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HARP: A Highly Sensitive Pickup Tube Target Using Avalanche Multiplication in Amorphous Selenium

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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. The target operating in the avalanche-mode is called HARP (High-gain Avalanche Rushing amorphous Photoconductor). It was confirmed that a color camera equipped with the HARP pickup tubes is about 100 times as sensitive as that of a CCD camera for broadcasting.

Key words: amorphous selenium, avalanche multiplication, HARP, photoconductor, pickup tube

1. INTRODUCTION

To meet the strong demand for a television camera with high-sensitivity for broadcasting, we had been studying a very sensitive image sensor at NHK Science & 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 pickup tube.” 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 pickup tube, or about 600 times as sensitive as the SATICON pickup tube. This ultrahigh-sensitivity HARP 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 night-time surveillance. In this review, the operational principle, the target structure, the fundamental characteristics of the 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 that 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 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.

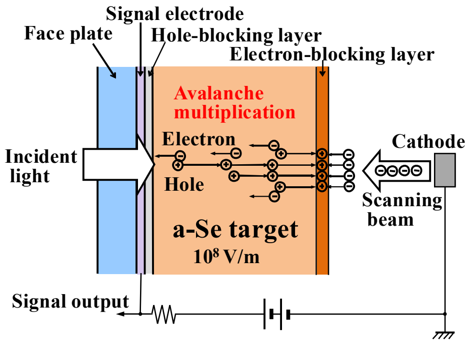

Figure 1 Operational representation of the HARP tube.

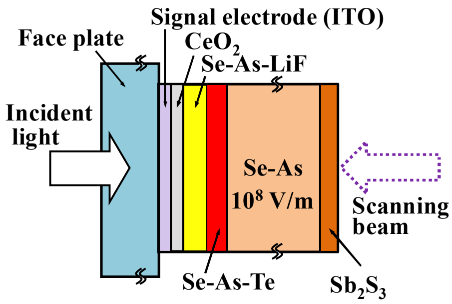

Figure 2 Target structure.

4. FUNDAMENTAL CHARACTERISTICS

Figure 3 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.

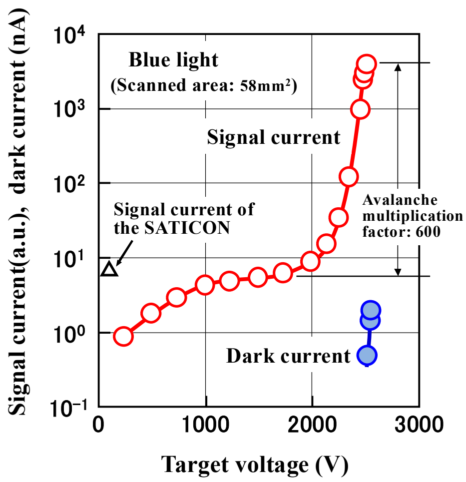

Figure 3 Signal current and dark current versus target voltage.

5. HARP CAMERA

An ultrahigh-sensitivity HARP camera equipped with the tubes has been developed. The target voltages of the three-tube HARP camera were adjusted to about 2500 V for each channel. Figure 4 (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 4 (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.

(a) A picture taken with the HARP camera. (b) A picture taken with a CCD camera (+18dB).

Figure 4 Monitor pictures produced by color cameras with HARP tubes and CCDs. Illumination is 0.3 lx and lens irises are at F1.7.

In addition, the HARP technology is attracting interest as an X-ray diagnosis technique that can lead to the early detection of cancer. In 2016, Prof. Wei Zhao, The State University of New York at Stony Brook, and her colleagues announced that they have succeeded in development of the solid-state HARP for X-ray medical diagnosis [4].

6. 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.

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Biographies

K. Tanioka received his Ph.D. from Tohoku University in 1994. From 1976 to 2008, he worked for NHK Science & Technology Research Laboratories (STRL), Tokyo, where he was engaged in the research of an amorphous selenium photoconductor for image pickup devices. He has contributed not only to the advanced broadcasting technologies but also to the fields other than broadcasting, e.g., observation of deep sea, living cells, X-ray images, etc. In 2006, he was appointed Director-General of NHK STRL. He retired from NHK in 2008. He is a visiting professor of Tokyo Denki University. Dr. Tanioka is an inventor of the highly sensitive HARP pickup tube. He was awarded fourteen prizes including the Imperial Invention Prize in 1996. He is an honorary member of The Institute of Image Information and Television Engineers of Japan (ITE).