulation result of cut off frequency as a function of *y*.

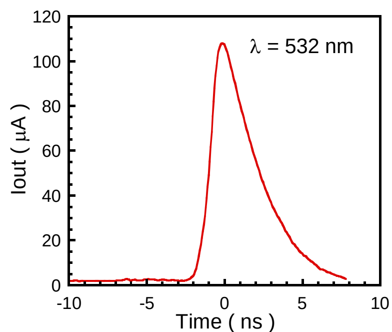

Fig.7 Response characteristics of fabricated photodetectors. Pulse duration of input laser light is 1 ns.

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Background

The increase of delay time due to the metal interconnect is one of the big problems with increasing the speed of the transistors.
One of the solutions to solve this problem is optical interconnection.

Purpose

Figure 1 shows the schematic of the optical interconnection integrated on Si wafer.
There is difficulty to integrate high-speed photodetectors on Si LSI monolithically.
Then we study the high-speed photodetectors which can be integrated on Si LSI.

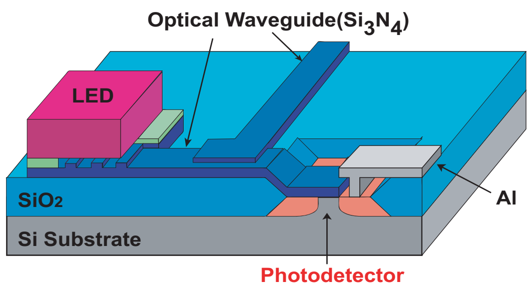


Fig.1 LSI with optical interconnection in which photodetectors are integrated.

Approach

Experimental investigation

Fabricate p-i-n photodiodes and measure laser-generated photocurrent with an oscilloscope.

Theoretical investigation

Use 2-dimensional device simulator "MEDICI" to analyze various measurement.

Device Structure

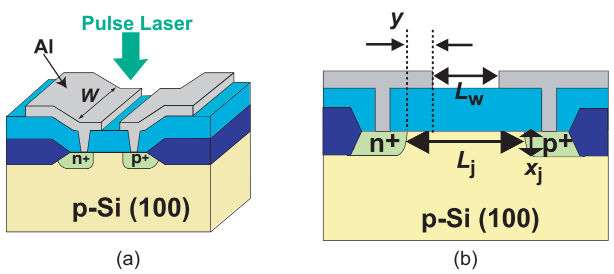


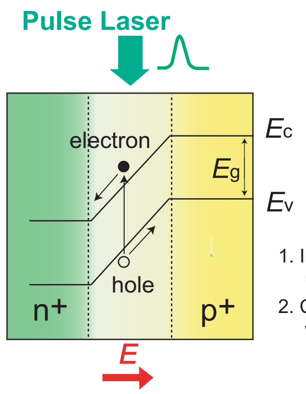
Fig. 2 Structure of the fabricated p-i-n photodetector, (a) bird's-eye view and (b) cross-section.

- p-type (100) silicon substrate with a resistivity of 8-12 Ω-cm.
- An ion implantation of B at 30 keV with a dose of 1×10^{15} cm^{-2} for the p+ region.
- An ion implantation of As at 80 keV with a dose of 1×10^{15} cm^{-2} for the n+ region.

Table. 1 The parameter of photodetector structure fabricated.

y(μm)	L_j(μm)
0.05	0.2 - 2.0 (ΔL_j=0.2), 4.0
0.1	0.4 - 2.0 (ΔL_j=0.2) 4.0
0.3	0.8 - 2.0 (ΔL_j=0.2) 4.0

Measurement System



Pulse laser
Wavelength 532 nm
Absorption coefficient ~ 1×10^4 cm^{-1}
depth ~ 1 μm
Average output power 4mW
Repetition frequency 10kHz

1. Inject pulse laser to the p-i-n junction under reverse bias
2. Collect generated carriers at opposite electrodes with different electric fields

Fig. 3 Energy band diagram of photodetector.

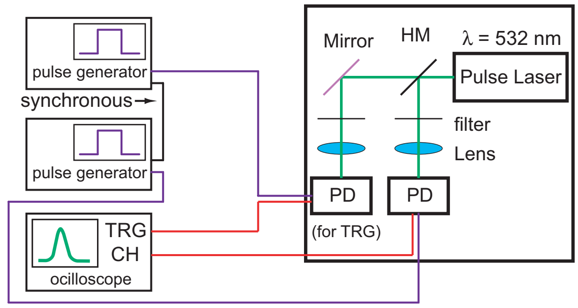


Fig. 4 Measurement system for optical response of photodetectors.

Current-voltage (I-V) characteristics

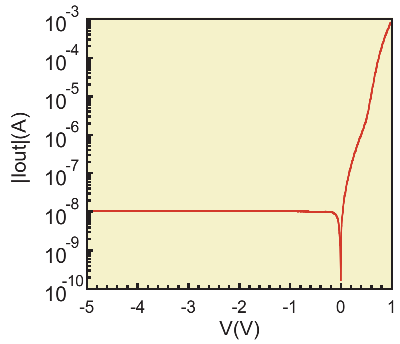


Fig.5 The current-voltage (I-V) characteristics of the fabricated pin junction.

Measured Response characteristics

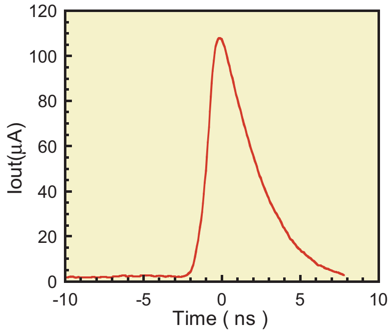


Fig.6 Response characteristics of fabricated photodetectors. Pulse duration of input laser light is 1 ns.

2-Dimensional Simulation : MEDICI

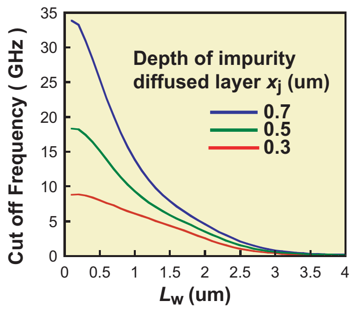


Fig. 7 Simulation result of cut off frequency as a function of x_j and L_j.

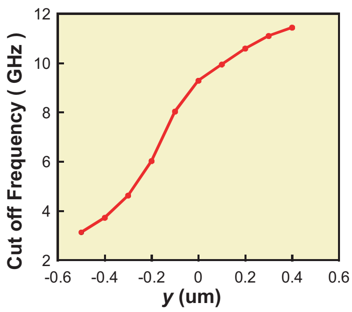


Fig. 8 Simulation result of cut off frequency as a function of y.

Conclusion

1. We fabricated pin photodetectors for the optical interconnection. And we measured photocurrent by using nanosecond pulse laser with the wavelength of 532 nm.
2. From simulation results of 2D simulators, we see the effect of y, x_j and L_j to the cut off frequency.

At present, fabricated p-i-n photodetector is far from the target of high speed response.
This may be because the light illuminates the impurity diffused layer and the fabricated device is not good. We will check out this reason. And we will fabricate high speed and high sensitive photodetectors.