Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 536-537

P6-3

Multiplication characteristics of a-Si:H p-i-n photodiode film in high electric field

Masahiro Akiyama, Masaki Hanada, Kazuaki Sawada and Makoto Ishida

Department of Electrical and Electronic Engineering,
Toyohashi University of Technology.
1-1 Hibarigaoka, Tempaku-cho, Toyohashi, Aichi 441-8580, Japan
Phone: +81-532-44-6747 Fax: +81-532-44-6757 E-mail: akiyama@icg.dev.eee.tut.ac.jp

1. Introduction

Hydrogenated amorphous silicon (a-Si:H) films have been widely used, not only as solar cells and thin film transistors, but also as image sensors. There are some advantages in their application. The a-Si:H film can efficiently absorb visible lights, and it is compatible with processes for conventional charge-coupled devices (CCDs) and complimentary metal-oxide-semiconductor (CMOS) devices. Therefore it seems that the a-Si:H photodiode film is suitable for photo-conversion film for stacked-type image sensors. If an avalanche phenomenon can be occurred in a-Si:H p-i-n photodiode film, the high sensitive and small size image sensor can be realized.

Recently we observed the avalanche multiplication phenomenon of photocurrent in an a-Si:H p-i-n photodiode film fabricated on the n-type Si substrate[1,2]. In this photodiode film, it was confirmed that there was 40-times maximum multiplication gain measured in the photodiode with a 360-nm-thick intrinsic a-Si:H layer, when a voltage of about 100V was applied to the device. The typical photocurrent and dark current characteristics are shown in Fig. 1 as functions of a reverse bias voltage.

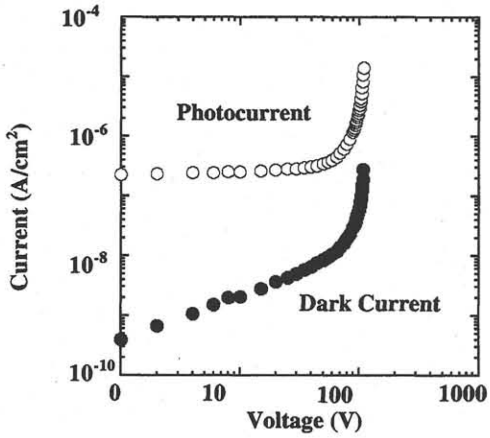

Fig. 1 Photocurrent characteristics of the p-i-n photodiode film

The photocurrent multiplication mechanism is evidenced by excess noise characteristics[3]. The avalanche process is intrinsically statistical in nature so that individual carriers have different avalanche gains characterized by a distribution with an average. This causes the excess noise [4]. If it occurred avalanche phenomenon, the device is generated on excess noise. Figure 2 shows the excess noise factor (F) [3]. Figure 2 also shows the excess noise factor of conventional crystal silicon APD (Hamamatsu Photonics S2381) which was determined using the same measurement setup. The excess noise of the conventional silicon APD increases with the multiplication gain. Similarly, the excess noise factor (f) of the a-Si:H photodiode increases with the multiplication gain. The result indicate that the excess noise is generated in the a-Si:H photodiode films when the photocurrent is multiplied. So the photocurrent multiplication mechanism is avalanche phenomenon.

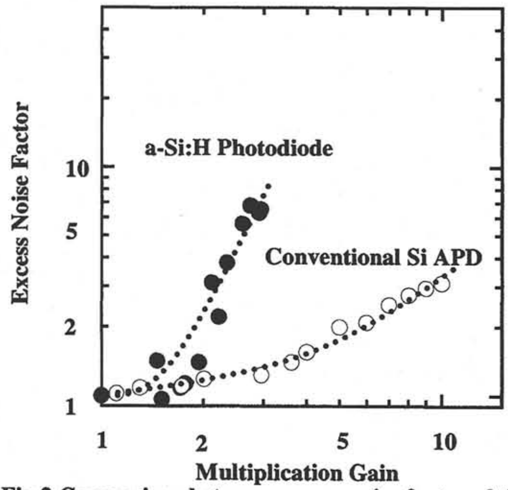

Fig.2 Comparison between excess noise factor of the conventional Si APD and the a-Si:H photodiode films

However, it is not satisfied that the elucidation of avalanche process in a-Si:H film. In this paper, we investigated a temperature dependences and residual stress of photocurrent multiplication rate to the elucidation of the avalanche process.

2. Experiments and Results

2.1 Photodiode film

A simple p-i-n photodiode with Pt / a-SiC:H (p-type) / a-Si:H (i-type) / c-Si (n-type) substrate structure. The a-Si:H and p-type a-SiC:H films were deposited using a plasma enhanced chemical vapor deposition (CVD) apparatus at a substrate temperature of 250°C, a RF power of 20W and a pressure of 0.12Torr. The thickness of an intrinsic a-Si:H layer (light absorbance layer) and a p-type a-SiC:H layer were 360nm and 140nm, respectively. Dark and photocurrent characteristics were measured under the irradiation of 500nm light. The value of photocurrent is defined as the difference between a value under the light irradiation conditions. and the dark current

2.2 Temperature characteristics

The photocurrent multiplication rate characteristics for the a-Si:H film temperature were studied. Figure 3 shows reverse bias characteristics of multiplication rate for various measurement temperatures. The temperatures were varied from 298K to 133K.

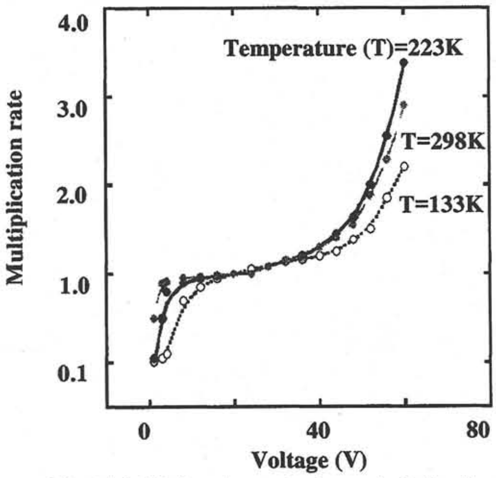

Fig.3 Multiplication rate characteristics for the temperature of a-Si:H film

From this figure, it was found that the multiplication rate increased with temperature until 223K, and it decrease from 223K contrarily. Figure 4 shows the temperature dependences of the ionization rate.

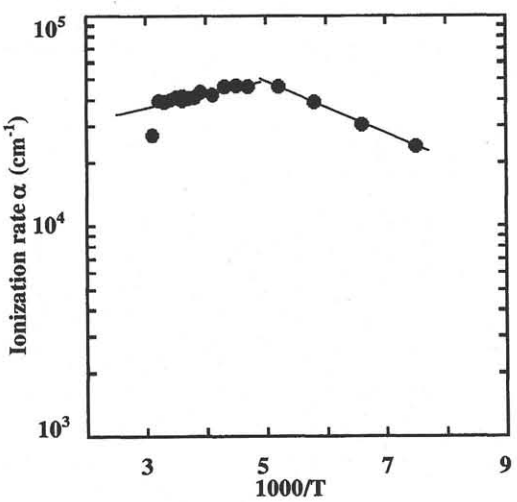

Fig.4 Ionization rate characteristics for the a-Si:H film temperature

The ionization rate characteristics were separated into two regions: one was high T region that was increasing ionization rate with the 1/T, where T was temperature value, and the other was low T region that was decreasing ionization rate with the 1/T. The cause of decreasing ionization rate was effected by geminate-recombination to decreasing temperature [5]. The cause of increasing ionization rate in the high T region was restraint by phonon scattering by decreasing temperature.

2.3 Deposited condition characteristics

The photocurrent multiplication rate characteristics for residual stress of a-Si:H film were investigated. Figure 5 shows the photocurrent multiplication rate characteristics of a-Si:H film in the device. The change parameters were the RF power density. The RF power were 20W and 30mW. In these p-i-n photodiode, a residual stress exist, and it was change by RF power density. The stress calculated by equation (1) [6-11].

$$\delta = \frac{Ed^2}{6(1-\upsilon)tr} \qquad (1)$$

where δ is stress, E is yaung's modulus, d is thickness of c-Si substrate, υ is poisson's ratio, t is thickness of a-Si:H film, r is the curvature radius. The residual compressive stress in the photodiode grown 20W was 2.255 [dynes/cm^2]. The residual compressive stress in the photodiode grown 30W was 3.012 [dynes/cm^2].

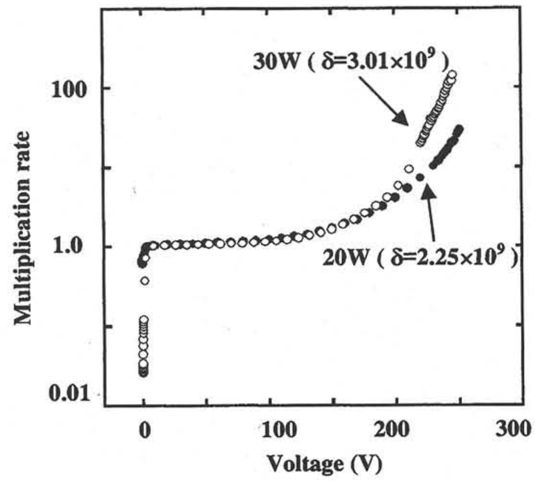

Fig. 5 Multiplication rate characteristics for the stress of a-Si:H film

From this figure, we can obtain the multiplication rate characteristics for the residual stresses. The multiplication rate is higher in the photodiode with high stress condition. This can be explained that, carrier mobility was made larger by stress of a-Si:H film.

3. Conclusion

The ionization rate characteristics were separated into two regions: one was high T region that was increasing ionization rate with the 1/T and the other was low T region that was decreasing ionization rate. The ionization rate characteristics were effected both lattice vibrations and geminate-recombination. The multiplication rate is changed by deposition condition of a-Si:H film. The multiplication rate increased with stress of a-Si:H film. These results indicate that multiplication rate is controlled by stress of a-Si:H film.

Acknowledgment

This work was partially supported by the Hoso Bunnka Fund.

References

[1]K.Sawada et. al., Appl. Phys. Lett. 65,1364 (1994)
[2]H.Ohtake et. al., Conference on Optoelectronic and Microelectronic Materials and Devices,(1998)
[3]M.Akiyama et. al., SSDM Tokyo,600-601(2001)
[4]R.J.McIntyer, IEEE Trans. Electron Devices, ED-13, 164(1966)
[5]L.Onseger:Phys.Rev.54,554(1938)
[6]M.Stutzmann,Appl.Phys.Lett.47(1),21(1985)
[7]Y.Kitsuno et al.,JpnJ.Appl.Phys.33,1261(1994)
[8]K.Ozawa et al.,Jpn.J.Appl.Phys.22,767(1983)
[9]H.Hakinuma et al.,J.Appl.Phys.59(9),3110(1986)
[10]M.Miyagi et al.,Jpn.J.Phys.20,289(1981)
[11]S.R.Kurtz et al.,Appl.Phys.Lett.49(15),951(1986)