RECENT PROGRESS IN PHOTOELECTRON IMAGE DETECTION WITH CCDs

John P. Choisser

Electronic Vision Company
A Division of Science Applications, Inc.
San Diego, California

ABSTRACT

During the past year, additional intensified CCDs (ICCDs) have been built and operated. These ICCDs are electrostatically and magnetically-focussed image tubes which use CCDs as anodes. The ICCDs have been shown to detect single photoelectrons, and have electron gain very near that which was predicted. This paper will present the first single-pixel pulse-height distributions, and will show the leakage current increases as a function of photoelectron irradiation. The advantages and disadvantages of front-and rear-illuminated designs will be discussed in light of differing applications requirements.

I. INTRODUCTION

A number of electrostatically-focussed ICCD Digicons have been fabricated at EVC during the past two years, and test results have been published as they have become available (1,2,3). These tubes initially used the Fairchild 100x100 CCD-201, and later the replacement array CCD-202.

Figure 1 shows the tube envelope used in the ICCD construction. The body is alumina, with copper flanges at each end for attaching the array header and photocathode by cold welds. We believe the combination of external photocathode processing and the use of molecular beam photocathode activation methods are responsible for minimizing the alkali metal damage to the semiconductor. Out of eight ICCDs only one CCD failed to operate after tube processing, and even that was an array whose operation had been intermittent before tube processing. Figure 2 shows a CCD mounted on the EVC Digicon tube header.

Figure 3 shows the first magnetically focussed Digicon ICCD-202, built recently and delivered to Dr. Robert Hobbs of NASA Goddard Space Flight Center. This tube was processed like a standard Digicon, using standard Digicon tube parts, except for an adapting flange at the anode end to make the one-inch diameter ICCD header fit the two-inch diameter tube body. This tube will be used for experimental astronomical imaging photon counting by Currie, of the University of Maryland, and Hobbs.

Two of the recent Digicon ICCDs have been built with UV-transmitting faceplates, to show a further advantage over unintensified CCDs. These first UV tubes, which use sapphire faceplates, will be followed by tubes using quartz and magnesium fluoride faceplates. A gated magnetically-focussed Digicon ICCD using the Fairchild ICCD-211 (190x244 picture elements) is now under construction.

II. SINGLE PHOTOELECTRON DETECTION

Last year, using one of the first EVC Digicon ICCDs, Currie (3) took pulse-height distributions of single and multiple photoelectron arrivals, accumulated over the central 3,000 pixels of the ICCD-201. These data, which included pixel-to-pixel dark signal variations, showed that the ICCD could be used for photon counting with reasonable photometric accuracy even without subtracting fixed-pattern noise. It would be expected, of course, that a better pulse height distribution exists at each pixel, and would be evident if the fixed pattern noise in the array were stored and subtracted from the output.

In EVCs demountable vacuum system, a CCD on its header was installed to make photoelectron bombardment damage tests, to be described later in this paper. During the experiment, a single pixel was monitored to determine both the pulse height distribution and the photoelectron incident flux rate for calibration of the overall experiment. The resulting pulse height distribution is shown in Figure 4.

The distribution represents a 100 second accumulation of outputs from a single pixel. In that time, there were a total of 7,847 events, approximately 4,319 of which were zeros (dark events), 2,783 were single photoelectron arrivals, 597 were doubles, 131 were triples, and 17 were quadruples. The average flux level was 43.5 photoelectrons per second, which is 0.56 electrons per scan at 77 scans per second. The single photoelectron arrivals were also clearly evident by visually monitoring the video signal. In the dark, the zero peak was perfectly symmetrical, except for an occasional thermal electron arrival. The data indicate that an ICCD may be used in a photon-counting mode to provide accurate multi-channel photometry at very low input flux levels.

III. ELECTRON BOMBARDMENT DAMAGE

The primary damage mechanism observed so far is an increase in leakage current as a result of electron bombardment. The 18KV electrons used in this test caused observable increases in leakage current in many of the pixels irradiated. These data were taken very recently and have not yet been fully analyzed. A cursory examination of the data, however, indicates that the anlysis will not be a simple task. For example, as dosage increases, some pixels have been observed to have their leakage current change reverse direction and begin decreasing, even to a level below that of non-irradiated pixels, in some cases. The data analysis problem is further complicated by the fact that each of the two interlaced fields exhibited different characteristics in leakage current changes. In an irradiated spot, pixels belonging to one field had increasing leakage currents while the other field had decreasing leakage currents. This caused a very pronounced striped effect in the leakage current pattern. It was subsequently discovered,however, that modifying the photogate voltage on the CCD could cause the high leakage current pixels to appear in the other field and vice versa. The average of the high and low leakage currents, however, is still higher that the leakage currents before irradiation.

Figure 5 shows some data taken very recently on two adjacent pixels in one column (so the pixels are in different fields). The variations in leakage current for the two pixels as a function of dose shows their different behavior, as well as the dependence on the photogate voltage.

The abcissa shows the accumulated dose in the number of 18KV electrons per pixel, and the ordinate the leakage current as a fraction of saturation at room temperature. The error in the vertical scale is probably significant, however,and a better vertical reference is shown by the 10 photoelectron equivalent signal shown at the right. Unfortunately the amplitude of the output signal is also somewhat dependent on the photogate voltage; this is one of several reasons why these very recent data are not yet thoroughly analyzed.

Irradiation-caused leakage current increases in some arrays have been shown to be a reversable process. At EVC, for example, we have, on numerous occasions, been able to decrease the leakage current in damaged diodes by irradiation of generally lower-energy electrons. Gordon(4) and Tull (5) have also shown that leakage currents in Reticon arrays can be reduced by electron irradiation. At EVC, we are beginning to determine whether damage effects on the CCDs may also be reversible. Hopefully we will have results over the next few months.

In summary, we have shown that image tubes can be built using the Fairchild CCDs and that the CCDs can survive the image tube processing schedules. We have also shown that CCDs with low noise electronics are capable of detecting single photoelectron arrivals. The present tubes may be suitable for applications at very low light levels, or when short array lifetimes can be tolerated. The currently available front-illuminated devices are being studied to learn more about their characteristics in hopes that periodic electron bombardment annealing may increase the array lifetime for more applications. It is also anticipated that in the future tubes will be built using thinned CCDs for rear bombardment which may preclude the electron bombardment damage from happening at all. Premiminary work by others using thinned devices has begun (6,7) and when either we or they are successful, devices will then be available that are useful in a wider range of applications.

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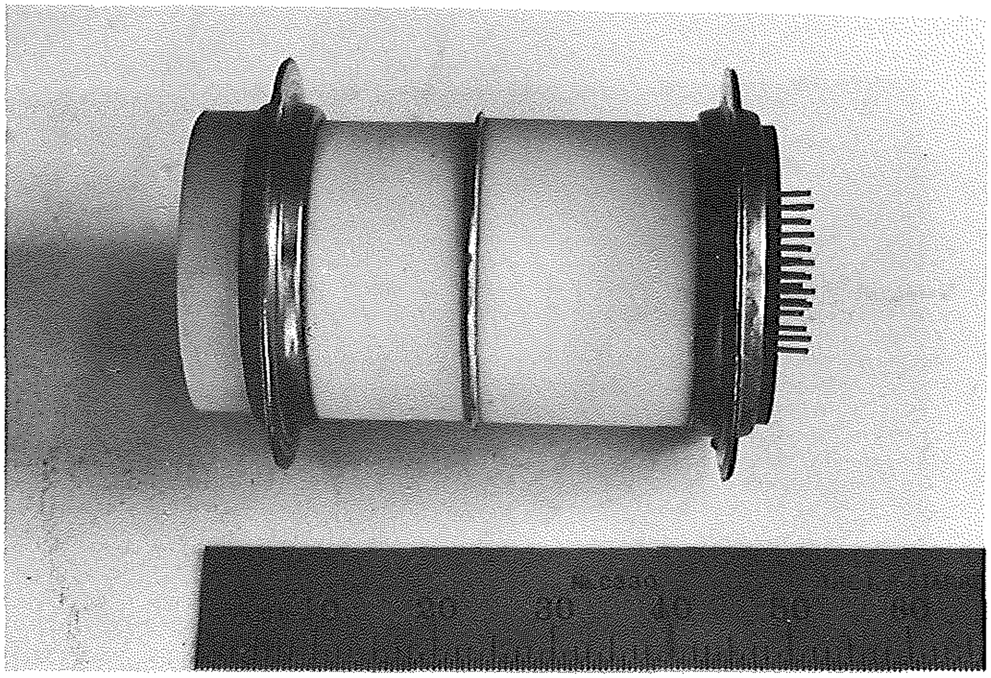

Figure 1. Electrostatically-focussed Digicon

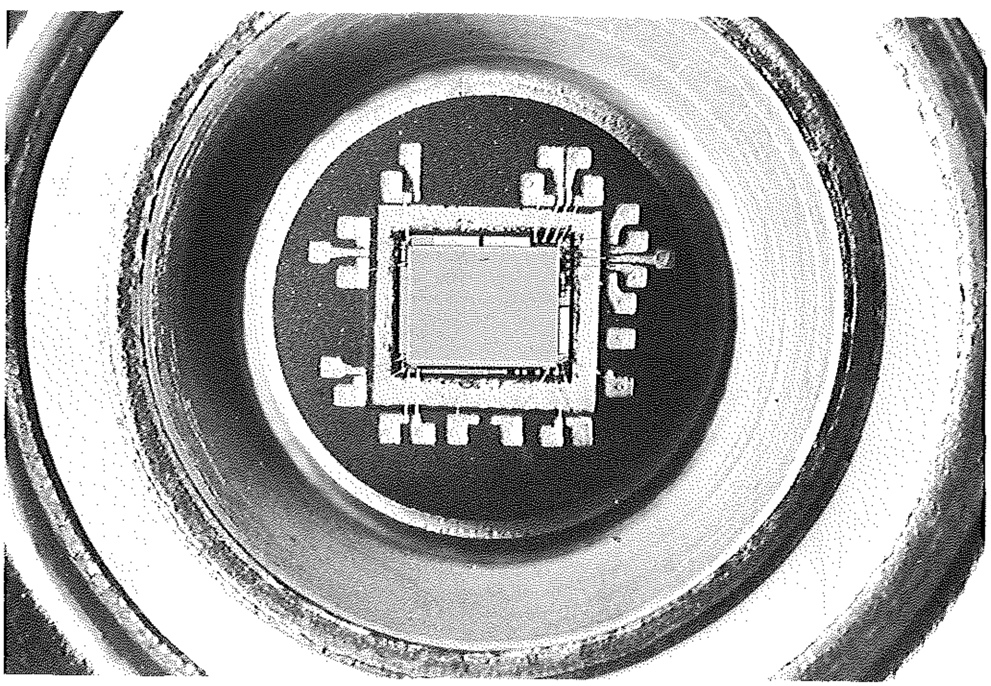

Figure 2. CCD-202 on Digicon header

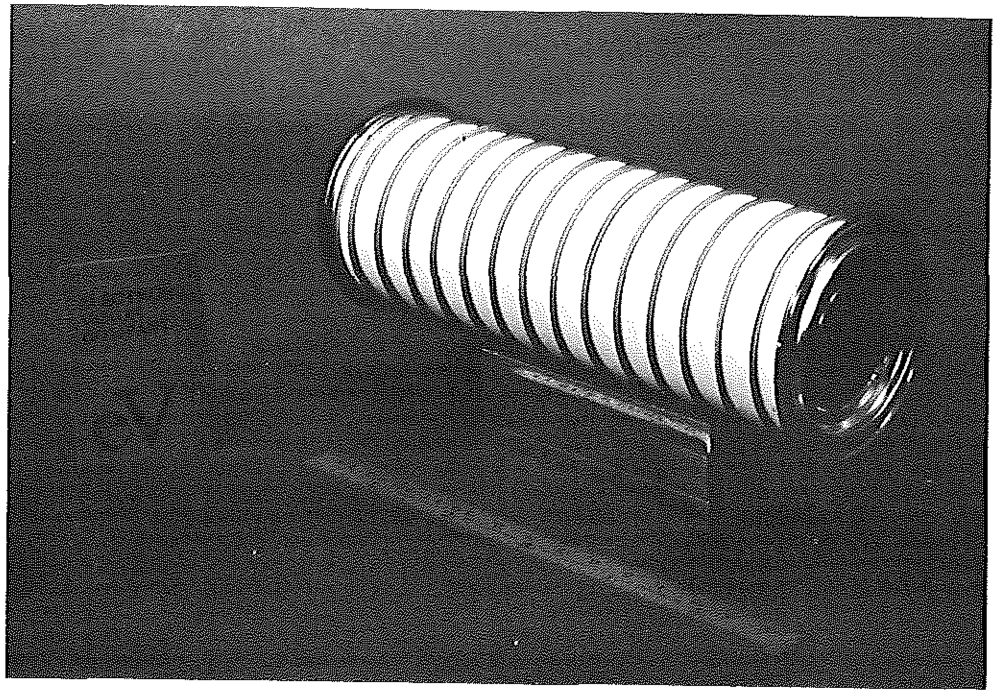

Figure 3. Magnetically-focussed Digicon ICCD-202

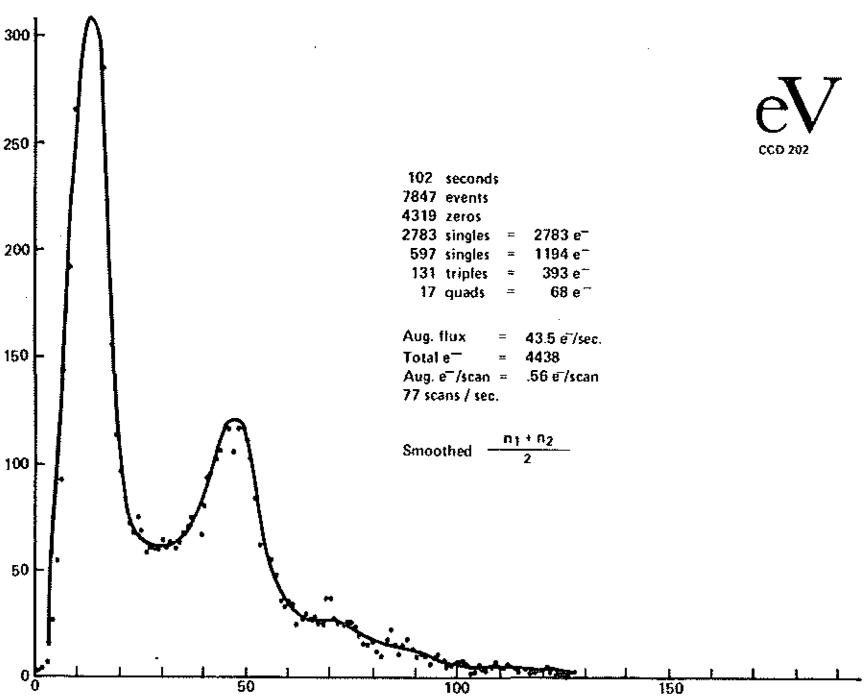

Figure 4. Photoelectron pulse height distribution for ICCD-202

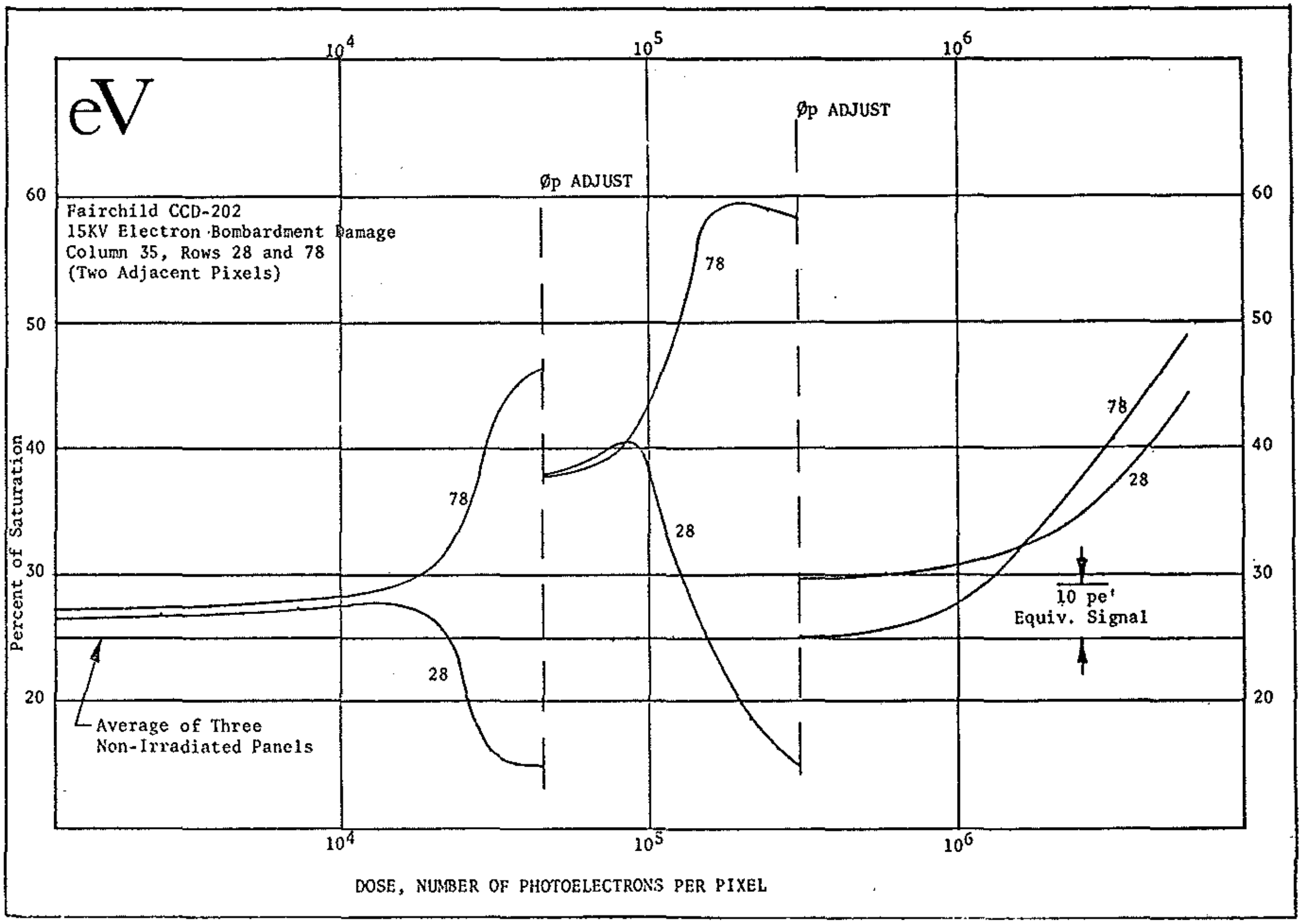

Figure 5. ICCD-202 photoelectron bombardment damage