# BACK SURFACE IMAGING OF THINNED C.C.D.

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## ABSTRACT

Samples of a three phase 100 bit linear C.C.D. have been thinned down to 20 $\mu$m and operated with back surface illumination. No treatment of the back surface to minimise the surface recombination has been attempted, because of the aluminium electrode structure; even so, the initial measurements have been encouraging.

Dark current and charge transfer inefficiency are unaffected by the thinning procedure. Measurements of spectral response indicate that with suitable treatment of the back surface the responsivity would be as good as the silicon vidicon diode array targets. M.T.F. measurements show an improvement on the previous results obtained from front surface illumination. Modulation depths greater than 30% are apparent at the limiting resolution of 16.6 lp/mm.

Two-dimensional pictures obtained by back imaging on the thinned devices show an improvement in grey scale and resolution when compared to the earlier samples obtained from front face imaging.

In summary, these results have demonstrated the potential of back surface imaging of thinned C.C.D. for low light level applications.

## INTRODUCTION

A possible alternative to front illumination of C.C.D.'s is illumination of the back surface. This eliminates the large surface inefficiency due to reflection by the metal electrodes, or the undesirable optical absorption of short wavelengths of polysilicon electrodes. For back surface illumination, however, it is necessary to thin the silicon substrate and suitably prepare the back surface with a shallow $p^+$ diffusion layer (for n-channel devices). This would lower the surface recombination velocity in order to preserve quantum efficiency.

## DEVICE THINNING

The linear C.C.D.'s supplied for thinning are of a three phase single level structure, fabricated using n-channel aluminium gate M.O.S. techniques. The devices are thinned using techniques already established for the reduction of silicon vidicon targets to thicknesses of 10 um or less. This is achieved using an etch of hydrofluoric, acetic and nitric acid in a rotating tub. Unlike the silicon vidicon, however, it is necessary to bond connections to the C.C.D. after thinning. It would be preferable to thin only the area beneath the imaging electrode structure, leaving the regions under the bonding pads thick in order to ease bonding and handling difficulties. However, attempts at thinning small areas proved unsatisfactory, due to turbulence in the etch bath resulting in excessive doming and non-uniformity. Consequently, whole slices are thinned after scribing.

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After thinning, the individual chips are mounted as shown in Figure 1. The devices are bonded ultrasonically at room temperature. Obviously, handling and bonding difficulties render this a low yield process. Working devices have been obtained 20 - 40 µm thick. Figure 2 shows a photograph of a section of a thinned linear C.C.D. using transmitted light. The device is approximately 10 µm thick and the uniformity of etching is clearly visible.

The aluminium electrode structure on these devices render it impractical to dope the back surface by high temperature diffusion and ion implantation techniques. Consequently, these thin C.C.D.'s will be insensitive to light at short wavelengths.

## RESULTS

### 1. Dark Current and Transfer Efficiency

Previous work has shown dark current levels to be consistent within each fabrication batch. Comparing dark current measurements between thin and normal C.C.D.'s from the same batch indicate that it is unaffected by the thinning. Typically the dark current density is 10-30 $nA/cm^2$.

Measured values of $\varepsilon$ (transfer inefficiency per transfer) using electrical inputs in normal devices are of the order $5 \times 10^{-4}$, at 1 MHz data rate. Optical inputs in thin C.C.D.'s indicate transfer inefficiencies of the same order of magnitude, again unaffected by the thinning.

### 2. Responsivity

Figure 3 illustrates the spectral response of two thin C.C.D.'s showing how the responsivity improves at shorter wavelengths for thinner devices. The spectral variations were obtained by filtering a white light source (colour temperature $2854^{\circ}$ K) from 400 to 1000 nm. using narrow-band-pass filters. A peak response of 75 mA/W was obtained at 800 nm.

At first sight, these measurements seem rather poor, but this can be attributed to the low quantum efficiency of the etched silicon surface. Previous work on the silicon diode array targets (Ref. 1) has shown that suitable treatment of the silicon surface will vastly improve the responsivity. Recently published results (Ref. 2) have shown the responsivity to be as good as the silicon diode array when the back surface is accumulated.

### 3. Resolution

The resolution of the thinned devices is measured by observing the output waveform as a function of the spatial frequency of the optical input signals. The optical input signal is in the form of a 100% contrast line pattern, the spatial frequency of the lines being within the range 1-16.6 line pairs/millimetre at the device. The limit of 16.6 lp/mm is governed by the geometric bit spacing of the device.

Measurements have shown an improvement in the modulation depth using back surface imaging. With front surface illumination the M.T.F. is degraded by carrier diffusion effects at longer wavelengths ($> 0.8$ µm) when the optical penetration depth is long compared to the depletion width. With back surface imaging, however, the M.T.F. is a function of silicon thickness and there is also a significant wavelength dependence, i.e. longer wavelengths having a higher M.T.F. (Refs. 3 and 4). Figure 4 shows the results of the M.T.F. for back surface and front illumination of a thin C.C.D. using white light. Figure 5 is a photograph showing a modulation depth of 30% at the limiting resolution by back surface imaging, although up to 40% has been observed.

## 4. Mechanically Scanned Images

Two-dimensional images have been obtained by imaging onto the back surface, using the usual mechanical scanning techniques. A photograph of a back imaged picture is shown in Figure 6. Reasonable grey scale and resolution is observed and shows an improvement to the earlier pictures obtained from front imaged unthinned devices.

As only 40 bits of the devices were visible from the back (see Figure 1), Figure 6 was built up from separate images to appear identical with a front-imaged picture using 100 bits read out.

## SUMMARY

Although it is still a low yield process to obtain a thin C.C.D., this yield should improve with more refined handling and mounting techniques. These results demonstrate the potential of back surface imaging of thinned C.C.D.'s for low light usage, possibly in conjunction with an image intensifier stage utilizing electron excitation of the C.C.D.

## REFERENCES

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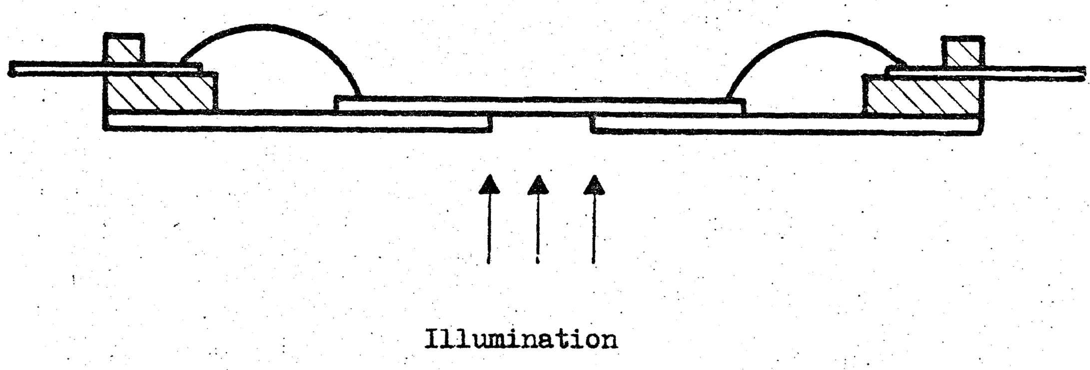
FIGURE 1

THIN DEVICE MOUNTED AND BONDED ON FLATPACK



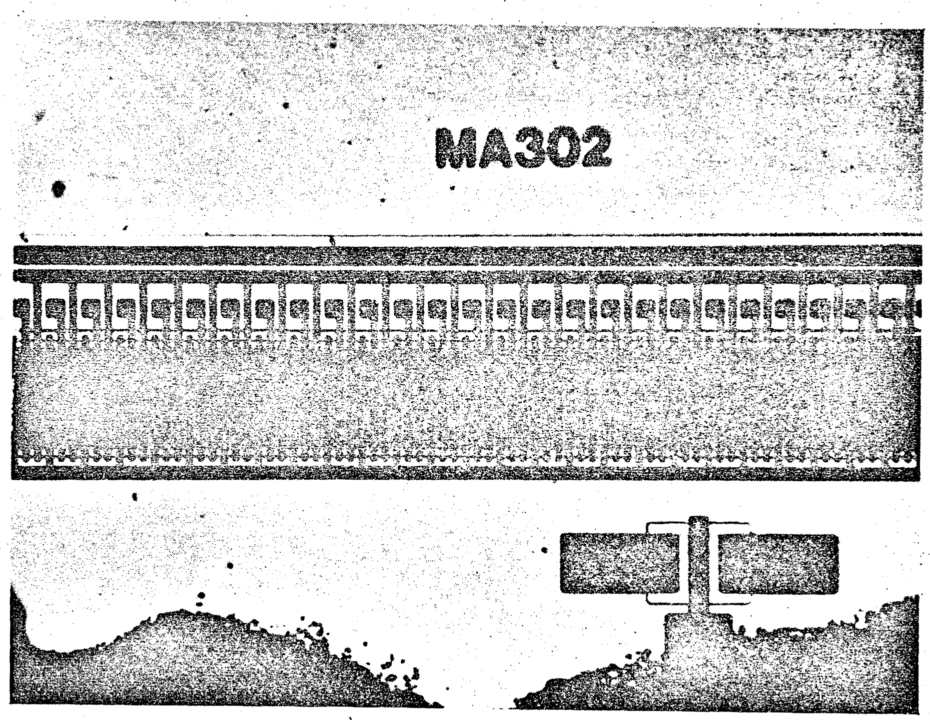



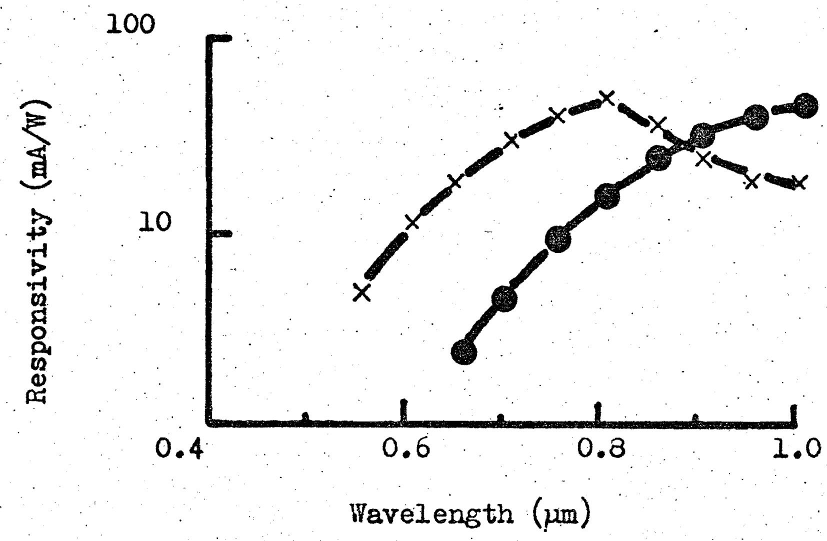

FIGURE 2

MICROPHOTOGRAPH OF THIN C.C.D. USING TRANSMITTED LIGHT

FIGURE 3

SPECTRAL RESPONSIVITIES OF THIN C.C.D.'s

ILLUMINATED ON THE BACK SURFACE

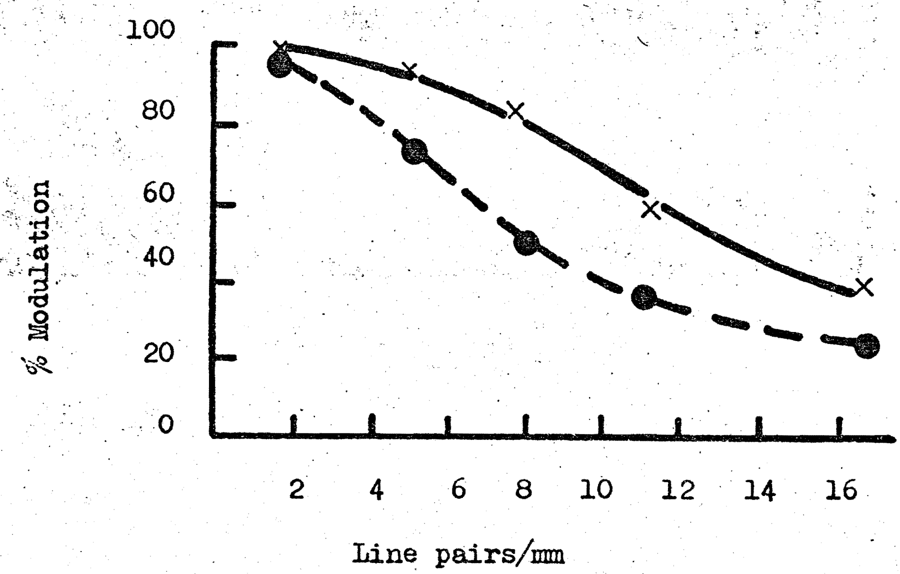



x DEVICE 20 µm

• DEVICE 35 µm

FIGURE 4

M.T.F. RESPONSE




x Thinned linear 100 bit C.C.D. with back surface imaging

• Front imaged unthinned 100 bit C.C.D.

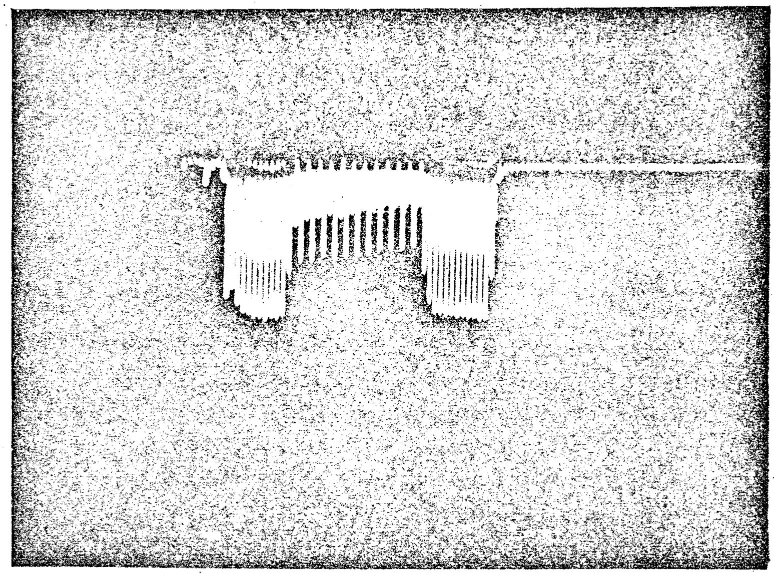


FIGURE 5

PHOTOGRAPH ILLUSTRATING 30% MODULATION DEPTH

AT 16.6 LINE PAIRS/MM AT THE DEVICE

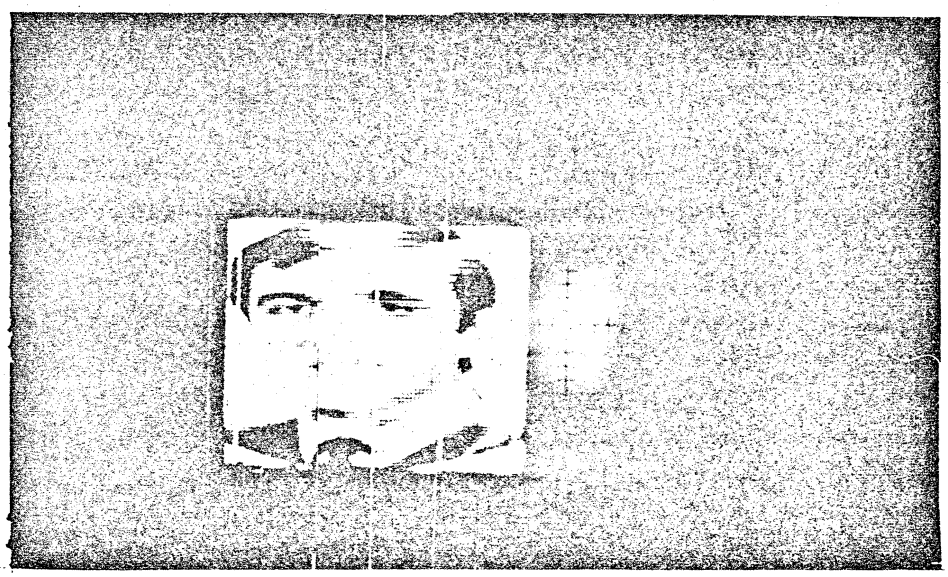


FIGURE 6

MECHANICALLY SCANNED HALF TONE IMAGE

FROM BACK SURFACE IMAGING OF 100 BIT LINEAR C.C.D.