P13

Super High-Sensitivity HARP Target

T. Matsubara[1]*, Y. Ohkawa[1], K. Miyakawa[1], S. Suzuki[1], T. Takahata[1], M. Kubota[1], K. Tanioka[1], K. Ogusu[2], A. Kobayashi[2], T. Hirai[2], T. Kawai[2]
[1]NHK Science and Technical Research Laboratories, Japan
[2]Hamamatsu Photonics K.K., Japan
*1-10-11 Kinuta, Setagaya-ku, Tokyo 157-8510, Japan
TEL: +81-3-5494-3271 FAX: +81-3-5494-3278 e-mail: matubara.t-ge@nhk.or.jp

Abstract

With the aim of realizing a 35-μm-thick HARP target that has five times the sensitivity of the present 15-μm-thick HARP target, we investigated ways to suppress the occurrence of defects caused by trapped electrons in the target. It was found that a target structure with minimum impurities in the a-Se layer and high-temperature operation can prevent these defects from occurring. The fabricated 35-μm-thick HARP target has better performance in terms of sensitivity and lag characteristics than the 15-μm-thick HARP target and has enough resolution to be mounted in an HDTV camera.

Introduction

To meet the stringent requirements for a television camera that can shoot clear pictures under low light conditions, NHK has developed the High-gain Avalanche Rushing amorphous Photoconductor (HARP) target made of amorphous selenium (a-Se) [1][2]. HARP target's high sensitivity is due to an avalanche multiplication phenomenon that appears when the applied target electric field is of the order of 10^8 V/m. Currently, a 15-μm-thick HARP target with a multiplication factor of 200 is being used in cameras.

In principle, a thicker HARP target leads to more charges being multiplied in the target and realizes higher sensitivity. However, the electric field of a thicker target may easily become non-uniform because of the trapped electron. A strong concentrated field destroys the target structure and generates defects on the screen.

To enable a multiplication factor of 1000 with a 35-μm-thick target, we investigated ways to suppress the occurrence of defects in the target.

Multiplication factor and defects occurrences

Figure 1 shows the operating principle of the HARP target. The incident light photon produces an electron-hole pair. The hole is accelerated by applying a large electric field, and this produce a new electron-hole pair through impact ionization. This phenomenon occurs repeatedly throughout the target.

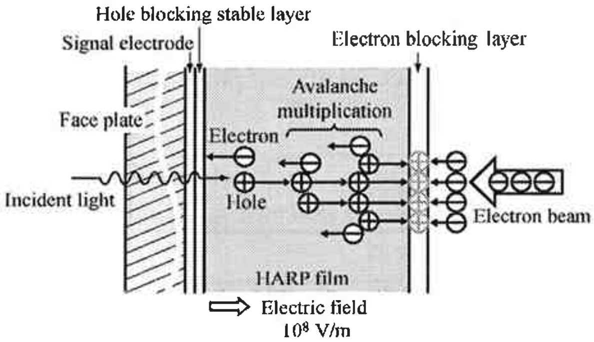
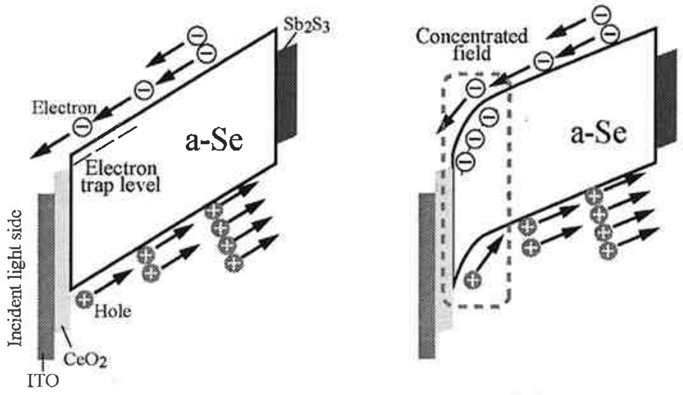


Fig. 1 Operating principle of the HARP target.

The multiplication factor M of the avalanche multiplication effect is

$$M = \frac{(\beta - \alpha)\exp((\beta - \alpha)L)}{\beta - \alpha\exp((\beta - \alpha)L)}$$

where L is the thickness of the a-Se target and α and β are the impact ionization factors



(a) (b)

Fig. 2 Mechanism of defect occurance of the HARP target.

of the electron and the hole, respectively [3]. α and β are given by

$$\alpha = 3.8\times10^{7}\exp(-1.5\times10^{7}/E)$$

$$\beta = 1.7\times10^{7}\exp(-9.3\times10^{6}/E)$$

where E(V/m) is the applied electric field[4][5]. As calculated by the above equations, the thickness of the target of 35 μm is needed to obtain the aimed multiplication factor of 1000, about five times that of the 15-μm-thick target.

However, a thicker target also means that the electron travel distance will be longer, leading to greater chance of the electron being captured in a trap level of the target. Initially, a uniform electric field is applied through the target (the band model of the target is shown in Fig. 2(a)). Once the avalanche multiplication phenomenon occurs, some of the electrons produced by impact ionization are trapped in the target (Fig. 2(b)). The strong concentrated electric field caused by the trapped electron locally destroys the hole blocking structure and generates defects on the screen (Fig. 3).

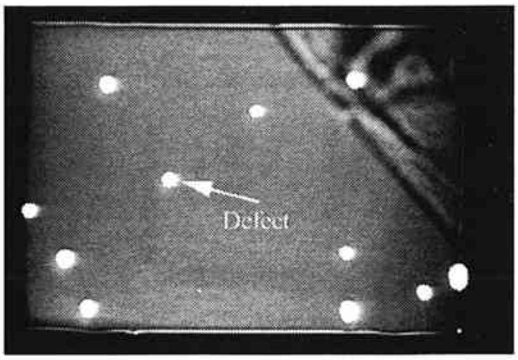


Fig. 3 Screen picture of defects on the HARP target.

Structure of 35-μm-thick HARP target

We chose the new target thickness of 35 μm in consideration of the calculated values of M, lag characteristics, and target voltage, and designed a new target structure that would make it hard for electrons to become trapped in the target. Figure 4 shows the target's structure consisting of a signal electrode, a hole blocking stable layer, the photosensitive and multiplying layer, and an electron blocking layer. In that target, the region of the a-Se layer next to the cerium oxide (CeO2) layer was doped with lithium fluoride (LiF) and arsenic (As) to weaken the internal field and to suppress the crystallization, respectively. Arsenic obstructs the transport of electrons and makes it easy for electrons to be captured in a-Se.

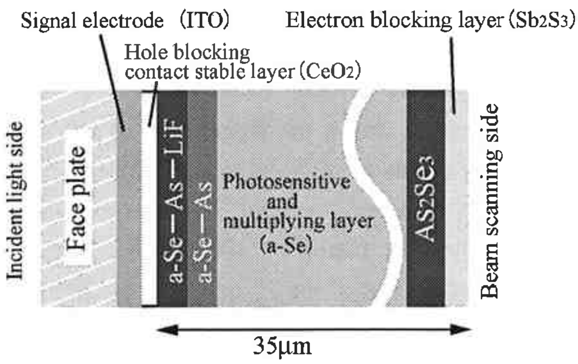


Fig. 4 Structure of 35-μm-thick HARP target.

Consequently, we tried to reduce the thickness of the impurity-doped layer to a requisite minimum in the new structure.

Suppressing defects by high-temperature operation

It is known that the electrical properties of a-Se change sharply according to the glass transition temperature. To investigate the target-temperature dependency of the defect occurrence, we measured the number of defects as function of the target temperature at the applied target electric field of 10^8 V/m after 3 hours continuous operation (Fig. 5).

It was found that the defect occurrence could be suppressed at target temperatures higher than 35°C. Thus, it may be said that the electrical properties of a-Se were changed by the high-temperature operation at the glass transition temperature, and fewer electrons became trapped in the target.

As mentioned above, the new structure and high-temperature operation has made it possible for fewer electrons to be trapped in the target. No defects were observed even after more than ten hours of continuous operation.

Characteristics of the 35-μm-thick HARP target

We put the 35-μm-thick HARP target into an experimental pickup tube using 2/3-inch MM(electromagnetic focusing and electro-magnetic deflection) electron optics and measured the following characteristics of the target.

(1)Sensitivity

Figure 6 shows the signal current and dark current versus target voltage in the 35-μm-thick HARP pickup tube. An avalanche multiplication factor of 1000, about 5 times greater than that of the 15-μm-thick HARP, was obtained at a target voltage of 3450 V. The dark current was as small as 2 nA.

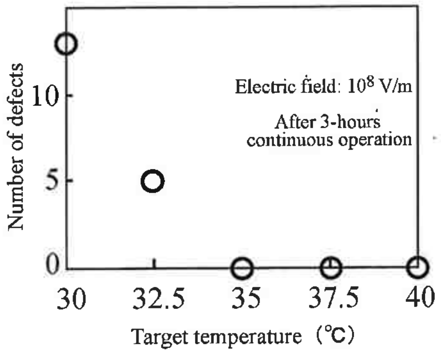


Fig. 5 Dependency of number of defects on target temperature.

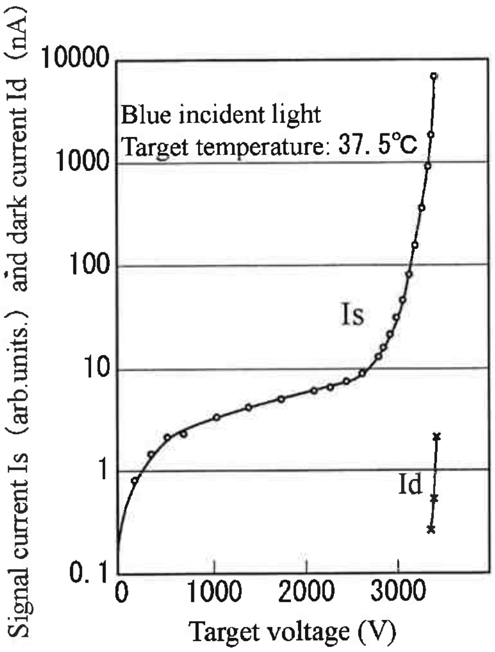


Fig. 6 Current-voltage characteristics of 35-μm-thick HARP tube.

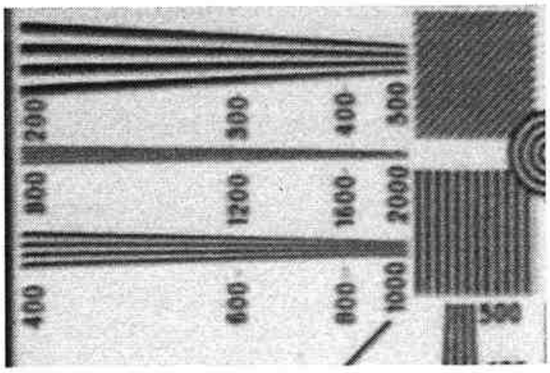
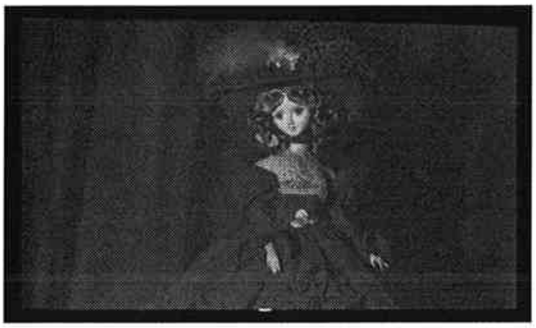


Fig. 7 Monitor picture of test chart reproduced with 35-μm-thick HARP tube.



(a) with 35-μm-thick HARP

(b) with 15-μm-thick HARP

Fig. 8 Monitor pictures produced by HDTV camera equipped with HARP tube (0.1 lx, F1.7).

(2) Lag

The decay lag of the new tube was negligible, because the target has an reduced storage capacitance of about 90 pF due to the increased thickness. The calculated lag value in the third field is 0.02 % below the measuring limit. The thicker target provided a great improvement in lag characteristics.

(3) Resolution

Figure 7 is a monitor picture of the test chart reproduced with the 35-μm-thick HARP pickup tube. The tube has a limiting resolution of 800 TV lines or more. The thicker target does not appear to cause any deterioration in resolution characteristics. This target has enough resolution to be mounted in a high-definition television (HDTV) camera.

Figure 8(a) shows the monitor picture produced by an HDTV camera equipped with the new tube. The illumination is 0.1 lx and the lens iris is at F1.7. Figure 8(b) was taken under the same conditions with an HDTV camera equipped with the 15-μm-thick HARP tube. There is a great difference in the sensitivity between both pictures

Conclusion

We have developed the 35-μm-thick HARP target that enables a multiplication factor of 1000. It was found that the target structure with minimal impurities in the a-Se layer together with operation at a target temperature higher than 35°C can suppress the occurrence of defects. The sensitivity of the fabricated 35-μm-thick HARP target was five times that of the current 15-μm-thick HARP target, with no degradation in picture quality. The decay lag of this target is negligible, and the resolution is 800 TV lines or more.

[1] K. Tanioka, et al., "An Avalanche-Mode Amorphous Selenium Photoconductive Layer for Use as a Camera Tube Target", IEEE Electron Device Lett. EDL-8(1987)

[2] M. Kubota, et al., "Ultrahigh-sensitivity New Super-HARP camera", IEEE TRANS. ON BRODCASTING VOL.42, NO3(1996)

[3] J.L.Moll, Physics of Semiconductor Devices 2nd ed. New York: Wiley(1981)

[4] K. Tsuji, et al., "Impact Ionization Process in Amorphous Selenium, ", J.Non-Crystalline Solids, 114, pp.94-96(1989)

[5] K. Tsuji, et al., "Avalanche Multiplication in Amorphous Selenium, ", The 19th SSDM, B-2-3, pp.91-94(1987)