MVA2013 IAPR International Conference on Machine Vision Applications, May 20-23, 2013, Kyoto, JAPAN

Development of Ultrahigh-sensitivity HARP Pickup Tube and Its Applications

Kenkichi Tanioka
Tokyo Denki University
Home: 2-5-4-502 Toyogaoka, Tama-shi, Tokyo 206-0031, Japan
taniokah@jb3.so-net.ne.jp

Abstract

In 1985, the author found for the first time that an experimental pickup tube with an amorphous selenium photoconductive target exhibits high sensitivity with excellent picture quality because of a continuous and stable avalanche multiplication phenomenon. We named the pickup tube with an amorphous photoconductive target operating in the avalanche-mode "HARP": High-gain Avalanche Rushing amorphous Photoconductor. A color camera equipped with the HARP pickup tubes has a maximum sensitivity of 11 lx at F8. This means that the HARP camera is about 100 times as sensitive as that of a CCD camera for broadcasting. This ultrahigh-sensitivity HARP pickup tube is a powerful tool for reporting breaking news at night and other low-light conditions, the production of scientific programs, and numerous other applications, including medical diagnoses, biotech research, and nighttime surveillance.

1. Introduction

The more sensitive image sensors are, the better they are able to produce clear pictures even in low lighting conditions. Consequently, achieving increased sensitivity has always been an important theme throughout the 80 or so years of research into image sensors.

To meet the strong demand for a television camera with high-sensitivity for broadcasting, we have been studying a very sensitive image sensor at NHK Science and Technology Research Laboratories since the early 1980s. In 1985, the author found for the first time that when an experimental pickup tube with a blocking-type target of an amorphous selenium photoconductor is operated in a strong electric field of about 10^8 V/m, exhibits high sensitivity with excellent picture quality because of a continuous and stable avalanche multiplication phenomenon. We named the pickup tube with an amorphous photoconductive target operating in the avalanche-mode "HARP": High-gain Avalanche Rushing amorphous Photoconductor.

In 1987, NHK and Hitachi, Ltd. developed a practical HARP pickup tube that consisted of a selenium target doped with impurities 2-μm thick [1]. The tube had sensitivity about 10 times greater than that of ordinary pickup tubes, such as SATICONs. After the development of the target 2-μm thick, we developed a greatly improved version of the HARP tube with a selenium target 25-μm thick because sensitivity as a function of the target's electric field increases with the target thickness [2], [3]. This improved version is about 60 times as sensitive as the conventional HARP tube, or about 600 times as sensitive as the SATICON pickup tube. This ultrahigh-sensitivity HARP pickup tube is a powerful tool for reporting breaking news at night and other low-light conditions, the production of scientific programs, and numerous other applications, including medical diagnoses, biotech research, and nighttime surveillance.

In this article, the operational principle, the target structure, the fundamental characteristics of the newly developed HARP pickup tube and its applications are described.

2. Operational principle of the HARP tube

An operational representation of the HARP tube is shown in Figure 1. The light energy absorbed in the selenium target generates an electron-hole pair. The carriers are accelerated by a large electric field, 10^8 V/m, then the hole, which has increased kinetic energy, generates a new electron-hole pair by means of impact ionization. This phenomenon occurs again and again throughout the target. The additional noise produced by the avalanche multiplication is negligible, so the tube has high sensitivity.

3. Target structure

Figure 2 shows a schematic representation of the HARP tube target inside the beam scanning area for

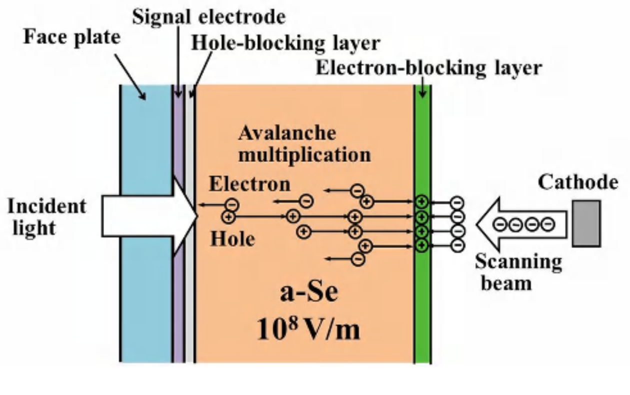

Figure 1. Operational reprsentation of the HARP tube.

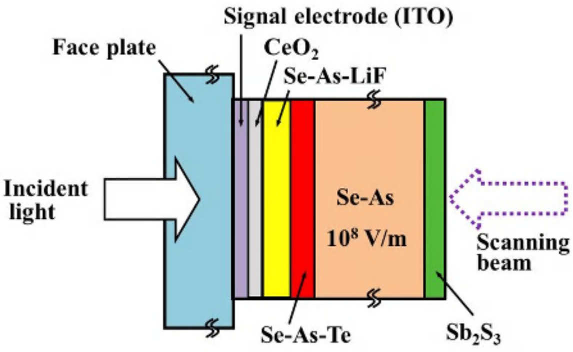

Figure 2. Target strucrure.

Figure 3. External view of the 2/3-inch HARP tube.

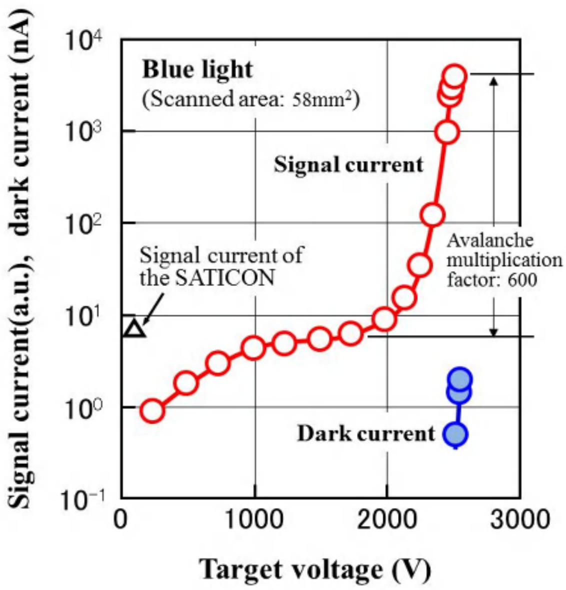

Figure 4. Signal current and dark current versus target voltage.

Figure 5. Appearance of the three-tube HARP camera.

practical use. The photosensitive layer is evaporated amorphous selenium. The target is 25-μm thick. The selenium layer is doped with arsenic to suppress crystallization and the selenium layer is also doped with tellurium to increase the sensitivity for red light. A thin region of the selenium layer next to the signal electrode was doped with a small amount of lithium fluoride to decrease the white blemishes. A thin layer of antimony trisulphide is deposited on the scanning side of the photoconductor to prevent excess electrons entering from the scanning beam, and to reduce the emission of secondary electrons. Between the selenium layer and the signal electrode, a very thin layer of cerium oxide is interposed to make the hole-blocking contact stable, so that even when the target voltage is very high, the target can be operated as a blocking-type target and scanned by a low-velocity beam.

This target was combined with 2/3-inch electron optics for standard television systems. An external view of the 2/3-inch HARP tube is shown in Figure 3.

4. Fundamental characteristics

Figure 4 shows signal current and dark current versus target voltage in the HARP pickup tube with a selenium target 25-μm thick. The incident light was blue. The signal current rapidly increased at target voltages of more than 1800 V. This phenomenon resulted from avalanche multiplication in the selenium layer of the target. The figure shows that an avalanche multiplication factor of 600 can be obtained at a target voltage of 2500 V. The sensitivity of the tube rises in proportion to a rise in the multiplication factor because the signal current is proportional to the multiplication factor in the avalanche regime. For comparison, the figure also shows the signal current measured from the SATICON, which is a conventional pickup tube, for the same incident light intensity. The HARP pickup tube achieves about 600 times this sensitivity at 2500 V. The dark current of the HARP tube also increases in the avalanche regime. However, at a target voltage of 2500 V, the dark current is as little as approximately 2 nA.

The limiting resolution, limited size of the beam, was more than 800 TV lines. With regard to the lag characteristics, the decay lag in the third field after the incident light was turned off was negligible. This is because the target of the tube has a very small storage capacitance of about 130 pF due to the increased thickness. A thicker target provides a great improvement not only in sensitivity but also in lag.

5. HARP camera

An ultrahigh-sensitivity HARP camera equipped with the new tubes has been developed. Its appearance is shown in Figure 5 and its major specifications are shown

Table 1. Specifications of the three-tube HARP camera.

Maximum sensitivity	11 lx, F8
Minimum scene illumination	0.03 lx (F1.7, +24dB)
Signal-to-noise ratio	59 dB
Limiting resolution	800 TV lines
Weight	5 kg
Power consumption	approx. 25W

(a) Image taken with the HARP camera.

(b) Image taken with a CCD camera (+18dB).

Figure 6. Monitor pictures produced by color cameras with HARP tubes and CCDs. Illumination is 0.3 lx and lens irises are at F1.7.

in Table 1. The target voltages of the three-tube HARP camera were adjusted to about 2500 V for each channel. Figure 6 (a) shows a monitor picture produced by the HARP camera. The illumination is 0.3 lx and the lens iris is at F1.7. To illustrate the big difference in sensitivity between the HARP camera and a CCD camera for broadcasting, Figure 6 (b) shows a picture taken under the same conditions with the three-CCD camera (+18 dB). In spite of the dim lighting, the picture produced by the HARP camera is very clear, but a doll in the picture taken with the CCD camera looks like a ghost because of lack of sensitivity. It was confirmed that the HARP camera has a maximum sensitivity of 11 lx at F8. This means that the HARP camera is about 100 times as sensitive as the CCD camera for broadcasting. This HARP camera can take color pictures of objects under conditions so dark that the objects are imperceptible to the naked human eye. It goes without saying that the sensitivity of the camera can be decreased by decreasing the target voltage, so that the camera is capable of producing excellent picture quality over a wide-range of shooting conditions from daylight to moonlight.

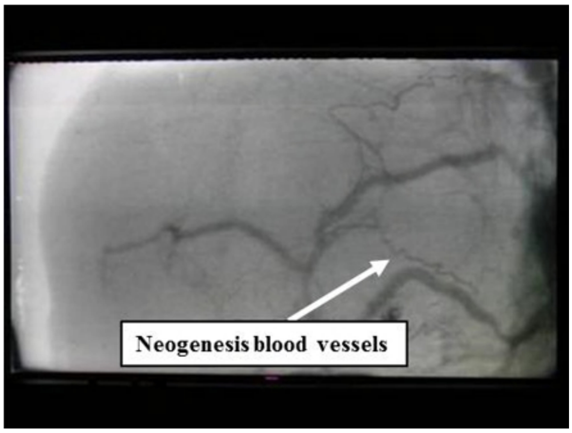

Figure 7. X-ray image of minute blood vessels.

6. Applications in medical research

The ultrahigh-sensitivity and superior picture quality of HARP cameras have also led to a considerable amount of interest from medical and scientific fields. This section describes how it is applied to research into X-ray medical diagnosis.

A notable example is the potential use of HARP cameras in next-generation X-ray medical diagnosis systems. This research has been done in cooperation with other organizations such as the Tokai University Medical Faculty group and the High Energy Accelerator Research Organization in Japan. The X-ray equipment currently used in hospitals is only able to see large blood vessels with a diameter of at least 0.2–0.5 mm, but this study aims to make it possible to obtain clear images of blood vessels that are several times smaller. It has been said that if narrow blood vessels with a diameter of 0.1 mm or less can be imaged, then it should be possible to detect cancer earlier and make better diagnosis of conditions such as heart attacks and cerebrovascular disorders.

For this purpose, it is necessary to have a special variety of X-rays that are absorbed well by a tiny quantity of contrast medium inside the narrow blood vessels to be imaged, and a TV camera that can clearly reproduce the image formed on a fluorescent screen (placed behind the subject being viewed) due to this absorption. For the special X-rays, we are using monochromatic X-rays with a specific energy obtained from synchrotron radiation. The TV camera is required to have superior sensitivity and resolution. This is because the image on the fluorescent plate is finely detailed and very dark (so as to restrict the exposure of the subject to X-rays).

We have therefore conducted experiments involving the use of an ultra-high sensitivity and high-resolution HD (High definition) HARP camera in the imaging section of a next-generation X-ray medical analysis system. Figure 7 shows a photograph (obtained using this system) of tiny blood vessels called neogenesis blood vessels that developed in cancerous parts of a mouse. This image shows narrow blood vessels of a characteristic shape with a diameter of 0.1 mm or less, which it has not been possible to see hitherto. This technology is attracting interest as an X-ray diagnosis technique that can lead to the early detection of cancer.

In addition, since a HARP target can convert X-rays into electrons directly, it should be possible to exploit this capability to produce X-ray imaging devices with unparalleled levels of resolution and sensitivity. Consequently, this technology is attracting high levels of interest for applications such as X-ray area detectors for protein crystallographic analyses.

7. Conclutions

We have developed an ultrahigh-sensitivity HARP pickup tube using the avalanche multiplication effect in an amorphous selenium photoconductive target. The pickup tube is a powerful tool for reporting breaking news at night and other low-light conditions, the production of scientific programs, and numerous other applications, including X-ray medical diagnosis systems.

Acknowledgment

I would like to extend sincere thanks to all those at Hitachi Ltd., Hamamatsu Photonics K. K., Hitachi Kokusai Electric Inc., and NHK Science and Technology Research Laboratories for their cooperation in research and otherwise over long years developing the HARP pickup tube and cameras that use it.

References

[1] K. Tanioka, et al.: "An avalanche-mode amorphous selenium photoconductive layer for use as a camera tube target," *IEEE Electron Device Letters*, vol.EDL-8, no.9, pp.392-394, 1987.

[2] M. Kubota, et al.: "Ultrahigh-senstivity New Super-HARP Camera," *IEEE Trans., Broadcast*, vol.42, no.3, pp.251-258, 1996.

[3] K. Tanioka, et al.: "Ultra-high-sensitiviy New Super-HARP Pickup Tube and Its Camara," *IEICE Trans., Electron.*, vol.E86-C, no.9, pp.1790-1795, 2003.