Final Technical Report

Grant: DE-FG0297ER14805, "Pixel Array Detector for Time-Resolved X-ray Science", S.M. Gruner, P.I.
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The goal of this grant was to research and develop prototype Pixel Array Detectors (PADs) for applications at the Advanced Photon Source (APS) and other synchrotron x-ray facilities. A Pixel Array Detector (PAD) consists of two functional layers: a radiation detection layer (a semiconductor diode array also referred as a high resistivity pixellated diode layer) and an electronics layer (Custom IC Chip) capable of storing up to eight frames of data under each pixel of the detective layer. The grant has succeeded in developing prototype PADs and applied them to significant applications of interest at the APS.

The work accomplished under this grant is part of an ongoing x-ray detector research program funded primarily by DOE, and is closely linked to ongoing DOE grant DE-FG02-97ER62443. Although the funds for the present grant DE-FG0297ER14805 have been exhausted and the grant has come to an end, the work will continue under DE-FG02-97ER62443. In particular, parts of the next prototype versions of the PAD detector are still being incorporated into new detectors. The resultant devices will continue to be tested at the APS and other synchrotron sources as part of ongoing collaborations with groups at the APS and elsewhere. Towards this end, we have sent a request to Dr. Dennis Mills of the APS administration that we be allowed to continue to use the equipment procured under this grant so that the work may continue.

Technical Progress

Progress of work under the grant has been mostly summarized in a series of publications which serve to disseminate the results of the research. These publications are attached as part of this report. They are as follows: *

1. S.L. Barna, J.A. Shepherd, M.W. Tate, R.L. Wixted, E.F. Eikenberry, S.M. Gruner (1997). Characterization of a prototype pixel array detector (PAD) for use in microsecond framing time-resolved x-ray diffraction studies. *IEEE Trans. Nuc. Sci.*, 4(3) : 950-956.
2. B.G. Rodricks, S.L. Barna, S.M. Gruner, J.A. Shepherd, M.W. Tate, R.L. Wixted (1996). Pixel array detector for time-resolved x-ray scattering. *Rev. Sci. Instrum.*, 67 (9): 1-5.
3. E.F. Eikenberry, S.L. Barna, M.W. Tate, G. Rossi, R.L. Wixted, P.J. Sellin, S.M. Gruner (1998). A pixel array detector for time-resolved x-ray diffraction. *J. Synchrotron Rad.* 5 : 252-255.
4. G. Rossi, M. Renzi, E.F. Eikenberry, M.W. Tate, D. Bilderback, E. Fontes, R. Wixted, S. Barna, S.M. Gruner (1999). Tests of a prototype pixel array detector for Microsecond time-resolved x-ray diffraction. *J. Synchrotron Rad.* 6 : 1096-1105.
5. G. Rossi, M. Renzi, E.F. Eikenberry, M.W. Tate, D. Bilderback, E. Fontes, R. Wixted, S. Barna, S.M. Gruner (2000). Development of a pixel array detector for time resolved x-ray imaging. *Synchrotron Radiation Instrumentation: Eleventh US National Conference*,

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Stanford, CA 13-15 October, 1999. (P. Pianetta, J. Arthur & S. Brennan, eds., Amer. Inst. Phys., AIP Conf. Proceed, Melville, NY)

6. P.J. Sellin, G. Rossi, M.J. Renzi, A.P. Knights, E.F. Eikenberry, M.W. Tate, S.L. Barna, R.L. Wixted & S.M. Gruner (2000). Performance of semi-insulated gallium arsenide x-ray pixel detectors with current-integrating readout. Nucl. Instr. Meth. A (In press).

Publications #1-3 summarize fabrications and testing of a 4x4 pixel PAD designed to test the electronic circuitry and the concepts of PAD fabrication.

Publication #4 is a detailed description of the fabrication and testing of 100x92 PAD with x-rays at the Cornell High Energy Synchrotron Source (CHESS). Radiation damage effects were also examined.

Publication #5 provides further test data, both with x-rays and with pulsed optical lasers. The optical laser data helped resolve issues of radiation effects on the PAD CMOS circuitry.

All of the above PADs consisted of a high resistivity Si detective layer solder-bump bonded to a CMOS circuitry chip. In order to examine the feasibility of PADs useful at higher x-ray energies, several of the CMOS chips were also bump-bonded to GaAs detective payers. The testing of these devices is described in publication #6.

As noted in the introductory paragraphs of this report, the work is ongoing under other DOE support, e.g. DE-FG02-97ER62443. Future progress will be reported in progress reports for that grant. However, it is useful to summarize some of this ongoing work:

1. In collaboration with Dr. Jin Wang and his group at SRI-CAT at the APS, we have used the 92x100 PAD to perform radiography of fuel injector sprays. The efficiency of fuel injection is a major concern for the DOE. Improvements of even a few per cent in the fuel efficiency or pollution reduction of gasoline and diesel fuel injectors can have enormously beneficial consequences for the nation. A typical fuel injection cycle lasts only a few msec. Further, it is very turbulent and difficult to computer model. Moreover, the fuel spray is optically dense and, therefore difficult to probe by optical means. Optimization of the fuel injection cycle, by varying such parameters as the injector geometry or pressure profile, results in repeatable modifications of fuel spray process. Using the 100x92 PAD we have succeeded in performing microsecond time-resolved x-ray radiography of a cerium-doped fuel spray. The resultant "movie" details the process of a 2 msec fuel injection cycle. Now that it has been demonstrated that time-resolved radiography at the appropriate time scales is possible, we expect to proceed over the coming months with more detailed exploration of fuel injectors. The next synchrotron run is expected to occur at CHESS in December, 2000.
2. The 1.2 micron CMOS process which was used to fabricate the prototype 100x92 PAD is unsuitable for future detectors because this scale of fabrication is no longer available. There are very good reasons for going to smaller scale CMOS processes. First, and most importantly, the smaller scale processes are expected to continue to be available for some time. Second, the smaller processes allow more complex electronics to be packed into each pixel, thereby allowing more functionality in the CMOS layer. Finally, it has been demonstrated at CERN that the threshold for radiation damage rises by at least three orders

of magnitude as the scale of fabrication shrinks below 0.25 microns, provided that the CMOS FET gate structures are made using a "ring-gate" geometry. Accordingly, we have designed, simulated and submitted for fabrication PAD test structures and parts in 0.5 and 0.25 micron processes. We have also designed a ring-gate library and submitted for fabrication parts using this library in small-scale processes. Most of these parts have not been fully tested; indeed, some parts still are in fabrication and have not yet arrived. Our task for the coming year is to fully test these parts. If the tests are successful some of the parts will be assembled into functional detectors and applied to synchrotron radiation problems. This work will be fully reported upon in the open literature.

Summary

The grant has been very successful in designing, fabricating, testing and applying PAD detectors for time-resolved synchrotron radiation work. Small-scale PADs were made and are being applied to significant research problems. It has been noted at recent international workshops on pixel array detectors that the effort funded, in part, by this grant is the premier analog time-resolved PAD effort in the world and has already produced devices well in advance of competing efforts. However, there is still much work to be done. This grant was always intended to be an R&D project towards the goal of development of a large area PADs. Although excellent progress has been made towards this goal, there is yet much work to be done before working large-area PADs move out of the R&D stage. This work is continuing and is likely to do so for years to come. As this work proceeds we expect to continue to produce and apply unique, useful detectors at all stages of the R&D process.