SECTION IV:

DETECTOR SYSTEMS

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SOLID STATE IMAGERS FOR ASTRONOMY

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This is a summary of the meeting "Solid State Imagers for Astronomy" held at the Harvard-Smithsonian Center for Astrophysics in June 1981. The main emphasis of this report is a comparison of the performance characteristics of the CCD detectors now in use.

1. INTRODUCTION

The development of new detectors for astronomy is a field that is experiencing rapid advancement, especially in the area of charge coupled devices (CCDs). To allow the workers in this field to exchange the latest information and compare notes, an international meeting on "Solid State Imagers for Astronomy" was organized by the Smithsonian Astrophysical Observatory for June 1981. The SPIE was invited to co-sponsor the meeting, and they took on the responsibility for producing the proceedings, now available as SPIE volume 290 (P.O. Box 10, Bellingham, Washington 98227-0010). Of the total of 34 papers, 27 were on CCD's, 3 on direct-illuminated Reticons, 3 on intensified arrays, and 1 on a charge injection device (CID). In this paper I summarize the highlights of the meeting, with special emphasis on a comparison of the performance characteristics of the CCD's now in use.

2. SPACE TELESCOPE DIGICONS

The detectors for the Faint Object Spectrograph (FOS) of the Space Telescope (ST) will be two 512 channel Digicons, one with a trialkali cathode, the other with a bialkali. All seven tube starts for this project have been successful, and the two best ones have passed all their survival tests and exceed or meet specifications in every respect. Thus the important FOS experiment on ST will have outstanding detectors. Their performance characteristics are summarized in table 1.

C. M. Humphries (ed.), Instrumentation for Astronomy with Large Optical Telescopes, 245–249.

Table 1 Space Telescope Digicon Performance

	Quantum efficiency peak	λ range	Dark rate $-10^{o}C$	Resolution 512 diodes
Trialkali	26% @ 250nm	200-700nm	25 cts/sec/cm^2	limited by
Bialkali	22% @ 250nm	120-400nm	2 cts/sec/cm^2	40 micron diodes

3. DIRECT ILLUMINATED RETICONS

Several groups now have direct-illuminated Reticons in operation. These linear arrays are best suited for high signal-to-noise spectroscopy, because the readout noise is usually larger than 500 e/pixel. The spectral response is very strong, with peak sensitivity of 70% in the red and good response out to about 1000 nm and even below 400 nm. One of the appealing features of direct-illuminated diode arrays is their geometrical stability. This was demonstrated impressively in a paper by Bruce Campbell et al., who reported stellar radial velocity measurements accurate to $\pm$ 15 m/sec at a dispersion of 10 A/mm. They used an HF absorption cell in the stellar beam and achieved signal-to-noise of 1200 for bright stars.

4. COMPARISON OF BIG CCDS

Very large CCDs suitable for astronomical applications are now being manufactured by Radio Corporation of America and Texas Instruments in the United States, and by General Electric Company in the United Kingdom. The characteristics of four of these devices are summarized in table 2, and some of their outstanding features are discussed in this section.

RCA SID 53612 320 x 512

Of all the CCDs now in use, the RCA SID 53612 thinned, buried-channel chip is clearly the people's choice, with 13 papers reporting on work with this device. Two key factors have made it popular: it has the best overall quantum efficiency of any imaging detector ever used for astronomy, and it is commercially available. The RCA chip presently has two problems which limit its usefulness for some applications, especially spectroscopy. First, the readout noise is rather high, typically between 50 and 100 electrons, due primarily to the use of a fairly noisy surface-channel transistor in the on-chip preamp. Second, the transfer efficiency is degraded when the total charge per pixel drops below several hundred electrons. Both these problems limit the usefulness of the RCA chip for some spectroscopic applications. However, for deep sky-limited photography of very faint objects neither of these problems degrades the performance of the RCA chip, and its remarkably high quantum efficiency makes it a very appealing detector for this application.

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Table 2 Characteristics of Big CCDs

	active area	pixel size	organi-zation	quantum efficiency peak	quantum efficiency range	readout noise	type
RCA	15.4 x 9.6 mm	30 x 30μ	512 x 320	80%	350-850 nm	50-100e/pix	thinned, 3 phase, buried
TI	12.0 x 12.0 mm	15 x 15μ	800 x 800	70%	500-1000 nm	83/pix	thinned, 3 phase
TI	12.0 x 12.0 mm	15 x 15μ	800 x 800	45%	500-800 nm	20e/pix	thick, virtual phase
GEC	12.7 x 8.5 mm	22 x 22μ	576 x 385	40%	600-1000 nm	20e/pix	thick, epitaxial

TI Three-Phase 800 x 800

The detector for the Space Telescope Wide Field Camera/ Planetary Camera will be a buried-channel three-phase back-illuminated 800 x 800 CCD. Several successful devices of this type have now been manufactured by Texas Instruments, and a few of these have been used for ground-based applications. Unfortunately the chip is not available commercially and probably never will be. The outstanding feature of this device is the remarkably low readout noise that has been achieved - 8 electrons. This makes possible a variety of applications involving low signal to noise. The quantum efficiency is also extremely good, although somewhat lower at peak than the RCA chip. Of particular interest for ultraviolet imaging is TI's success in coating chips with 160 nm of coronene, a phosphor that converts ultraviolet light to the visible. Coated chips have about 10% quantum efficiency in the ultraviolet down to about 100 nm, and a peak visible response that is enhanced by the antireflective properties of the coronene coating.

The big TI chips are remarkable detectors that have just a few residual problems. There is a small amount of transfer inefficiency at very low charge levels, but the problem is much less severe than with the RCA chip. There is also some charge injection that can generate spurious signal in long exposures. This can be avoided by turning down the voltages on the serial clocks during the exposure. Flatfields work well down to about the 1 or 2% level, but there are residual problems at very high accuracies that are not yet fully understood. Finally, the TI chips cannot be grossly overexposed to very bright light without generating charge in the substrate that can only be coaxed out with multiple reads.

TI Virtual Phase 800 x 800

Originally the Planetary Camera for the Galileo mission was scheduled to be a TI three-phase CCD. In-depth research disclosed that the three-phase device was extremely sensitive to ionizing radiation and would not be viable in the Jupiter environment. A new device with virtual-phase architecture is now being perfected. At the time of the conference, only one really successful chip of this type had been built. Its characteristics were very promising, making the virtual-phase CCD a strong candidate for chip of the future. The peak quantum efficiency is nearly 50%, with reasonable blue response. The readout noise of the one successful device was at least as good as 20 electrons. TI seems committed to the new virtual-phase technology, and there is some hope that these devices will become available commercially.

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GEC MA357 576 x 385

This is a thick front-illuminated chip. Therefore it has only modest peak quantum efficiency and no blue response. However, it does have low readout noise, and is relatively immune to cosmic rays because it is fabricated by growing a layer of epitaxial silicon on top of a low-resistivity substrate. No transfer problems at low charge levels have been observed. Production of the MA357 is being transferred to English Electric Valve, while further developments on thinning and larger formats will continue at GEC.

5. FAIRCHILD CCDS

Much of the pioneering work on the astronomical applications of CCDs was done with relatively small chips supplied by Fairchild. Most of these devices suffered from low quantum efficiency, typically 15% at peak, because they were front-illuminated through a polysilicon gate structure which was half blocked by aluminum stripes over the shift registers. In most cases very good noise performance was achieved. Perhaps the most interesting work with a Fairchild chip was reported by Monet, who described some very promising tests of a 211 camera for astrometry at Kitt Peak. More recently Kitt Peak has evaluated 221 chips with a 380 x 488 format, one of them with the shift registers not blocked by aluminum. The noise of these chips has been a little disappointing, in the 30 to 60 electron range.

6. THE FUTURE

There can be little doubt that CCDs are the detector of the future for many applications in astronomical imagery and spectroscopy. The quantum efficiency can be close to ideal, the linearity is remarkably good, and the noise characteristics are well behaved. The most difficult residual problems, (namely low-light level transfer inefficiency, spurious charge injection, and flat-field instability), were not expected but presumably can be resolved. In the meantime the problem is to decide what characteristics have to be compromised, because there is no chip commercially available that incorporates all the optimum performances into one device.

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