# RECENT DEVELOPMENTS IN CID IMAGING

G. J. Michon, H. K. Burke, and D. M. Brown
General Electric Company
Corporate Research and Development
Schenectady, New York

Readout of CID imaging arrays was first performed by injecting and detecting the signal charge from each sensing site in sequence. An epitaxial structure was used to provide a buried collector for the injected charge to allow high-speed operation and to eliminate crosstalk of the injected charge. This technique is also compatible with nonsequential scan formats (random-scan).

A new readout method, termed "parallel injection," has been developed in which the functions of signal charge detection and injection have been separated. The level of signal charge at each sensing site is detected during a line scan, and during the line retrace interval, all charge in the selected line is injected. The injection operation is used to reset (empty) the charge storage capacitors after line readout has been completed. Nondestructive readout is possible by deferring the injection operation.

The parallel injection technique is well adapted to TV scan formats in that the signal is read out at high speed, line by line. A 244-line by 248-element TV-compatible imager, employing this technique and including an on-chip preamplifier, has been constructed and operation demonstrated. The performance level that can be achieved is presented.

An additional improvement in the CID structure has been the replacement of the opaque aluminum electrodes with transparent conductors. Devices fabricated in this way have achieved quantum efficiencies in the order of 70% over the spectral range of 4000 Å to 8000 Å, front illuminated.

## I. BASIC DESCRIPTION

The CID solid-state image sensors use an X-Y addressed array of charge storage capacitors which store photon-generated charge in MOS inversion regions. Readout of the first self-scanned arrays was effected by sequentially injecting the stored charge into the substrate and detecting the resultant displacement current to create a video signal (Refs. 1,2). The charge storage sites can be read out in any arbitrary order. Arrays can be designed with integral digital MOS decoders for X and Y line selection to allow "random" access. The integration time as well as the scan sequence could then be externally programmed for special applications.

An array designed for raster scan which includes integral shift registers is diagrammed in Figure 1a. Each sensing site consists of two MOS capacitors with their surface inversion regions coupled such that charge can readily transfer between the two storage regions. A larger voltage is applied to the row-connected electrodes so that photon-generated charge collected at each site is stored under the row electrode, thereby minimizing the capacitance of the column lines. The sensing site cross-sections (Figure 1b) illustrate the silicon surface potentials and locations of stored charge under various applied voltage conditions.

A line is selected for readout by setting its voltage to zero by means of the vertical scan register. Signal charge at all sites of that line is transferred to the column capacitors, corresponding to the "row enable" condition shown in Figure 1b. The charge is then injected by driving each column voltage to zero, in sequence, by means of the horizontal scan register and the signal line. The net injected charge is measured by integrating the displacement current in the signal line over the injection interval. Charge in the unselected lines remains under the row-connected electrodes during the injection pulse time (column voltage pulse). This corresponds to the "half select" condition of Figure 1b.

The array is constructed on an epitaxial layer so that the reverse biased epitaxial junction can act as a collector for the injected charge. This effectively prevents the charge injected at any site from being collected by neighboring sites.

## II. PARALLEL INJECTION

A new readout technique, termed "parallel injection," has been developed in which the functions and signal charge detection and injection have been separated. The level of signal charge at each sensing site is detected during a line scan and, during the line retrace interval, all charge in the selected line can be injected.

A diagram of a 4 × 4 array designed for parallel injection is illustrated in Figure 2, with the relative silicon surface potentials and signal charge locations included. As before, the voltage applied to the row electrodes is larger than that applied to the column electrodes to prevent the signal charge stored at unaddressed locations from affecting the column lines. At the beginning of a line scan, all rows have voltage applied, and the column lines are reset to a reference voltage $V_S$ by means of switches $S_1$ through $S_4$ and then allowed to float. Voltage is then removed from the line selected for readout ($X_3$ in Figure 2), causing the signal charge at all sites of that line to transfer to the column electrodes. Voltage on each floating column line then changes by an amount proportional to the signal charge divided by the column capacitance. The horizontal scanning register is then operated to scan all column voltages and deliver the video signal to the on-chip preamplifier $Q_1$. The input voltage to $Q_1$ is reset to a reference level prior to each step of the horizontal scan register.

At the end of each line scan, all charge in the selected line can be injected simultaneously by driving all column voltages to zero through switches $S_1$ and $S_4$. Alternately, the injection operation can be omitted and voltage reapplied to the row after readout, causing the signal charge to transfer back under the row electrodes. This action retains the signal charge and constitutes a nondestructive readout operation.

The parallel injection approach permits high-speed readout and is thus well adapted to TV scan formats, and offers optional nondestructive readout. A 244-line by 248-element imager, employing this technique and including an on-chip preamplifier, has been designed, fabricated, and evaluated in both the normal and nondestructive readout modes.

For TV-compatible operation, a line time interval of 63 μsec (5 MHz element rate) is used, and the vertical scan rate is 60 scans per second. The imager is completely read out during each interlaced field of the standard TV frame such that video is displayed on all 488 active lines of the 525-line system.

The parallel injection technique, in general, retains the high performance characteristics of CID imaging (Ref. 2) such as low dark current, wide dynamic range, and high modulation transfer function. Significant differences exist, however, with regard to nondestructive readout and overload immunity.

## A. Nondestructive Readout

The nondestructive readout characteristics of the 244 × 248 array have been evaluated by operating the device at low temperature to minimize dark current and thereby achieve long storage time intervals.

Two experiments were performed to identify the limiting factors in nondestructive image readout. First, a charge pattern of an image was generated and stored by momentarily opening a shutter, and then the image was read out continuously at 30 frames per second, until image degradation was noted. At a chip temperature of -70°C, images were read out for 3 hours (324,000 NDRO operations) with no detectable charge loss. The charge lost during each NDRO operation was, on the average, much less than one carrier per pixel per frame.

The second experiment was performed to insure that charge could be generated and stored at very low light levels under continuous (30 frames per second) NDRO conditions. A series of time exposures were made at successively lower light levels, and the time required to reach a given level of signal voltage was measured. The results (Figure 3) show that the exposure time is inversely proportional to light level, with no measurable reciprocity loss for exposure times up to 3 hours. The lowest light level used was equivalent to about two carriers per pixel per frame in the highlight regions of the image. Here again, the readout loss was not measurable and was much less than one carrier per pixel per frame.

## B. Blooming

Unlike the sequential injection approach, this new technique exhibits relatively little blooming in the displayed image as a result of sensing site overload. This is because the half-select and injection operations occur during the horizontal blanking interval.

While excess charge can accumulate during a line scan interval and cause column brightening for overloads occurring in the right-hand portion of the image field, this effect is attenuated by the line-to-frame integration time ratio.

For NDRO operation, virtually no blooming occurs, since the charge is not injected. The affected sites simply saturate and cease collecting charge.

In all cases, radial spreading of excess charge is prevented by the underlying charge collector.

## III. TRANSPARENT ELECTRODES

The incorporation of transparent metal oxide electrodes into a self-scanned CID high-density imager has recently been reported by Brown, Ghezzo, and Garfinkel (Ref. 3). This development is reviewed here because of its significance in scientific imaging applications.

The use of metal oxide (tin, antimony, indium oxide) electrodes in imaging array structures presents significant advantages because of three important physical properties:

(1) The index of refraction (~2) is a close match to silicon dioxide (~1.46) and silicon nitride (~2), the commonly used dielectrics in MOSFET integrated circuits.

(2) The spectral transmissivity of these materials is very high in the visible spectrum (~80%) and extends from 4000 to 9000 Å.

(3) The conductivity of these materials is good, being as good as or better than doped polysilicon ($\leq 100\ \Omega$/square).

The incorporation of this material in a self-scanned CID array imager has been successfully carried out, as shown by the photomicrograph. In Figure 4, the central array is the imager array (32 × 32) using 1.7 × 1.3 mil cell spacing, with lines fanned out to the scanning circuits on the chip's periphery.

The spectral quantum efficiency of this high-density self-scanned array is given in Figure 5. The high and nearly constant visible wavelength spectral efficiency is due to the fact that the major portion of the array is covered by metal oxide electrodes, and photon conversion can occur in the underlying depletion layer of each CID cell. These arrays have excellent blue response, nearly uniform spectral response from 8000 Å to 4000 Å, and very high sensitivity (~70% quantum efficiency.)

## IV. CONCLUSIONS

High-density, high-speed CID imaging arrays with wide spectral response characteristics, when front-illuminated, are now practical.

Nonsequential addressing, now being explored, promises interesting new applications.

The capability of repeated readout, during or subsequent to exposure, allows a number of system functions not previously possible, such as exposure monitoring and extended time image processing.

## ACKNOWLEDGEMENTS

Development of the 244 X 248 imager was partially funded under the sponsorship of the Advanced Research Projects Agency (ARPA) and the Air Force Systems Command, US Air Force.

## REFERENCES

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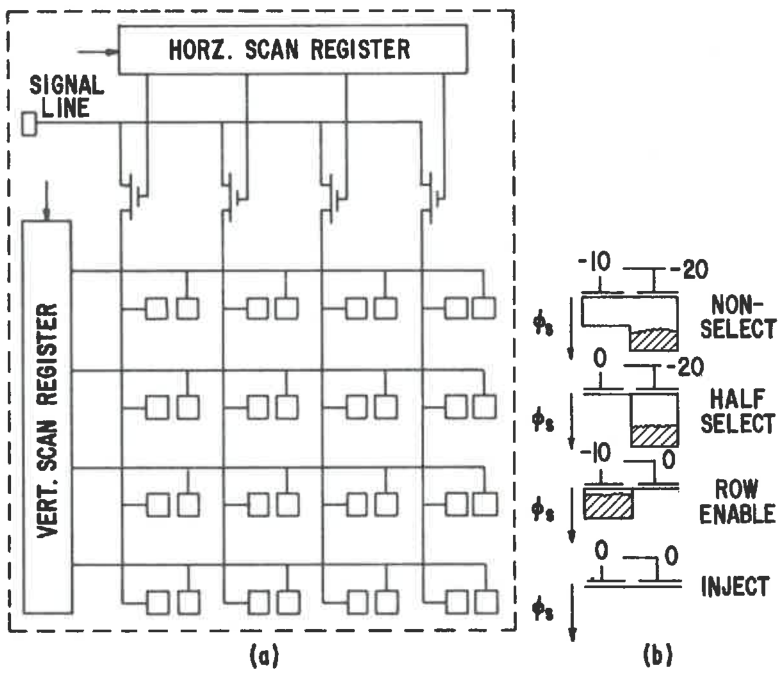


Figure 1. Sequential injection CID imager: (a) array diagram, (b) sensing site cross-sections illustrating surface potential ($\phi_s$) and location of stored charge under various bias conditions

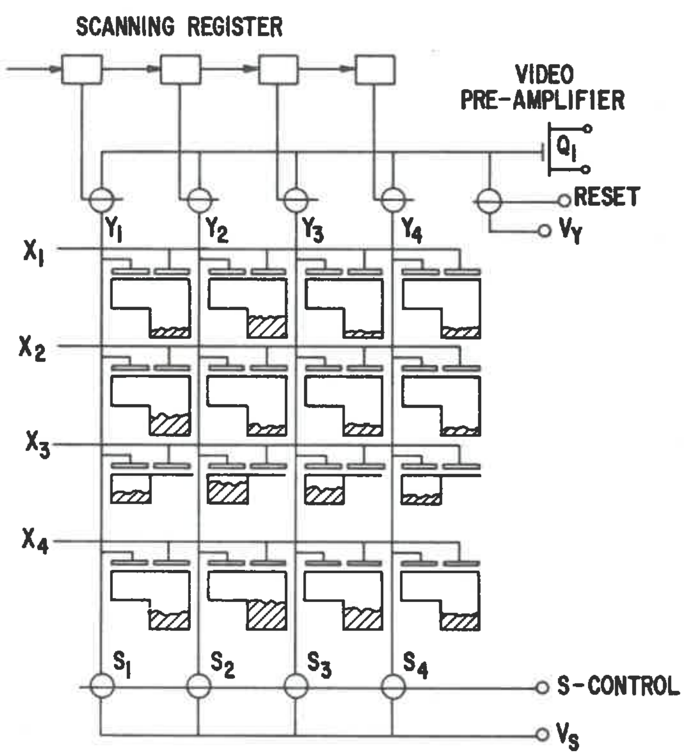


Figure 2. Parallel injection array schematic illustrating location of stored charge in selected ($X_3$) and unselected ($X_1$, $X_2$, $X_4$) rows

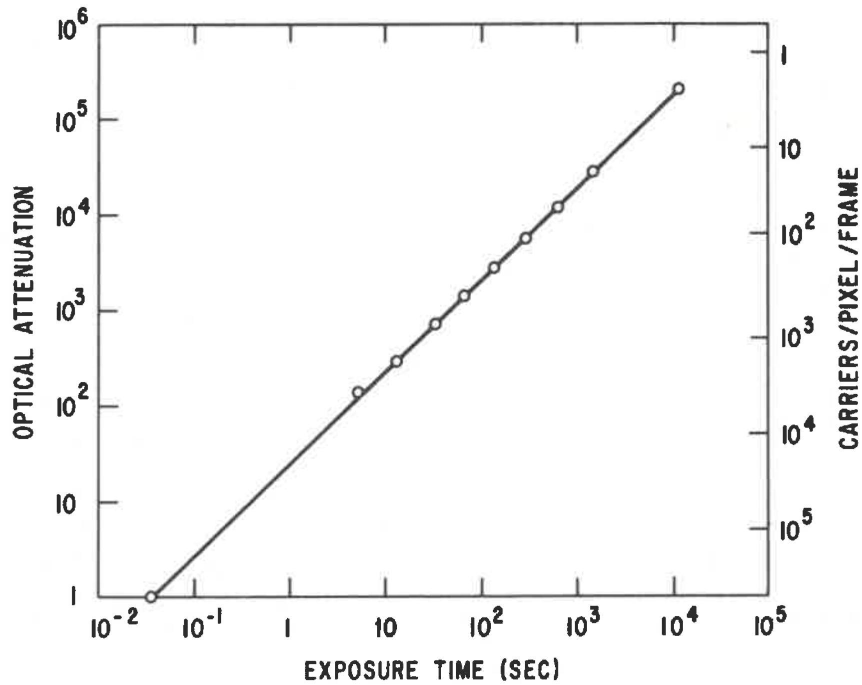


Figure 3. Exposure time required to reach a given level of output signal, as a function of optical attenuation (inverse light level), under continuous, 30 F/S nondestructive readout

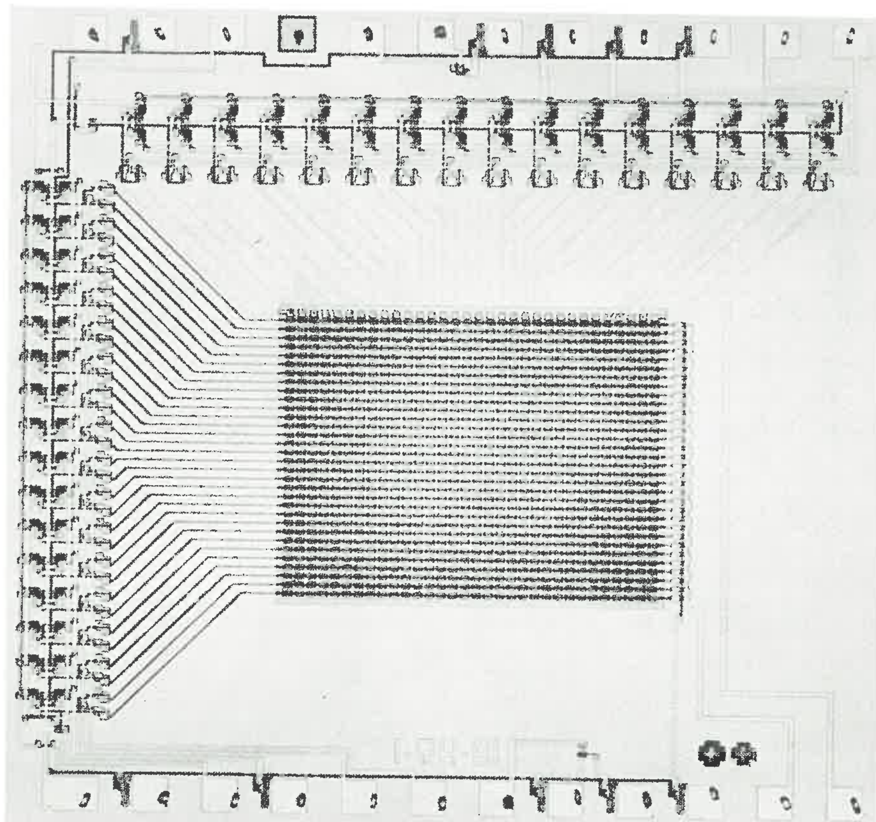

Figure 4. Photomicrograph, 32 X 32 self-scanned imager incorporating a high-density, transparent electrode image sensing array

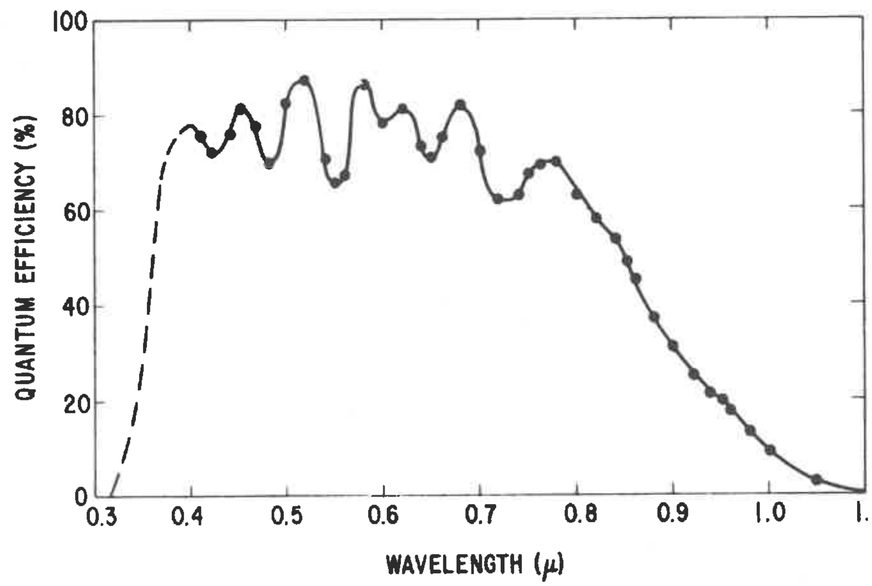


Figure 5. Measured spectral quantum efficiency of transparent electrode CID imager