Large Area Digital X-ray Specific Imagers

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1. Introduction

The field of radiography has been in existence for over 100 years. However, it is currently one of the last "holdouts" of analog, chemistry-based film technology and only now maturing into the digital age. The digital revolution in imaging began in the early 1970's with the introduction of the first digital imagers, along with microprocessors to analyze and manipulate the resulting images. In the 1980's digital imaging technology spread to camcorders, and in the 1990's to digital still cameras. Finally, it's radiography's turn to take advantage of digital imaging technologies. This challenging application has been saved for last, mostly because the lack of suitable x-ray optics requires large-area imaging devices which are harder and more costly to make. These devices have been in serious development for the last decade, and are now becoming available for digital radiography applications.

2. Markets and Applications for Digital Radiography

Typical markets for digital radiography cover the spectrum from industrial applications such as non-destructive testing (NDT) and process monitoring to scientific instrumentation and medical imaging. One of the foremost applications is inspection of articles including small components, printed circuit boards, welded parts, agricultural and food products, and contraband detection. Scientific instrumentation in need of digital x-ray images includes crystallography, spectroscopy and beam profiling.

3. X-ray Specific Imager Technologies

X-ray specific technologies for analog imaging include film and image intensifiers. The digital technologies we'll discuss in this paper are amorphous silicon panels, charge-coupled device (CCD) imagers and CMOS imagers.

3.1 Overview of Amorphous Silicon Imagers

Amorphous silicon imagers are typically photodiode arrays with an active thin-film transistor (TFT) matrix readout, similar to active matrix flat panel displays. The thin-film technology enables very large imaging areas (20 cm by 20 cm and larger), and the amorphous silicon has very high radiation tolerance. However, it has limitations in both resolution (typically > 100 µm) and performance (noise, contrast) owing to the less-than-ideal properties of the amorphous silicon semiconductor. In addition, it requires a specialized fabrication process with a dedicated manufacturing facility, increasing both production and development costs relative to competing technologies.

3.2 Overview of CCD with Optical Interface

For the past two decades, CCD imagers have been established as the leading technology for high-performance optical imaging. Unlike matrix-addressed imagers like amorphous silicon panels and CMOS imagers, CCDs read out their signal by transporting charge packets across the silicon substrate. Their advantages include high resolution, low noise and high sensitivity. In digital radiography, they are typically combined with a fiber-optic taper that increases the field-of-view and protects the CCD from radiation damage. CCDs are very sensitive to radiation damage, and even with the added shielding of the taper they can only be used in low-energy x-ray imaging applications (typically < 50 kV). As with amorphous silicon, their production requires a specialized process that adds to their development cost. The fiber-optic taper is also costly, difficult to interface to the CCD chip, and decreases the CCD's sensitivity by the square of its magnification.

3.3 Overview of CMOS Imagers

CMOS imagers, like amorphous silicon panels, are matrix-addressed photodiode arrays. However, they take advantage of a highly developed manufacturing infrastructure – the semiconductor industry – by using the same fabrication processes and equipment that is used to make microprocessors and logic arrays. In other words, the IC industry has already paid for the technology development and fabrication equipment, and is continuing to do so. Today's small-linewidth processes allow the addition of special features on a per-pixel basis, vastly improving the performance of the CMOS array. Noise levels comparable to CCDs can now be achieved, and the dynamic range of a CMOS imager is typically several times larger. In addition, CMOS arrays can integrate timing and readout functions on the same device. Their highly integrated architecture allows the design of a "system on a chip" (SOC), which is ultimately less costly than an imager requiring a large amount of support electronics.

Technology	*Active Pixel CMOS*	*Passive Pixel CMOS*	*CCD with Fiber Optic Taper*	*a-Silicon Passive Pixel*
Availability of Technology	available from foundries	available from foundries	requires special process	requires special fab
Pixel Architecture	active photo-diode pixel	passive photo-diode pixel	field-induced detector	passive photo-diode pixel
Overall Performance	●●●●●	●●●	●●●● (depends on taper)	●●
Noise	●●●●	●●●	●●●● (depends on taper)	●●
Dynamic Range	●●●●●	●●●●●	●●● (depends on taper)	●●●●●
Radiation Tolerance	●●●●	●●●●●	●●● (saved by the taper)	●●●●●
Level of Integration	●●●●●	●●●●●	●●	–
Resolution	> 10 µm	> 10 µm	10-50 µm w/o taper > 50 µm with taper	> 100 µm
Cost Effectiveness	●●●●	●●●●●	●●	●●

Figure 1 – Comparison of X-ray Specific Imager Technologies

4. RadEye™ X-ray Specific CMOS Imagers

In 1997, Rad-icon Imaging Corp. was founded to develop and manufacture x-ray specific imagers based on CMOS technology. The RadEye™ line of large-area CMOS imagers features integrated on-chip electronics and low-noise differential signal extraction combined with a large-area, high-resolution pixel array suitable for x-ray imaging. Additional features such as variable integration times (from 60 ms to 60 s) and non-destructive readout enable this device to work in a wide range of imaging applications. The complementary line of Shad-o-Box™ cameras makes use of the RadEye™ sensors in a self-contained, PC-ready x-ray camera.

The basic RadEye™ building block is a three-side buttable active pixel CMOS imager consisting of 512 by 1024 pixels on 48 µm centers. The active area is approximately 25 by 50 mm. The dynamic range is better then 10,000:1 (> 80 dB). With a maximum pixel data rate of 2.5 MHz, the RadEye™ imager can run up to 4.5 frames per second (fps). The frame rate can be increased to 17 fps by using sparse sampling (skipping every other row and column). At the opposite extreme, the very low average dark current of 4000 electrons per second allows the RadEye™ imager to integrate signal for tens of seconds before running the risk of saturating.

Since the RadEye imager is buttable on three sides, several of these devices can be combined to form larger mosaics. Two devices side-by-side form a 1024 by 1024 pixel detector with 50 by 50 mm active area (the RadEye™2). Eight devices can be combined for a 2048 by 2048, 100 by 100 mm detector. For special applications these devices can even be mounted on a curved substrate to approximate a curved image surface.

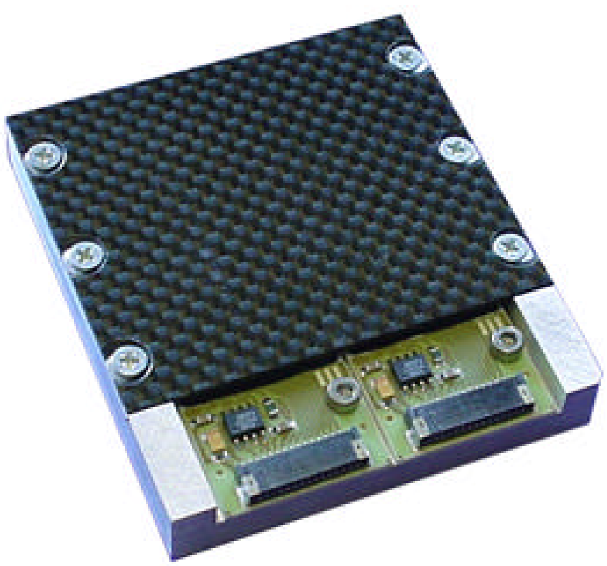

Figure 2 – RadEye™2 Imager

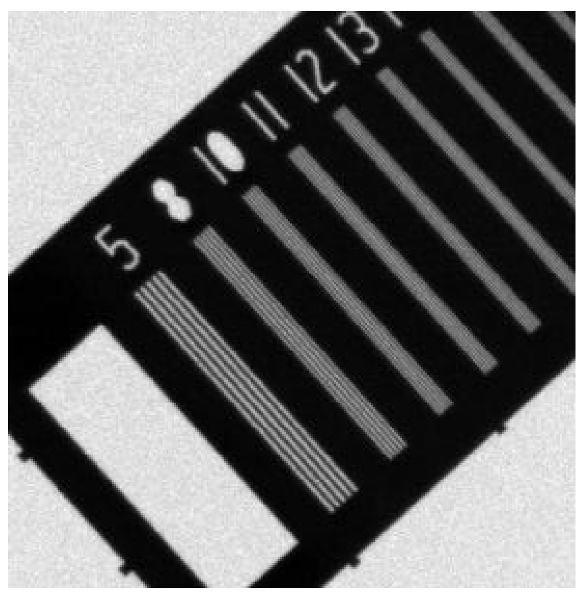

Figure 3 – Resolution Chart

5. Future Outlook

CMOS technology is continuously expanding to larger wafer sizes. The current "workhorse" six inch wafer size allows for image sensors up to 100 mm long, which can be tiled to form up to 20 cm wide image planes. Eight inch wafers, currently becoming more widely available, would allow for up to 30 cm image planes. Even larger image sensors can be realized with the twelve inch wafer fabs that are now coming under construction. CMOS foundries will soon adopt the new technology, while the development continues to be funded by the IC industry.

	Amorphous Silicon Panel	*CCD with F.O. Taper*	*CCD without F.O. Taper*	*X-ray Specific CMOS Imager*
Field of View	●●●●●	●●●	●	●●●●
Resolution	●●	●●●	●●●●●	●●●●●
Performance	●●●	●●●●	●●●●●	●●●●●
Adaptability of Technology	●	●	●	●●●●
Cost Effectiveness	●●	●●●	●●●●	●●●●●

Figure 4 – Future outlook for improved x-ray image capture

6. Summary

We presented a brief review of digital radiography, its major markets and its applications. We compared several digital x-ray specific imager technologies, namely amorphous silicon panels, CCDs with fiber-optic tapers, and CMOS imagers. Amorphous silicon panels have the size advantage, but lack sensitivity. CCDs excel at the latter, but are costly and prone to radiation damage. CMOS imagers present a low-cost alternative with excellent performance in a variety of digital x-ray imaging applications. The RadEye™ x-ray specific CMOS imager is an example of such a device. The RadEye™ imager features high resolution and a modest active area size, but can be tiled to achieve large imaging areas. As CMOS technology continues to develop to larger wafer sizes, CMOS x-ray imagers will be able to grow in size as well to address an even wider range of digital radiography applications.

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