Large Format A-Si:H 2-Dimensional Array as Imaging Devices

X. D. Wu, R. A. Street, R. Weisfield, D. Begelsen, W. Jackson, D. Jared, S. Ready and R. Apte

Xerox Palo Alto Research Center, Palo Alto, CA 94304

ABSTRACT

We discuss large amorphous silicon 2-dimensional image sensor arrays. The device is a matrix addressed array of light detectors fabricated from hydrogenated amorphous silicon on a glass substrate. Each imaging pixel consists of a light sensor and a thin film transistor (TFT). We will describe the performance of a particular imager with approximately 8" x 10" in area and 1536 x 1920 pixels with a pixel size of 127 microns, which gives a spatial resolution of 200 x 200 spi. The array has a minimum read-out time of 30 msec, making it ideal for real-time applications as well as high-speed imaging. It has an intrinsic dynamic range of nearly 10^4, although the present dynamic range of the system is limited by present 8-bit read-out electronics. The sensors have a broad sensitivity spectrum from 400nm to 700nm and we achieve color document imaging using a flash light source and appropriate color filters. The sensor array can operate in both contacting mode as well as in projection mode. This large area imaging device is also ideal for digital medical x-ray imaging with a phospher layer placed in contact with a sensor array.

The future challenges for this technology are to achieve higher sensitivity, higher resolution and easier packaging of the electronics. We are exploring novel designs to allow a very high fill factor, significantly increasing the sensitivity and performance of an X-ray imager.

SENSOR ARRAY

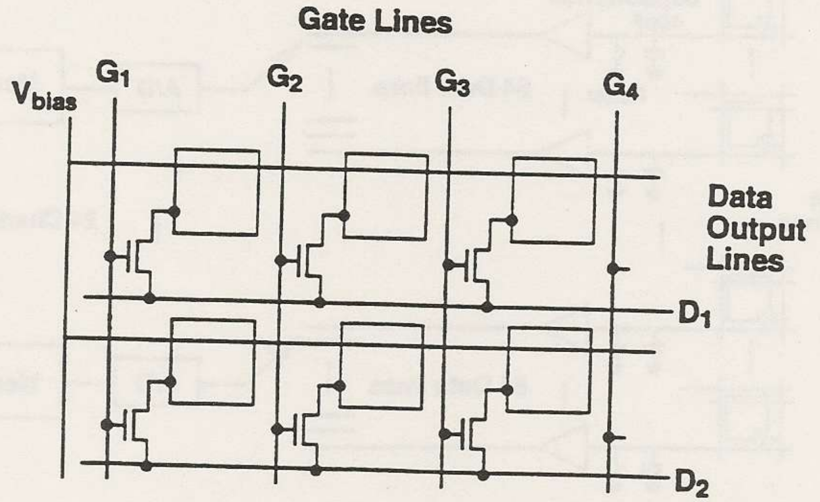

Figure 1. Schematics of pixel structures in an amorphous silicon sensor array. The light sensor is a n-i-p diode and the thin film transistor (TFT) controls the charge transfer.

The 2-dimensional sensor array is addressed with metal gate lines and data output lines in a matrix fashion.[1,2,3] Each pixel consists of a n-i-p diode light sensor and a TFT. Figure 1 shows a schematic of the sensor array. Charges generated by incident light are stored in the intrinsic capacitance of the sensor diode. Measurement of the stored charge is enabled by switching on an attached TFT. One measures the charges created by incident light with a voltage sensitive amplifier connected to the data output line. By sequentially clocking a gate voltage through all the gate lines, one reads out charges in all the sensors.

In order to allow for contacting imaging, the sensor is designed to have a size of 88 x 88 micron^2, which gives a fill factor of 36%. Each sensor has an intrinsic capacitance of about 0.8 pF. The on-resistance of the TFTs is about 4 MOhm at 10V of gate voltage. If we assume a charge transfer time of 5 RC time constants, we calculate the frame time of the sensor array to be 30 msec giving a scanning speed of 33 pages/sec. Raising the TFT voltage and perhaps increasing W/L allow imaging at video rates, where W and L are the width and length of the gate electrode. It can be shown that the frame time is roughly independent of the array resolution and the pixel size and is only proportional to the dimension of the whole array.[4] Although the real scanning speed is more likely to be limited by the data transfer rate of the readout electronics, the high-speed performance of the sensor array makes it most adequate for high-speed document imaging applications.

The sensor array is very sensitive to light. The maximum signal charge that can be stored in a pixel is:[4] $C_{sens}V \approx 4$ pCoulombs, assuming a sensor voltage , V, of 5V. With a frame time of 100 msec, the maximum charge corresponds to an absorbed light flux of about 1 erg/cm^2 and requires an illumination of the order of 1 cd/m^2. Therefore, the amorphous silicon sensor array can operate with very low level of illumination.

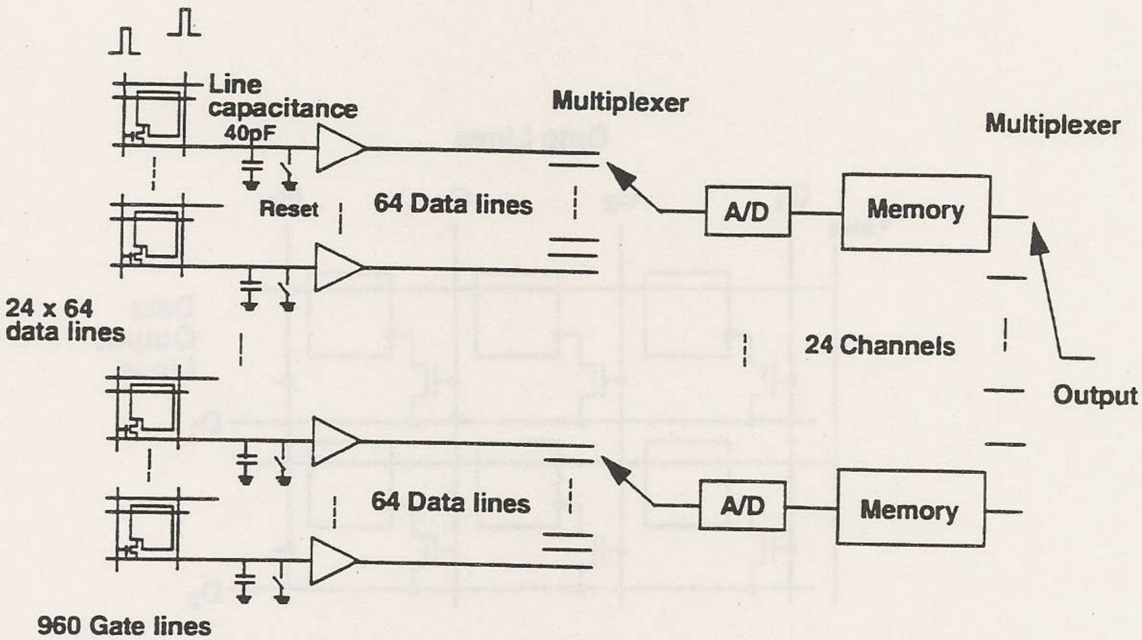

Figure 2. A schematic of the readout electronics. Every 64 data lines are connected to an IC that has 64 amplifiers. A complete image is stored in 24 memory buffers after a readout.

The dynamic range of each sensor is about 10^4 to 10^5. The dynamic range of a sensor is determined by random electronic noise and thermal noise generated from the on-resistance of the TFT coupling with the sensor capacitance.[5] The large dynamic range intrinsic to the sensor array surpasses the requirement for document imaging as well as that for medical imaging applications. In the current setup of our experiment, the dynamic range of the system is limited to 500~1000 by the signal-to-noise ratio of the readout amplifiers and further limited by an 8 bit A/D. Implementation of readout amplifiers with a higher signal dynamic range will improve the performance of the imager.

READOUT ELECTRONICS

The matrix-addressing scheme shown in Figure 1 allows a parallel data output and it greatly enhances the readout speed comparing to a raster readout scheme that is normally used in a CCD sensor array.

The sensor charges are measured with voltage sensitive amplifiers. Each readout chips have 64 integrated double correlated sample and hold amplifiers. The pre-amplified signals of the 64 input channels are multiplexed at an output of each chip. Figure 2 shows a schematic of the readout electronics. After a complete readout of an image frame, the image data are scrambled in the memory buffers. An unscrambled image is reconstructed while reading out date from memory chips to a PC in a pre-programmed fashion. The image is then processed by two i860 microprocessor for gain and offset. A broad bandwidth for the serial link and faster image processors will improve the imaging speed up to the intrinsic frame rate of the imager. Figure 3 is a schematic for the system electronics of the imager.

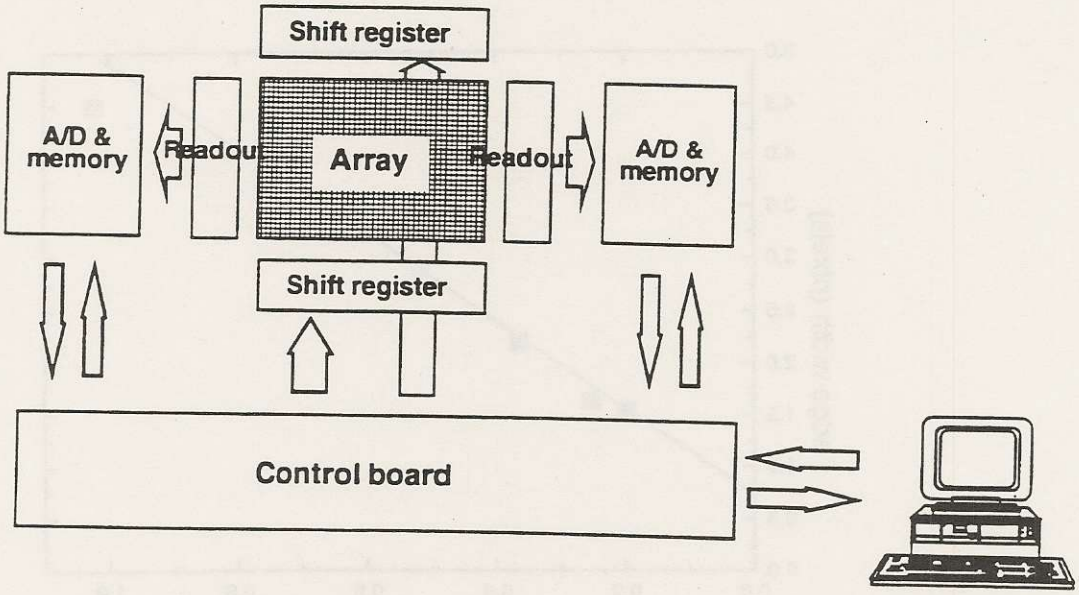

Figure 3. The system electronics for the 2-dimensional imager. A control board supplies all the control logic and addresses for the readout boards, gate drive boards and A/D boards. The data line with a PC is serial/8 bits wide.

An opaque document can be imaged with a 2-dimensional sensor array by placing the document in contact with the array. There are gaps that are transparent to light between light sensors. This allows one to illuminate an opaque document from the back of the sensor array through the gaps. A 2-d imager operating in a contacting mode is compact in size because it needs no imaging optics. It is most adequate for desktop scanning applications. The quality of an image acquired with contact imaging depends on the thickness of the space between a document and the light sensors. A transparent film with a thickness of half of a pixel size maintains a good contrast transfer function of the imager.[6]

In a projection mode, a lens forms an image of a document on the surface of the sensor array. The projection optics offers a large depth-of-focus for the system. However, a projection system has a much lower light efficiency than that of a contact imager. With some minor absorption of light by the sensor substrate, protection film, and a document, a contact imager has a light efficiency close to one. For a projection system, the light efficiency η can be written as:[7] $\eta = M^2/8F$ where M is the magnification of the lens system and F is the f-number of the collection lens. Even with an 1:1 magnification, the light efficiency of the system can be more than one order of magnitude less than that of a contact imager. For a imager with a reduction optics, like some of the CCD scanners, the light efficiency can be even lower.

The 2-d amorphous sensor arrays are also good color imaging devices. The photodiodes are sensitive across the visible spectrum, from 400 nm to 700 nm, with a broad peak centered at about 550 nm. In either imaging mode, one can sequentially expose a color document with red (R), green (G), and blue (B) illuminants and acquire all three color primaries of the document.

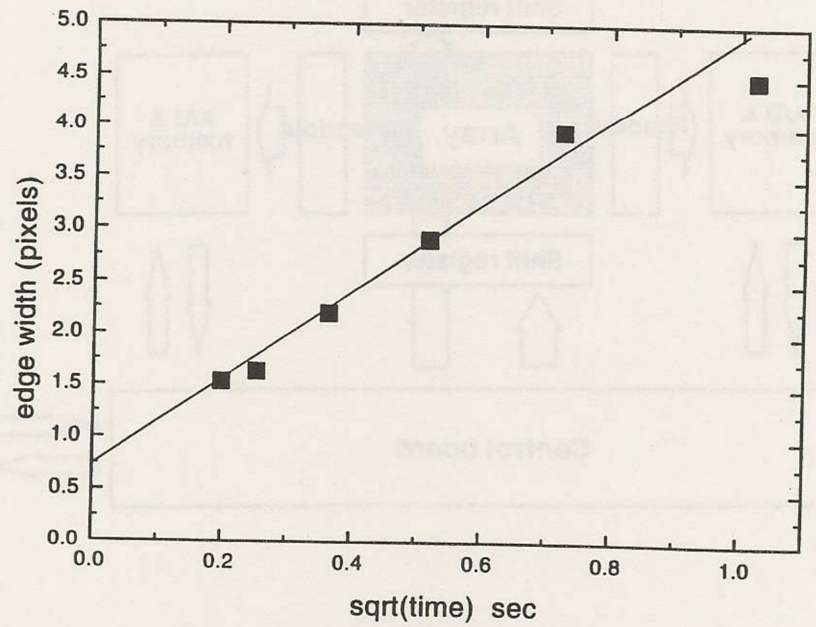

Figure 4. Change in edge width with length of frame time shows that light-generated charges diffuse within sensor layer of 100% fill factor.

With a color correction for the illumination and the sensor response, we find that the amorphous silicon sensor array scans color documents with a color quality comparable to a commercial high-end flatbed color scanner used for graphic art applications. ($\Delta E^* \leq 5$ for a color image acquired of a Kodak Ektachrome film target Q60A, which has known CIE L*a*b* values.)

We also have made a test array of sensors with 100% fill factor, as an attempt to achieve higher light collecting efficiency, which is important for X-ray imaging applications. We have found that the contrast ratio of an acquired image decreases as the frame time length increases. This is due to the result of charge diffusion within the sensor layer. We have measured an edge width of a perfect edge in an acquired image and have plotted it out as a function of time (Figure 4). We see that the edge width(between 20% and 80% intensity) varies linearly with square root of frame time period. It indicates the diffusion characteristic of light-generated charges within the sensor layer.

SUMMARY

We have developed an imaging system that uses a 7.7" x 9.6" 2-dimensional amorphous silicon sensor array with 1536 x 1920 light sensors. We have demonstrated imaging with the array in both contact imaging mode as well as in a projection imaging mode. The image resolution is 200 x 200 spi and the sensor array has a frame rate of 120 frames/sec. The sensor array is very sensitive to light, and the technology is well suited for high-speed and high-resolution imaging. We have also investigated the color reproducibility of the imager as a color scanner. Experiments on a test sensor array with a 100% fill factor sensor layer shows the diffusion characteristic of light-generated charges within a sensing layer.

REFERENCES

1. R. A. Street, I. Fujieda, R. Weisfield, S. Nelson, and P. Nylen, "Large area 2-dimensional a-Si:H imaging arrays", MRS Symp. Proc., 258, 1145, 1992.

2. R. A. Street, R. Weisfield, S. Nelson, P. Nylen, and X. D. Wu, "Page sized a-Si:H 2-dimensional imaging arrays", MRS Symp. Proc., 297, 957, 1993.

3. X. D. Wu, R. A. Street, R. Weisfield, S. Nelson, M. Young, M. Nguyen, and P. Nylen, "Imaging with page sized a-Si:H 2-dimensional sensor arrays", SPIE Symp. Proc., Vol.2172, 144, 1994.

4. R. A. Street and L. E. Antonuk, "Amorphous silicon arrays develop a medical image", IEEE Trans., Circuits and Devices, 38, July, 1993.

5. I. Fujieda, R. A. Street, R. Weisfield, S. Nelson, and P. Nylen, "High sensitivity readout of 2d a-Si imager sensors", Jpn. J. Appl. Phys. 32, 198, 1993.

6. R. A. Street, R. L. Weisfield, S. E. Nelson, and R. Chang, "Page-sized amorphous silicon image sensor arrays", SPIE Proc., 1900, 135, 1993.