Ultra-high-sensitivity New Super-HARP Pickup Tube

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Abstract

We developed an ultra-high-sensitivity "New Super-HARP" pickup tube by using avalanche multiplication in a photoconductive target. The pickup tube, which has an amorphous selenium target 25 μm thick, exhibited an avalanche multiplication phenomenon at applied target voltages of more than 1800 V. A thin region of the selenium layer next to the signal electrode was doped with tellurium to increase the quantum efficiency of the target. The performance of the tube was evaluated in a color camera. It was found that the "New Super-HARP" pickup tube is about 100 times more sensitive than CCDs.

I. Introduction

To meet the strong demand for a television camera with ultra-high sensitivity for broadcasting, we have been studying a very sensitive image sensor since the early 1980s. In 1987, we announced for the first time that we had developed an experimental pickup tube with an amorphous selenium photoconductive target that exhibited high sensitivity with excellent picture quality because of a continuous and stable avalanche multiplication phenomenon [1]. We named the pickup tube with an amorphous photoconductive layer operating in the avalanche-mode "HARP": High-gain Avalanche Rushing amorphous Photoconductor.

In the early 1990s, we developed a practical pickup tube that consisted of a selenium layer doped with impurities 6-8 μm thick [2]. The tube had sensitivity about 10 times greater than that of CCDs. This device, which we called the "Super-HARP" pickup tube, has already been used in program production.

We have recently developed a greatly improved version of the Super-HARP tube with a selenium layer 25 μm thick because sensitivity as a function of the target's electric field increases with the target thickness. This improved version, which we call the "New Super-HARP" pickup tube, is about 10 times as sensitive as the Super-HARP tube, or about 100 times as sensitive as CCDs. The target structure and fundamental characteristics of the New Super-HARP pickup tube follow.

II. Operational Principle

An operational representation of the HARP tube is shown in Fig. 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.

III. Target Structure and Fabrication

Except for the thickness and the amount of tellurium in the selenium layer, the target structure inside the beam scanning area of the New Super-HARP is almost the same as in the conventional HARP target. However, a newly designed structure outside the scanning area of the target stabilizes the beam scanning inside the scanning area even when the applied target voltage is very high.

We increased the thickness of the target to 25 μm; therefore, the applied target voltage had to be raised to about 2500 V in order to cause avalanche multiplication. Outside the beam scanning area of the target, the surface potential rose to almost the target voltage. Because of this, a very large difference in surface potential appeared between the outside of the beam scanning area and the inside, where it only rose to about 20 V at most. This distorted the picture quality at the edges as the electron beam was bent toward the higher potential, and the increase in secondary electron emissions from the target caused spurious images to appear as shown in Fig. 2. To solve these problems, the new insensitive target structure was designed and fabricated outside of the beam scanning area. The structure of the insensitive target is compared in Fig. 3 to that of the sensitive target inside the beam scanning area. Basically, the insensitive target (Fig. 3(b)) was fabricated by adding a selenium layer doped with arsenic to the sensitive target (Fig. 3(a)). Lithium fluoride was doped near the boundary surface of the extra layer. A band model of this insensitive target is shown in Fig. 4. It consists of an optical absorption layer and a transit layer for holes. Initially, a uniform electric field is applied through the target (the broken line of Fig.4). Once incident light has illuminated the target, positive space charges are formed in the selenium layer doped with LiF in the extra layer. This reduces the internal electric field almost to zero, making the excited carriers disappear through recombination. The electric field of the transit layer for holes is kept less than 8×10^{7} V/m by making it about 30 % thicker than the optical absorption layer. No avalanche multiplication effect occurs at this electric field intensity. The sensitivity outside the bean scanning area was measured. It was confirmed that the sensitivity there decreased to $1/10^{6}$ of the sensitivity inside the beam scanning area. As mentioned above, the new insensitive target introduced outside the beam scanning area made it possible to prevent an increase in surface potential. No picture distortion or spurious images were observed even with 2500 V applied to the target, so stable operation of the New Super-HARP tube is dramatically assured.

As shown in Fig. 3, a thin region of the selenium layer next to the signal electrode was doped with tellurium to increase the quantum efficiency for green and red incident light. The concentration of tellurium in the layer is about 15 % by weight.

IV. Fundamental Characteristics

Figure 5 shows signal current and dark current versus target voltage in the New Super-HARP pickup tube. The incident light was green. 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 several hundred 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-mode region. The dark current also increases in the avalanche-mode region. However, at a target voltage of 2500 V, the dark current is as little as approximately 2 nA.

Figure 6 shows the spectral response characteristics of the New Super-HARP target. In order to show the increased quantum efficiency achieved for it by using a selenium layer doped with tellurium, that layer is compared to a selenium layer without tellurium in Fig. 6. The quantum efficiency of the New Super-HARP target for green incident light (wavelength of 540 nm) was found to be double that of the selenium layer without tellurium. We estimated that the signal to shot-noise ratio was improved by three dB.

The limiting resolution, limited size of the beam, was more than 800 TV lines. The decay lag in the third field after the incident light was turned off was negligible.

V. Color Camera Test

A three-tube color camera was used to evaluate the performance of the new tubes. The target voltages were adjusted to about 2500 V for each channel. Figure 7(a) shows a monitor picture produced by the three-tube color camera equipped with the new tubes. The illumination is 0.15 lx and the lens iris is at F1.7. To illustrate the big difference in sensitivity between the New Super-HARP camera and a CCD camera, Fig. 7(b) shows a picture taken under the same conditions with a three-CCD color camera. The comparison demonstrates that the New Super-HARP camera has a maximum sensitivity of 11 lx, F8. This means that the new camera is about 100 times as sensitive as CCD cameras. It can take color pictures of objects under conditions so dark that the objects are imperceptible to the naked human eye.

Conclusions:

By increasing the target thickness, we have developed a New Super-HARP pickup tube that has better performance than the conventional HARP tube. A special insensitive target structure outside the beam scanning area was added to achieve stable operation at a very high target voltage of 2500 V. The New Super-HARP tube is about 100 times as sensitive as CCDs. A handheld camera equipped with the new tubes can serve as a powerful tool for reporting breaking news at night, for the production of scientific programs, and for other applications.

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[1]K. Tanioka, J. Yamazaki, K. Shidara, K. Taketoshi, T. Kawamura, S. Ishioka and Y. Takasaki, "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, Sept. 1987.
[2]J. Yamazaki, K. Tanioka and K. Shidara, "Development of the Super-HARP Camera, a Rival to the Human Eye, for the Next Generation of Broadcasting", SMPTE, A Television Continuum-1967 to 2017, pp.100-108, 1991.

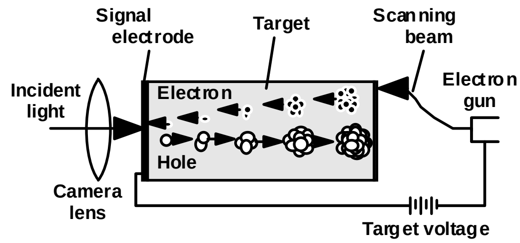


Fig. 1: Operational representation of the HARP tube.

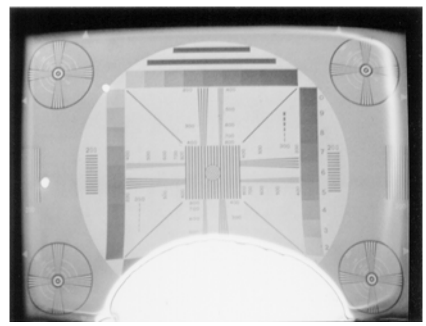


Fig. 2: Spurious images caused by secondary electron emission.

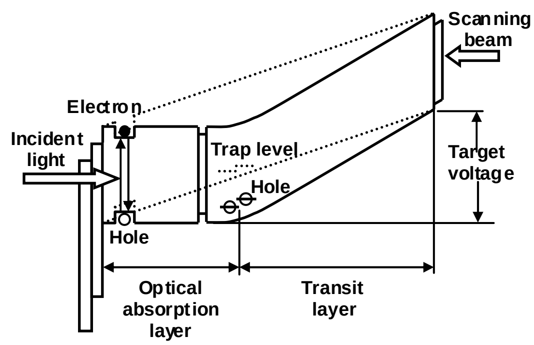


Fig. 4: Band model of the insensitive target.

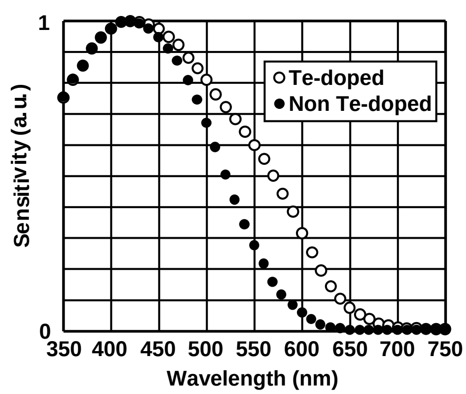


Fig. 6: Spectral response characteristics of the New Super-HARP target.

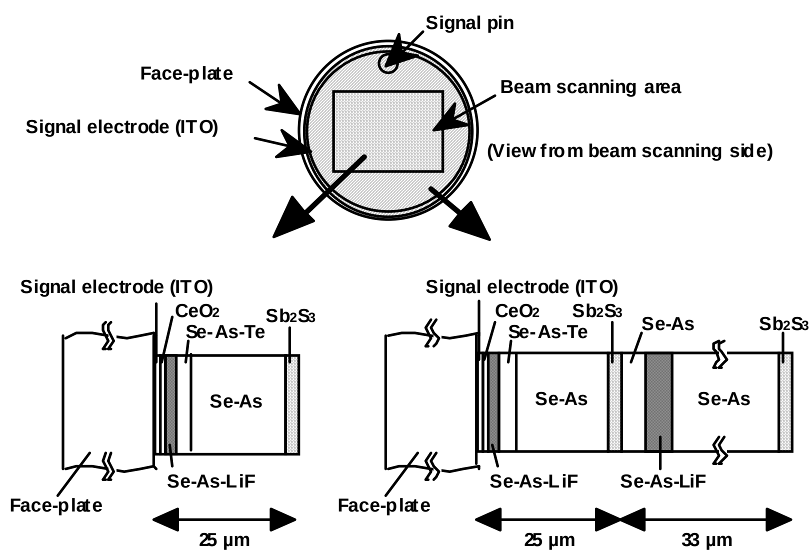


Fig. 3: Structure of the New Super-HARP target (a) inside beam scanning area and (b) outside beam scanning area.

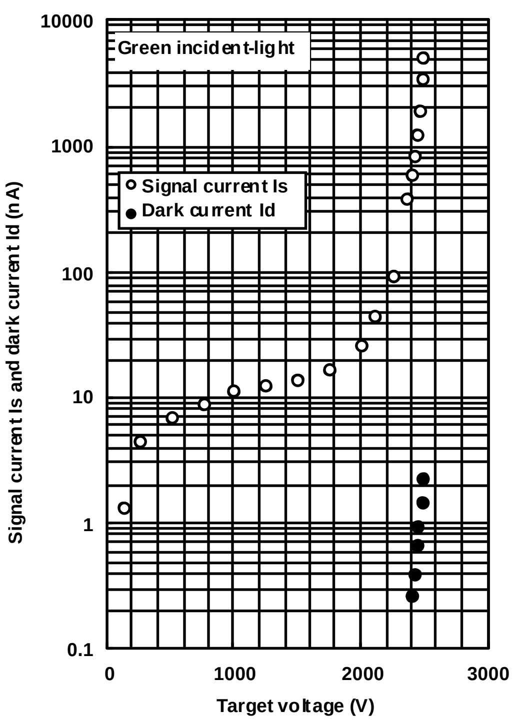
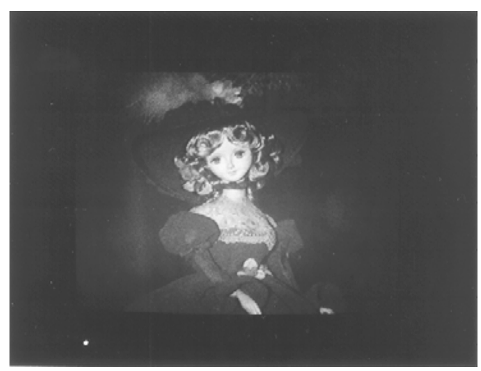
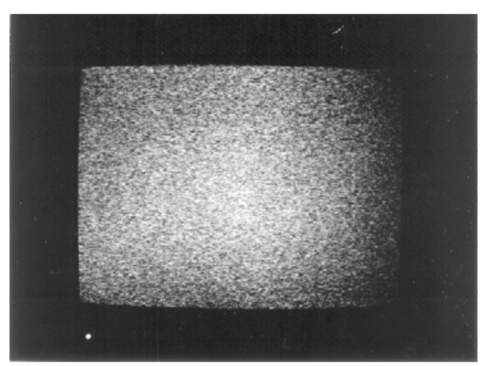


Fig. 5: Signal current and dark current versus target voltage in the New Super-HARP pickup tube.



(a) Image taken with the New Super-HARP camera.



(b) Image taken with a CCD camera (+30dB).

Fig. 7: Monitor pictures produced by color cameras with New Super-HARP tubes and CCDs. Illumination is 0.15 lx and lens irises are at F1.7.