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Fabrication of Avalanche Multiplication type a-Si:H Photodiode Films with Low Operation Voltage

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Abstract

We demonstrated a staircase avalanche photodiode (APD) film with low operation voltage. The avalanche multiplication on the staircase APD give an extra energy from the band offset. In the result, the low operation voltage type a-Si:H APD was fabricated. The maximum multiplication gain ratio is 2, the applied voltage is 7V.

1. Introduction

Recently, avalanche multiplication type compact TV camera is developing in field emitter array image sensor [1]. The avalanche process needs high applied voltage [2]. On conventional avalanche photodiode (APDs), the impact ionization energy was given by the reverse biased electric field (kinetic energy). To realize a low operation voltage APD with a linear graded structure has been considered [3]. The avalanche multiplication on the staircase APD give an extra energy from the band offset.

The hydrogenated amorphous silicon (a-Si:H) film can efficiently absorb visible light, and it is compatible with the conventional charge-coupled device (CCD) and complimentary metal-oxide-semiconductor (CMOS) process. The a-Si:H photodiode film is suitable for a photo conversion film of the stacked-type image sensor [3]. Figure 1 shows schematic diagram of stacked type image sensor. Previously we have been investigated about avalanche multiplication type a-Si:H photodiode film on Si substrate. Multiplication gain ratio of the a-Si:H pin photodiode film at the operation voltage 70V was 3, and that of the staircase APD at 30V was 2. However, decrements of the operation voltage less than 10V are necessary for conventional CMOS imager. In this paper, we demonstrated a staircase photodiode film with low operation voltage.

2. Experimental

Figure 2 shows the schematic diagram of the cross section of a-Si:H/a-SiC:H staircase photodiode film. Figure 3 shows the energy-band diagram of an a-Si:H/a-SiC:H staircase photodiode film with one linear graded-gap region. The a-Si:H/a-SiC:H staircase photodiode films were fabricated by computer-controlled plasma-enhanced chemical-vapor deposition (PECVD) system at a substrate temperature of 250°C, an RF power density of 20 mW/cm^2 and a pressure of 0.12 Torr. A highly doped n-type Si wafer (0.1Ωm) was used as the substrate. The bandgap of the undoped a-Si:H was 1.75 eV. Each graded region was deposited using SiH_4 (10%) and C_2H_4 (10%) gases, diluted with H_2. The typical deposition conditions are summarized in

Table I. The band offset exists on an interface between the Si substrate and a-$Si_{1-x}C_x$:H, and is varied from 0.2 to 0.7 eV by changing the C_2H_4 flow rate. The photo-generated electrons are accelerated by the reverse biased electric fields and given a kinetic energy. Just as the electrons pass through the band offset, they are given an extra energy from the band offset (ΔE_c). Photocurrent and dark current characteristics of the photodiode film with one linear graded-gap region are shown in Fig. 4, as a function of a reverse-bias voltage. Once the photocurrent of the photodiode films reaches the value of the current corresponding to the unit quantum efficiency (η=1), it starts to increase, and it reaches values corresponding to two times the unit quantum efficiency and saturates. Figure 5 shows multiplication gain ratio characteristics of photodiode film with one linear graded-gap region and conventional photodiode film, as a function of a reverse-bias voltage. The applied voltage at which avalanche multiplication is started of photodiode film with one linear graded-gap region is smaller than conventional photodiode film. It is important to know a suitable structure of a staircase layer. Three kinds of staircase photodiode, which thickness of the staircase layer were change 35nm, 70nm, 140nm, were fabricated. In a photodiode with 35nm thick staircase layer, it was found that photocurrent was multiplied 2 times at 7V reverse bias voltage. Figure 6 shows multiplication gain ratio characteristics for a-Si:H/a-SiC:H staircase photodiode thickness, as a function of a reverse-bias voltage.

3. Summary

To realize a low operation voltage APD with a linear graded structure is considered. The avalanche multiplication on the staircase APD give an extra energy from the band offset. In the result, the low operation voltage type a-Si:H APD was fabricated. The maximum multiplication gain ratio is 2, the applied voltage is 7V.

References

1. Yoshiro Takiguchi, Extend abstracts of STRL NHK Open House, pp. 52-57, 2004.
2. Safa Kasap, and J. A. Rowlands, Journal of Applied Physics, Vol. 96, No. 4, pp. 2037-2048, 2004.
3. Kazuaki Sawada, Masahiro Akiyama, and Makoto Ishida, Applied Physics Letters, Vol. 75, No. 10, pp. 1470-1472, 1999.

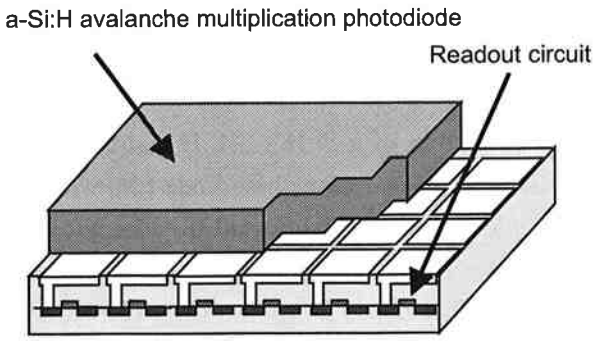

Fig. 1. Schematic diagram of stacked image sensor.

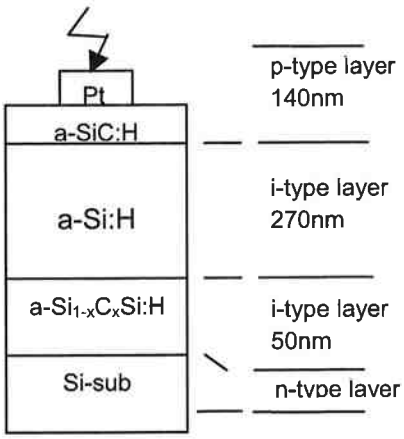

Fig. 2. Schematic diagram of the cross section of a-Si:H/a-SiC:H staircase photodiode film.

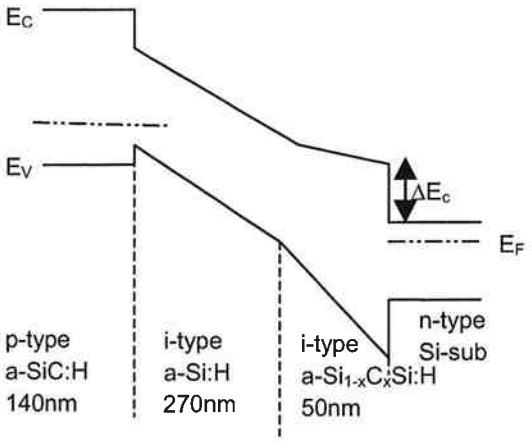

Fig. 3. Energy band diagram of an a-Si:H/a-SiC:H staircase photodiode film with one linear graded-gap region.

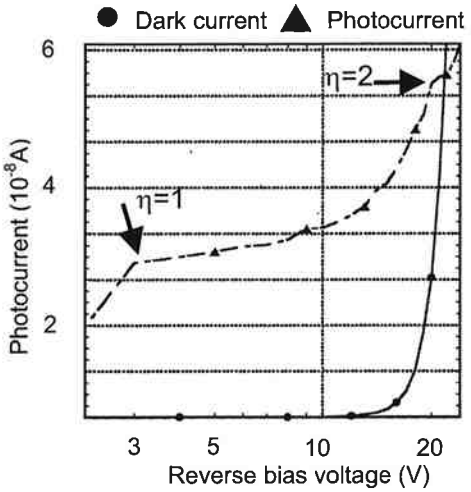

Fig. 4. Photocurrent and dark current characteristics of the photodiode film with one linear graded-gap region.

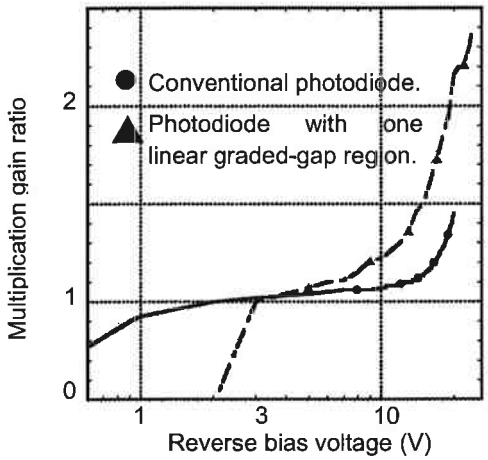

Fig. 5. Multiplication gain ratio characteristics of photodiode film with one linear graded-gap region and conventional photodiode film.

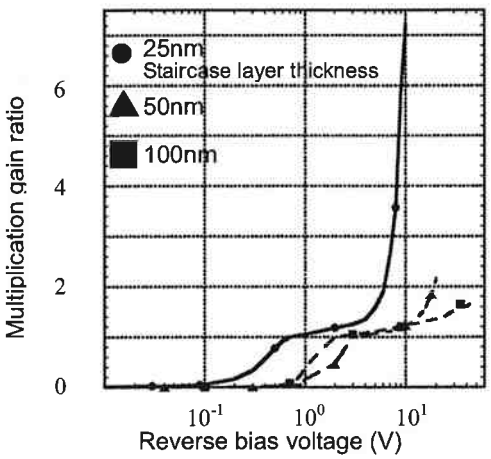

Fig. 6. Multiplication gain ratio characteristics for photodiode thickness.

Table 1. Typical deposition conditions of the staircase photodiode films.

Base pressure	:1x10^{-7} Torr
Sub. Temp.	:250 °C
R.F. power	:20 mW/cm^2
Depo. Pressure	:120 mTorr
SiH4 flow rate (10%)	:20 sccm
C2H4 flow rate (10%)	:20 - 0 sccm (continuously decreases)