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A Camera Tube with a Silicon Diode Array Target

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A variety of electronic cameras have been developed for television systems.[1] Among these the vidicon[2] and the Plumbicon[3] have the inherent advantages of high sensitivity, small size, and simple mechanical construction. The operating principles of the vidicon and the Plumbicon are quite similar since they both utilize a thin photoconductive layer to convert the optical image to a stored charge pattern which is periodically scanned and erased by an electron beam. Erasing the charge pattern creates the video signal. However, there is a distinct difference in overall device performance since the photoconducting target in the Plumbicon (PbO) is deposited in a manner to form a single, large area, graded p-n junction, each layer having high resistivity. In the vidicon, the evaporated layers of Sb_2S_3 forming the target behave like a semi-insulating photoconductor.

A new type of target consisting of an array of electrically isolated reverse-biased diodes, as first suggested by Reynolds,[4] later discussed by Heijne[5] and more recently by Wendland[6], has several valuable attributes.

(*i*) The dark current and the light-induced current can be essentially independent of target (reverse bias) voltage and the response characteristic can have a gamma of unity as in the Plumbicon.

(*ii*) The time constant associated with the charge leakage of an array of reverse-biased diodes can be very much larger than the intrinsic (dielectric relaxation) time constant of the bulk material. This implies that an infrared responsive camera operating at room temperature can be realized.

(*iii*) The spectral response can cover a wide range including the visible and consequently much greater and more uniform sensitivity can be achieved than in the vidicon or Plumbicon.

(*iv*) The target performance is insensitive to electron beam bombardment and is unaffected by intense light sources so that deleterious burn-in does not occur.

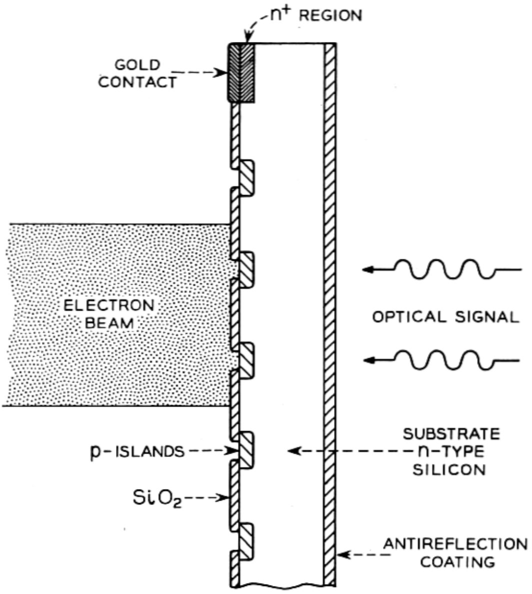

Fig. 1 — Schematic drawing of the diode array. In practice the perimeter thickness was made ≈4 mils to obtain a self-supporting structure.

(*v*) There is no image persistence due to photoconductive lag.

(*vi*) The assembled tube may be processed using standard vacuum techniques including a high temperature bake.

(*vii*) The operating lifetime can be expected to exceed that of the vidicon and Plumbicon by a considerable margin.

In this brief, experimental results obtained from targets consisting of a 540×540 array of reverse-biased Si diodes are reported. The substrate is 10 Ω-cm, n-type Si, is self-supporting and can be anti-reflection coated. The p-type islands are formed by diffusing boron through 8μ diameter holes in the SiO_2 film, the center-to-center spacing between holes being 20μ. This arrangement provides sufficient diode capacitance $\approx 1000\ \mu\mu fd/\text{cm}^2$) to integrate the diode photoresponse over the time interval of 1/30 sec (one frame period in commercial television). Ohmic contact to the array is obtained via the gold ring evaporated onto the n^+ region near the perimeter of the Si wafer chip.

In normal operation, the electron beam, the diameter of which is larger than that of a single diode, periodically charges the p-type islands down to cathode (ground) potential while the potential of the n-type material is held at ≈5 to 10 volts. This potential difference can be sustained for a normal television frame time so long as the dark current is $< 5 \times 10^{-13}$ amps/diode. The SiO_2 film, also charged down to cathode potential by the beam, remains there and isolates the substrate from the beam. The incident light associated with the image is absorbed in the Si, creating hole-electron pairs. Since the thickness of a self-supporting wafer is $\geqq 10^{-3}$cm and the absorption coefficient of Si for visible light is greater than 3000 cm^{-1}, most of the hole-electron pairs will be generated near the incident surface; the minority carriers (holes) then diffuse to the depletion region of the diodes, discharging the diodes by an amount proportional to the light intensity. The recharging of the diodes by the scanning beam creates the video signal.

An exact analytical evaluation of the performance of the diode array shown in Fig. 1 is quite complicated. However, with a simpler model in which the p-regions of the array are replaced by one large homogenious p-region with no lateral conductivity, it is possible to estimate the loss in light sensitivity and resolution due to minority carrier recombination and diffusion. An analysis of this simpler model indicates that for a minority carrier lifetime of ≈ 10 μsec, a surface recombination

Fig. 2—Photograph obtained with the 540 × 540 diode array target. The subject was a black and white transparency illuminated with a tungsten lamp.

velocity of $\approx 10^4$ cm/sec, and a wafer thickness of $\approx 10^{-3}$ cm, the collection efficiency (ratio of collected holes to generated holes) for uniform illumination with visible light is $\approx$80 percent. Lateral diffusion will degrade the spatial resolution. For example, if the spatial variation in the visible light were sinusoidal with a period corresponding to 4×10^{-3} cm or twice the center-to-center spacing of the diodes, the ac signal would be reduced to $\frac{5}{8}$ of the dc signal.

The performance of a Si diode array is illustrated by Fig. 2. This photograph was obtained from a Kintel[7] closed circuit system with commercial television standards. The usual vidicon camera tube was replaced by a tube using a 540 × 540 diode array target. The defects in the picture reflect a localized high dark current and can be partly attributed to defects in the bulk crystal from which the array was fabricated and to defects in the SiO_2 film.

The measured spectral response of a camera tube with a diode array target is given in Fig. 3 for two wafer thicknesses. In these measure-

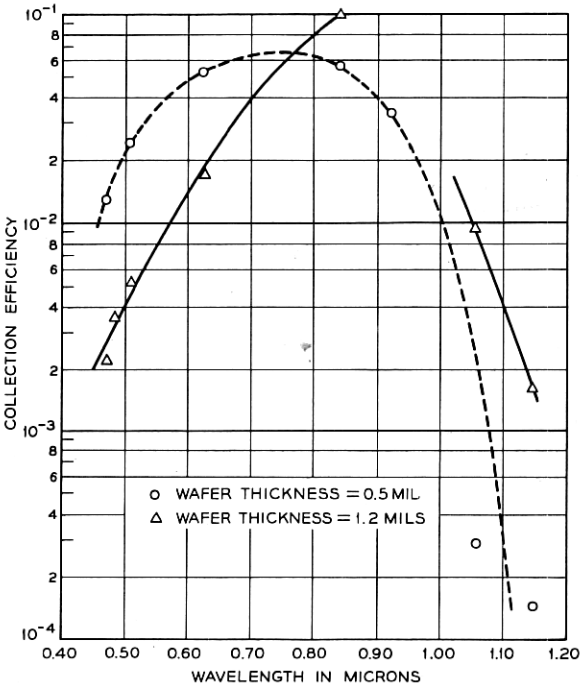

Fig. 3 — Spectral response without reflection loss corrections of experimental diode array targets for two wafer thicknesses. The photograph shown in Fig. 2 was obtained with the 1.2-mil target.

ments, the whole diode array was illuminated with a uniform light intensity and the light induced dc current (average video signal) in the target lead was measured. Continuous laser transitions were used to obtain the absolute response at several wavelengths. The actual target collection efficiency was better than that indicated in the figure since no anti-reflection coating was used and no reflection loss corrections were made. For Si, the reflection coefficient varies from 30 percent in the near infrared to $\approx$65 percent in the blue portion of the spectrum.[8] With a single layer anti-reflection coating, the reflection can be reduced to a few percent. This implies that if such a coating had been used on the experimental targets a maximum collection efficiency of $\approx$20 percent would have been obtained. At this maximum, the sensitivity would have been 0.16 μamps/μwatt. Because of its wider spectral response, the camera tube with a diode array target was $\approx$25 times more sensitive than an 8134 RCA vidicon for illumination with an incandescent lamp at normal operating temperature. The measured gamma was unity.

The observed dark current for the entire array was $\approx 5 \times 10^{-8}$ amps for a reverse bias of 5 to 10 volts. This implies that the leakage current per diode was $\approx 2 \times 10^{-13}$ amps. The resolution was not limited by leakage between diodes.

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