Very Sensitive UV Pick-up Tube Using Avalanche Multiplication in an Amorphous Selenium Target

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Abstract

Ultraviolet (UV) pick-up technology is now entering a new era with the appearance of the High-gain Avalanche Rushing amorphous Photoconductor (HARP) tube. HARP exhibits extremely high sensitivity with high resolution and low lag for UV as well as for visible light, and it has been found that HARP is a powerful tool for picking up UV images applicable to High Definition TV (HDTV). Besides, study of the HARP characteristics for UV light enable us to separate the generation and avalanche multiplication phenomena of photocarriers in the amorphous selenium.

Introduction

In 1987, the authors developed a revolutionary photoconductive target, called 'HARP', using an avalanche multiplication effect in an amorphous selenium layer to which a large electric field was applied.[1] A HARP tube camera with ten times more sensitivity than conventional cameras was used for HDTV broadcasting of the Seoul Olympic Games in 1988. Recently, a more sensitive Super-HARP tube has been developed[2] and has successfully videotaped HDTV pictures of the northern lights for the first time ever. The HARP technology will bring great changes to TV program production and news gathering.

In order to apply the HARP technology for picking up weak ultraviolet light, the authors test-manufactured a HARP tube with UV transmittable materials for the face-plate and signal electrode and evaluated the characteristics of the tube for incident UV light.

Test-manufacture of UV HARP

UV is generally defined as the wavelengths between 10nm and 400nm. However, UV of less than 200nm, the so called vacuum UV light, is absorbed by oxygen in the air. Accordingly, UV image pick-up targets the wavelengths of 200-400nm.

The choice of materials for the face-plate and signal electrode, the so called 'window materials', is especially important in the case of an image pick-up tube for invisible light because the materials affect the characteristics of the spectral response of the tube. Fig.1 shows the spectral transmittance of some kinds of glasses. Synthetic quartz glass and calcium fluoride (CaF_2) glass have large transmittances of about 90% at wavelengths of 200-700nm. On the other hand, the transmittance of Corning7056, Ohara E2 and E8 glasses drops sharply at wavelengths under 350nm. The comparisons of spectral transmittance for several conductive films are shown in Fig.2. Aluminum shows large transmittance over 50% for the whole UV wavelength range and also has low resistivity, as shown in Table.1. Synthetic glass and aluminum were thus used for the face-plate and signal electrode, respectively, of the experimental UV HARP tube. Fig.3 shows the structure of the experimental target. The photosensitive layer of amorphous selenium is 2μm thick and doped with arsenic to prevent crystallization. A thin layer of germanium oxide (GeO_2) and cerium oxide (CeO_2) is interposed between the signal electrode and the selenium layer to make the hole-blocking contact stable. A porous antimony trisulphide (Sb_2S_3) layer is deposited on the beam scanning side for electron beam landing. Total transmittance, including the face-plate, signal electrode and hole blocking layer, is about 60% at 300nm.

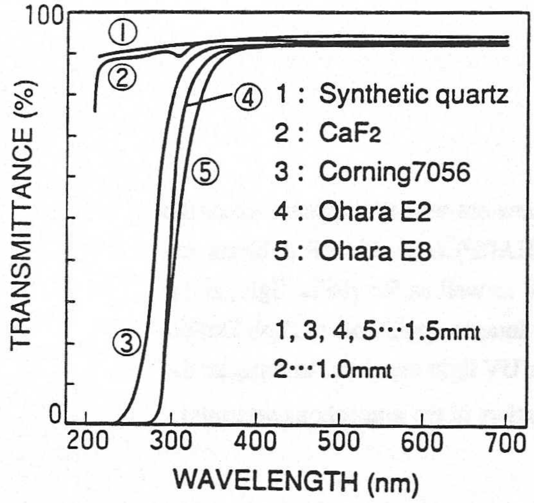

Fig.1 Spectral transmittance of glasses

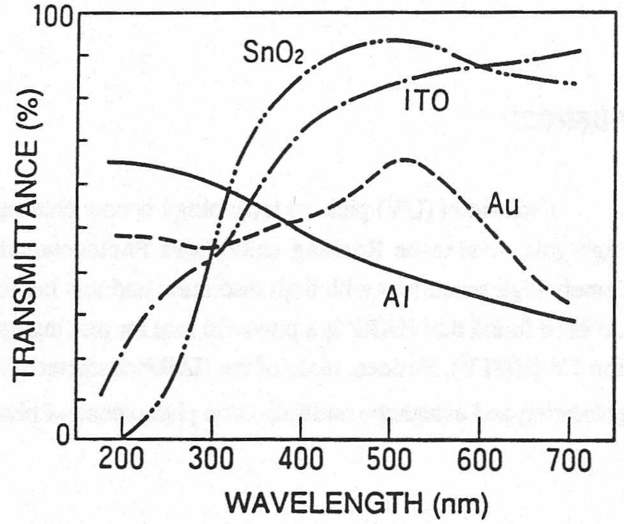

Fig.2 Spectral transmittance of conductive films

	Method of deposition	Thickness(Å)	Sheet resistance(Ω/m)
ITO	Sputtering	280	250
SnO2	CVD	500	750
Au	Evaporation	94	150
Al	Evaporation	80	30

Table.1 Thickness and resistance of conductive films

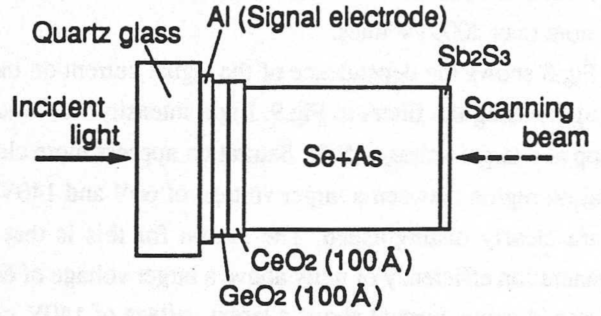

Fig.3 Schematic diagram of the experimental target

UV characteristics of the experimental tube

Fig.4 represents the result of measurement of the spectral response. Fig.5 shows corrected values of Fig.4 in consideration of the transmittance of the window materials and the light-transfer characteristic of the tube ($\gamma < 1$). In other words, Fig.5 shows the spectral response of the amorphous selenium itself. The tube has high sensitivity corresponding to a quantum efficiency in excess of unity at a target voltage of 250V for UV light as well as for visible light.

The build-up and decay-lag characteristics of the tube at a target voltage of 250V is shown in Fig.6. The decay-lag in the third field after the incident UV light was turned off was 4.6%. This value is equal to the capacitive lag of 4.6% calculated from a target storage capacitance of 1600pF and an electron-beam temperature of 3000K. This indicates that the lag of the tube can be reduced by increasing the thickness of the target.

Amorphous selenium, the main material of the HARP target, displays very high resolution because it has no

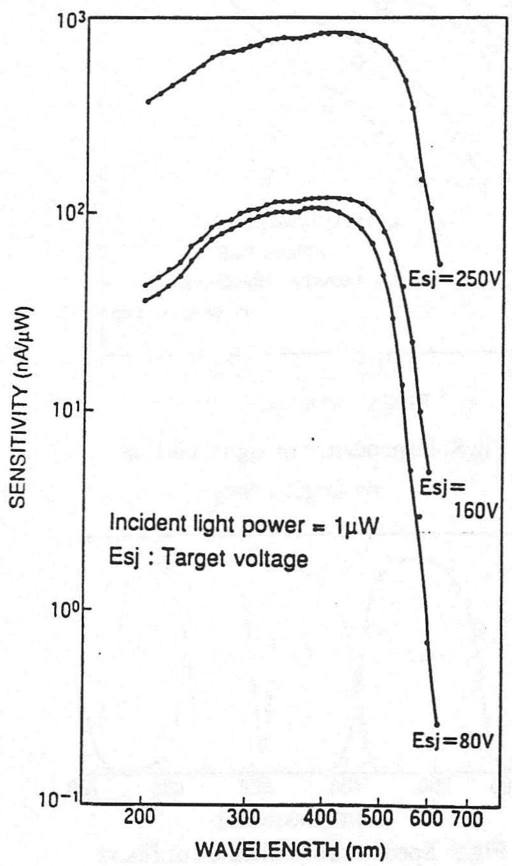

Fig.4 Spectral response

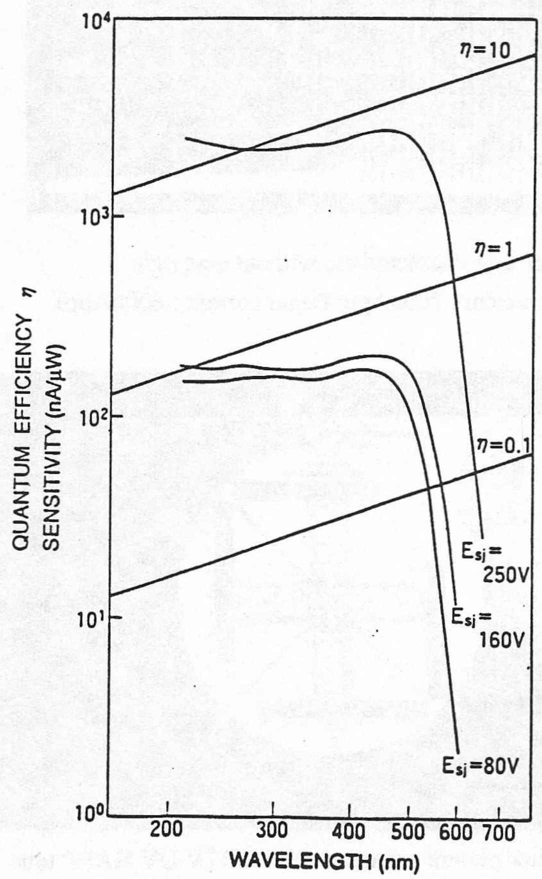

Fig.5 Corrected spectral response

optical scattering and exhibits high resistivity. Fig.7 is a monitor picture of the HDTV resolution chart produced with the UV HARP tube combined experimentally with HDTV electron optics. It shows that the limiting horizontal resolution is more than 2000TV lines.

Fig.8 shows the dependence of the signal current on the target voltage measured for incident light at various wavelengths using the filters in Fig.9. Light intensity was adjusted in each case to the value giving signal current of 200nApp at a target voltage 250V. Saturation appears more clearly at shorter wavelengths. With UV light especially, a saturation region between a target voltage of 60V and 140V and a multiplication region above a target voltage of 140V are clearly distinguished. The reason for this is that incident UV light generates photocarriers with the photogeneration efficiency of unity above a target voltage of 60V due to the large photon energy.[3] Therefore, the rate of increase in signal current above a target voltage of 140V indicates the very avalanche multiplication factors. The value of dark current of this tube was about 0.5nA at a target voltage of 250V.

Fig.10 shows the signal-to-shot noise ratio (SNR) performance versus the avalanche multiplication factor G of the 12μm thick HARP target. The values of G were obtained from the current-voltage characteristics, as mentioned above. The results of SNR measurement for incident UV light are better than the value of shot noise calculated by the formula ;

$$S/N_{shot}\,(dB)=20\log(I_s/\sqrt{2eI_sGBK})$$

(I_s=200nApp : signal current, e=1.602$\times 10^{-19}$C : electron charge, B=4.2MHz : bandwidth, K=1 : excess noise factor)
We think that this feature is influenced by the lag, light-transfer and resolution characteristics of the tube and we have

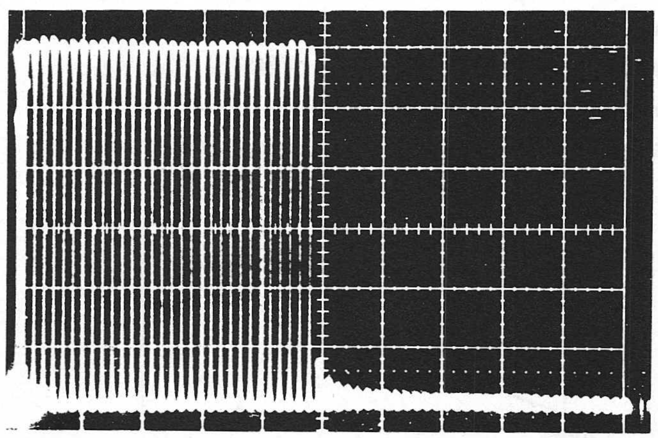

Fig.6 Lag characteristic without bias light
(Signal current : 200nApp Beam current : 600nApp)

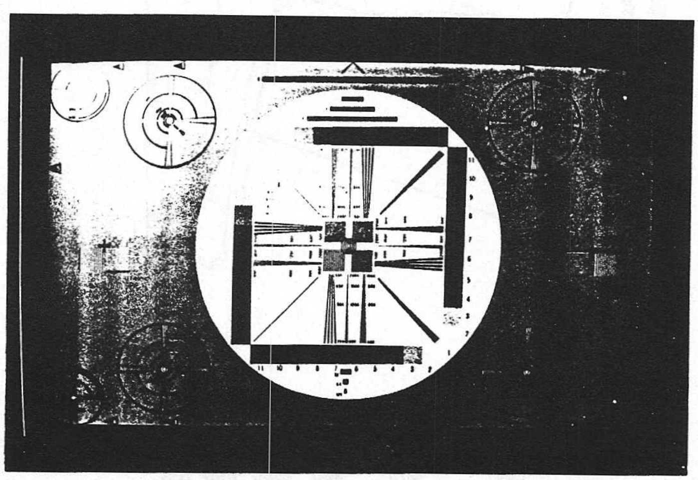

Fig.7 Monitor picture produced with HDTV UV HARP tube

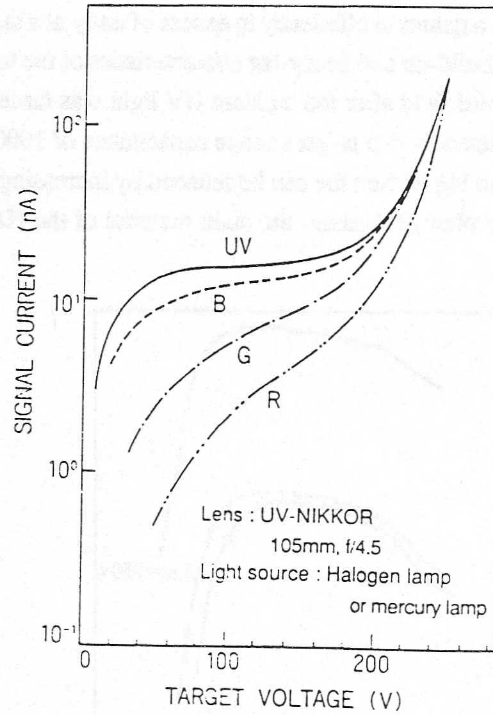

Fig.8 Dependence of signal current on target voltage

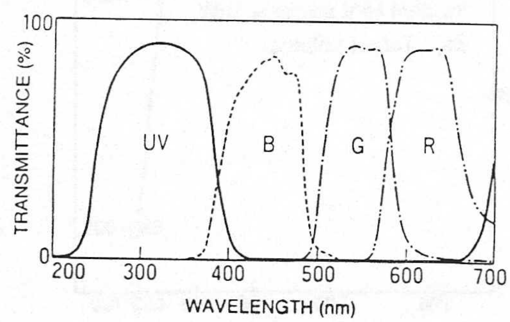

Fig.9 Spectral transmittance of filters used in measurements

still been making further investigation.

Application of the UV HARP

Fig.11 is a picture of a human fingerprint produced by an HDTV camera equipped with a UV HARP tube. The rugged surface of the finger is extremely clear in the high resolution image. Applications of UV pick-up technology have now extended into many fields, including medical science, biology, astronomy, criminal investigation and metal fatigue inspection, because much useful information which unattainable using visible light can be perceived with UV. However, UV light is greatly attenuated by optical systems such as lenses and prisms and the use of small quantities of UV exposure is desirable for reason of safety. It has been confirmed that the high sensitivity UV pick-up technology of HARP tubes meets these demands.

Conclusion

In order to realize high sensitivity UV pick-up devices, we develop a UV HARP tube with UV transmittable materials for the face-plate and signal electrode. The tube exhibit very high sensitivity for UV light, without deterioration of picture quality, never obtained with conventional image pick-up devices. Besides, since UV light is absorbed completely very close to the surface of the target layer and shows small recombination due to the large photon energy, the generation and avalanche multiplication phenomena in the amorphous selenium can be separated by investigating the UV characteristics of HARP tube.

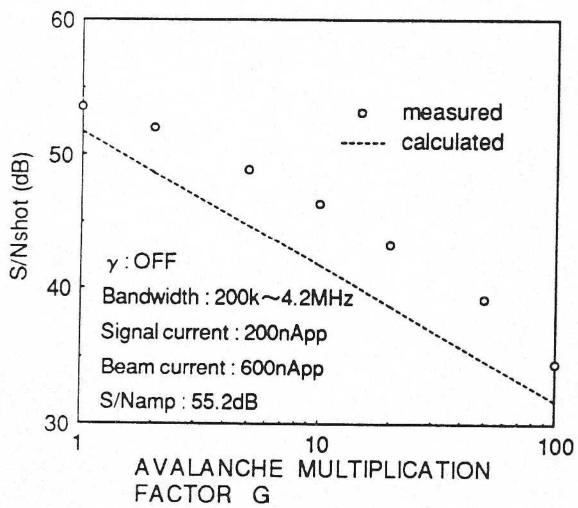

Fig.10 SNR performance versus avalnche multiplication factor

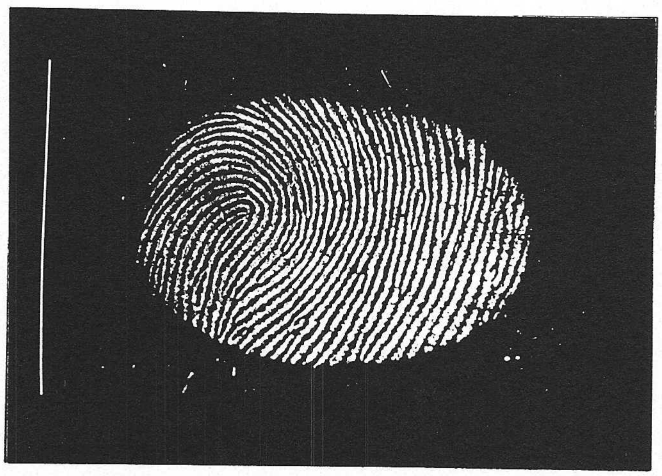

Fig.11 Example picture obtained with UV light (a human fingerprint on glass)

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