

# Large Area High Resolution CCD Imaging Devices

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## Abstract

This paper summarizes rapid progress made in the past few years in the development of large area scientific imaging arrays. CCD imaging arrays from 3cm x 3cm (2048x2048 pixels) to 8cm x 8cm (9k x 9k pixels), will be described. These devices show exciting promise in a variety of medical, astronomical, and high resolution commercial imaging applications.

## Introduction

Silicon processing technology has made tremendous strides over the past 30 years. Bipolar transistors were fabricated on 1.5" silicon wafers in production during the late 60's. By the early 70's a stable MOS process had been established and wafers had moved to 2" and 3" in diameter. Boyle and Smith of Bell Laboratories described and demonstrated working Charge Coupled Devices in 1970<sup>1,2</sup>. They are elegantly simple devices which manipulate signals as small packets of charge from one area to another across the silicon surface. An array of MOS capacitors are fabricated over the silicon. The discrete packets of charge are coupled from one capacitor to the next by alternately clocking voltages from one capacitor gate to the next. For scientific applications the signal packets are as small as only a few electrons. During the 70's the quality of the silicon starting material, process chemicals and laboratory cleanliness had not matured adequately to fabricate devices larger than several millimeters on a side. Imaging arrays of 380x488 pixels demonstrated good high level performance, but showed significant signal trapping and fixed pattern noise at signal levels less than 1000 electrons<sup>3</sup>.

During the seventies CCD's were proposed to fulfill a variety of functions ranging from analog memories, adaptive filters, radar signal processors, and imaging devices. The mainstream of silicon processing proceeded rapidly pushing the technology in digital CMOS and DRAMS. Production wafers moved from 3" to 4" to 5" to 6", until present day where Intel, Motorola and the rest of the world's major facilities are utilizing 8" wafers for production. Costs of such facilities now cost over \$1 Billion and can only be sustained by very high volumes. Digital devices have taken over the potential CCD applications of signal processing and memory. CCDs remain dominant for imaging applications. They provide a small size, low power, and high sensitivity replacement to vidicon tubes. Sony and other vendors routinely manufacture over a million high quality color CCDs per month for use in camcorders. The improvement in process technology now makes it possible to fabricate very large area arrays.

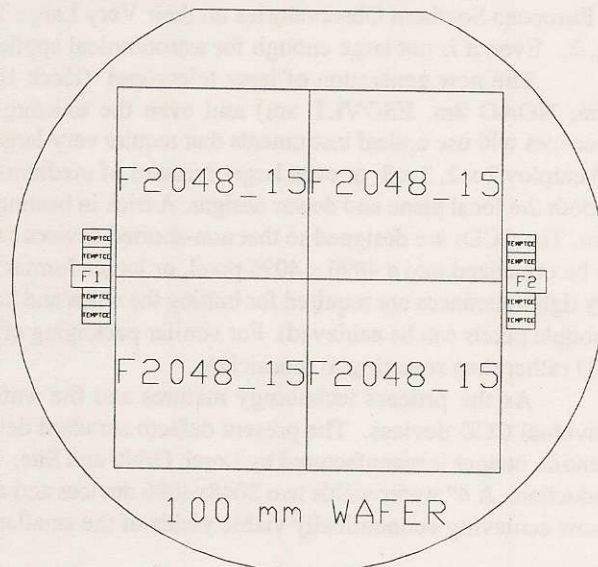


Figure 1 Four Devices per four inch wafer.

\*\* Note: A version of this paper will be presented at the IS&T Conference "Imaging on the Information Superhighway" May 1995 WashDC.







Because of the huge investment involved in the construction of these large ground based telescopes every effort is done to achieve the absolute maximum performance from the CCDs. One of the great advantages of the CCD as a detector is the possibility of achieving extremely high quantum efficiencies over a broad range of wavelengths. The highest sensitivities are achieved by thinning the device and illuminating from the back side. In this manner and in combination with appropriate anti-reflection coatings, it is possible to obtain quantum efficiencies that exceed 90% at the peak<sup>9</sup>. Currently this method of greatest QE enhancement is also the most expensive. Backside thinning is very labor intensive. The many process steps require constant monitoring, exotic equipment in a specialized laboratory and a little black magic. There are also associated costs with the required fanout and custom packaging. There is a loss of yield when thinning arrays which can be quite expensive when working with very large area CCD arrays. Thinning is done on an individual die basis and currently costs in the range of tens of thousands of dollars per device. Typically it requires at least two good frontside devices to achieve one good backside device. A thinned CCD is less than 20 microns thick and quite fragile.

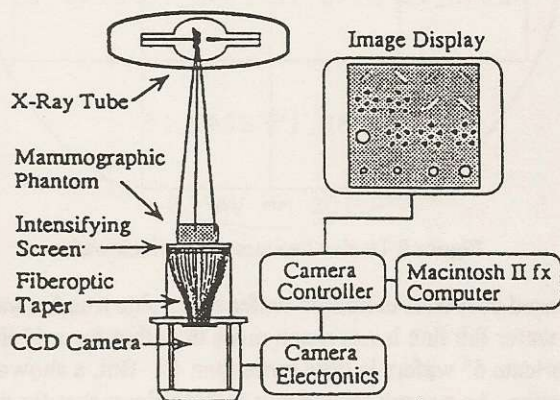


Figure 4 Schematic of fiberoptic CCD X-ray system<sup>12</sup>.

incorporate a cooled CCD camera system which is optically coupled to an X-ray scintillating plate. The coupling is effected by using either a lens assembly or a fiberoptic plate, Fig. 4. The x-ray beam is converted into light photons by a scintillating screen; then the CCD pixel array samples the optical scene and creates a digital image. The scintillating screen is usually made of a polycrystalline material such as gadolinium oxysulfide or cesium iodide. The transfer of light from the scintillating screen to a CCD imager can be accomplished by direct contact of these components. However, the currently available CCDs are usually not larger than 5cm x 5cm. Therefore a demagnifying optical coupling (either a lens or a fiber taper) must be used between the intensifying screen and the imager in order to cover an area larger than the size of the imager. Initial demonstrations utilized a Loral 2Kx2K CCD imager with an active area of 3cm by 3cm. Recently Loral has delivered a 4Kx4K imager with an active area of 6cm by 6cm. This is sufficient to image a complete biopsy area without requiring a tapered fiberoptic bundle. The scintillator plate may be attached directly to the CCD. Requirements for a full-field, 18cm by 24cm imaging system for mammographic screening and diagnosis will still require a more complex multiple CCD system.

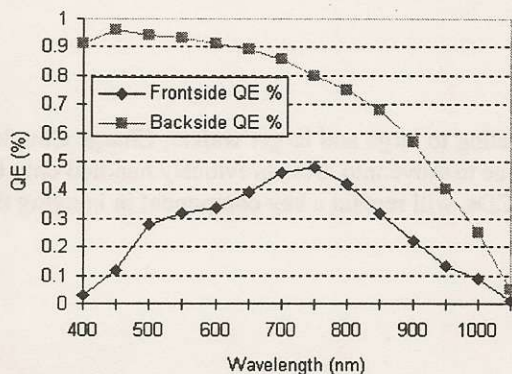


Figure 3 Backside vs Frontside QE.

## Large Area Medical Imagers

Medical X-ray imaging is another area in which film is rapidly being replaced by large area digital CCD imaging devices. The requirements are similar to astronomy, requiring large dynamic range, high quantum efficiency, low dark current, and stable solid state operation. Medical applications include biological x-ray microscopes, medical x-ray cameras (e.g., spot mammography) and dental x-ray cameras. In particular, a CCD-based filmless imaging system for stereotactic biopsy procedures in mammography has been shown to significantly improve the speed and accuracy of the biopsy<sup>10,11</sup>.

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Smaller X-ray imagers 2.6cm by 3.3cm suitable for intra-oral dental imaging are now being produced in the thousands. A scintillator plate is mounted on the face of the CCD and encapsulated in an autoclavable package for insertion in the mouth. The advantages of an all digital approach over film are similar to those in mammographic applications. A dramatic drop in radiation level is achieved. There is a significant reduction in exposure time



and less X-ray neutralization of trauma drugs. The images can be displayed immediately with a wider dynamic range and can be electrically transmitted to a remote site for archival on the information superhighway.

### High Resolution Digital Imaging

By the middle 80's the commercial market for camcorders was completely dominated by CCD's. Vidicon tubes common in the first generation cameras had been replaced by the solid state, stable, low power CCD. Higher resolution CCDs are migrating up into the higher end still camera arena as a film replacement. Several Japanese manufacturers now produce high resolution (>1300x1000 pixel) HDTV imagers which are now being seen in still cameras. Minolta and Nikon describe such devices in this conference. In the United States, Leaf and Mega-Vision are producing replacement camera backs for Hasselblad cameras. The camera backs use the Loral 2Kx2K CCD for both monochrome and color operation. Their high cost (>\$25K) limits their use to high end commercial photographic applications at this time. As the yields and volumes increase, prices will drop and applications expand.

The same philosophy which works for microprocessors and memory chips, increased yield and decreased cost with increased wafer size holds true for large area high resolution CCD imagers. The capital costs for a 6" wafer fab line is not much more than that for a 4" line. The time, manpower, chemical costs and moves required to fabricate 6" wafers is little more than 4". But, as shown in Figure 5, twelve 2Kx2K CCDs are fabricated on a single 6" wafer. As a result the thruput is three times that for a 4" fab line. Presently major semiconductor manufacturers utilize 8" wafers which would contain a total of 21 devices. Of course, if the wafer is bigger someone will want to fill it. There are customers whose applications dictate the largest imager possible and can tolerate the significant cost. And as yields and the technology improves full wafer imagers move within the realm of practicality.

A full wafer 5040x5040 element large optical format aerial reconnaissance imager has been demonstrated by Dalsa and fabricated through the foundry at Orbit on 4" wafers.

Loral has fabricated a 4096x4096 15µm, three side buttable, scientific imaging array with satisfactory yields at both Newport Beach and Milpitas. A multi-phase 4096x4096 array has also been fabricated specifically for mammographic applications. The real piece de résistance is a 9216x9216 pixel imaging array under development at Loral Federal Systems 5" wafer facility in Manassas. This reconnaissance imaging array has an incredible 85 million pixels per frame. With 32 outputs and a readout rate of 2.5 megahertz it will take a full second to readout a frame. Digitized to 12 bits a single frame would occupy 127 million bytes. Clearly an information superhighway is necessary to prevent overwhelming any form of data storage when imaging at a reasonable frame rate. The pixel size is 8.75 µm square forming an image area of 8cm by 8cm. The imager uses a special three layer polysilicon process and optimum design rules to achieve optimum yield.

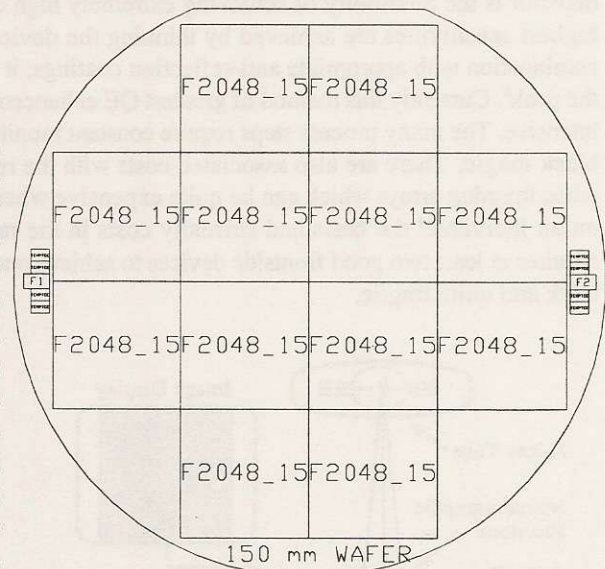


Figure 5 Twelve Devices per six inch wafer

### Conclusion

As semiconductor technology continues to improve, migrating to large and larger wafers, Charge Coupled Devices will keep pace. The use of these imaging devices will continue to move into areas previously handled only by photographic film as costs drop and speed and resolution expand. CCDs. will remain a key component in imaging the visual environment on the Information Superhighway.

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