Review Report of The SACLA Detector Meeting

Dec. 9, 2011

The 2nd Committee Meeting @ SPring-8
Date: Nov. 28-29, 2011
Committee Members:

Dr. Peter Denes, LBNL, U.S. (Chair of the Committee)
Prof. Yasuo Arai, KEK, Japan.
Prof. Andrew Holland, The Open University, UK.
Dr. Grzegorz Deptuch, Fermilab, US. (Absent)

Introduction

The SDAC (SACLA Detector Advisory Committee) has been chartered as a collegial advisory committee (rather than a formal independent review committee) with the goal of sharing experience and advice in order to ensure that the SACLA Detector Team's activities maximize the scientific output of SACLA. The Mandate of the Committee as presented at the 1st Committee Meeting is:

1. The following general issue.
   - 1.1. Any Potential risk in the current on-going projects
   - 1.2. Alternative approach to achieve the detector performance in short and long term
   - 1.3. Is there any need to add committee member? If so, what area of expertise do we need?
   - 1.4. Adequacy and balance of researchers' own goal.
   - 1.5. What Infrastructure do we need to invest in short and long term?
   - 1.6. Strategic direction
   - 1.7. Any other suggestions.
2. The specific issues that the DAQ team is facing.
   - 2.1. The list of the specific issues will be issued separately.

During our meeting, we were presented the state of the project, detector development, and a discussion of an important application of the newly developed detectors in coherent imaging:

SACLA Project Status and Future Perspective – M. Yabashi
Imaging Science at SACLA – C. Song
Overview of Detector Development Program – T. Hatsui

This was followed by detailed status reports on the MPCCD and MVIA developments, as well as other topics:

MPCCD status overview – T. Kameshima
Status of CCD Sensor and Readout Electronics of MPCCD – T. Hatsui
MPCCD Octal Detector System – S. Ono

Upgrade of MPCCD Readout Electronics – Minglee Chu (Academica Sinica)
Multi-Via Detector Status – T.Hatsui
DAQ Front-End: Current Status and Future Perspectives – T. Ohata

In a change from the 1st Committee Meeting, the collection and transport of digital data, referred to here as "DAQ", is now the responsibility of the JASRI Controls and IT groups, and no longer falls under the mandate of this committee.

Findings

Significant progress is continuing on the two principle current detector developments:

MPCCD

The MPCCD is an 8-port, 0.5k x 1k CCD in both single and octal (2k x 2k) formats. The octal detector was being prepared for first FEL light on the day after our Committee Meeting. The CCD itself is being developed in four phases:
Phase 1 is a front-illuminated, partially-depleted device with 50 µm depletion depth for direct X-ray detection. This is the device currently in use.
Phase 2 uses the same device, but with a phosphor. P46 has been selected as a phosphor, based on work done by the SPring-8 group, but light yield is low, and further evaluation is required to see if there is a science case match for such a detector.
Phase 3 would replace the Phase 1 CCD with a fully depleted CCD in order to achieve lower noise and higher QE (quantum efficiency). Production of such a CCD is expected to start shortly.
Phase 4 would be a thinned version of the Phase 3 sensor, optimized for soft X-rays. This development is on hold, pending better definition of the science case requirements.

	Specification	**Measured**
Noise	< 300 [e-]	< 250 [e-]
Peak signal	5 [Me-]	2.7 [Me-]
Frame rate	60 [Hz]	30 [Hz]
Cross-talk	< 1000 [ppm]	< 3000 [ppm]
PSF	< 50 [um]	~ 21 [um]

MPCCD specifications and measurements to date are shown in the table above. Although several parameters meet or exceed specification, certain improvements are needed, and are underway:

- The frame rate has not achieved the 60 Hz requirement. The cause has been identified as a slew rate limitation due to high capacitive loading, and is being addressed by the insertion of buffer amplifiers directly outside of the detector chamber. 60 Hz operation is predicted to be achieved by summer 2012.
- Cross-talk between outputs is observed. While not fully understood, it is anticipated that improved layout of the kapton interconnect circuit can alleviate this problem.

- A discrepancy in the measured full well of MPCCD pixels remains between measurements by the manufacturer, e2V – using their equipment, and SACLA – using the Meisei elecronics. At present, it is suspected that this difference is due to the quality of vertical clocks.
- Initial radiation hardness studies have been undertaken, although the results presented to us were somewhat inconsistent.

MVIA

MVIA is a medium-term development based on SOI (Silicon-on-Insulator technology) developed in collaboration with KEK and Lapis Semiconductor. One pixel consists of several charge collection diodes. One diode is connected to a high capacitance node, in order to form a low-gain channel, and the other diodes are connected together to form a high-gain channel. The goal is a 500 µm thick detector with a full scale per pixel of 7×10^6 e^- and a noise of 150 e^- per 30 µm pixel, corresponding to a 16-bit dynamic range. The final sensor design is 65 x 27 mm^2, with 12 high-gain and 12 low-gain pseudo-differential ports. Power consumption is expected to be 1W average assuming a 10% duty factor.

Since the last review, the pixel design has been significantly changed. Previously, a gated integrator with op-amp input stage was used, which has been replaced with a 4T design. In addition, due to 1/f noise, it has been concluded that correlated double sampling is needed to meet the noise specification, so that 120 Hz frame rate readout is required.

In order to fabricate the desired sensor geometry, the group has worked with the manufacturer to develop a simple but effective stitching technique.

SOI is a relatively novel technology, and several process-related questions remain:

- Can one obtain suitable high-resistivity substrate material?
- Can the SOI structure achieve suitable radiation tolerance?

Active R&D by the larger SOI collaboration is under way in both of these areas.

Further topics

Detector requirements

Overall detector requirements remain unchanged from the 1st Committee Meeting:

1. Match the repetition rate of XFEL pulse (60 Hz for SPring-8 XFEL)
2. Single photon detection capability
3. Better quantum efficiency for 6-12 keV in short term. Wider range in longer term.
4. Higher peak signal. Higher delivers wider applications, and more opportunities to explore.
5. Resistant to estimated 30 Mrad annual dose.

Mid-to-long term requirements have been slightly revised:

1. 1.Optical shielding
2. Higher photon energy (may be up to 20-30 keV)
3. Lower photon energy (may be down to **50 eV**) (*previously 200 eV*)
   ~~Higher frame rate to record background up to 180 Hz~~ *(previous requirement, no longer valid)*
4. Higher frame rate to meet accelerator upgrade toward higher repetition rate, probably 300 Hz in future. (*was 120 Hz; 1 kHz eliminated*) Then will start soft x-ray regime.

New collaborations

During the Committee meeting, a group from Academia Sinica presented plans to produce a more compact readout for the MPCCD. Since the readout is mounted directly on the endstation, this would be desireable.

Comments and Recommendations

MPCCD

The day after the Committee meeting, an Octal MPCCD took the first FEL images in the coherent scattering chamber. The team is to be highly commended for this accomplishment.

As part of radiation tolerance studies, the use of thermal annealing in order to enhance lifetime should be investigated.

Support effort in early operations should be carefully examined. In transitioning to user operations, subtle problems – which require time from detector experts – often arise.

MVIA

In order to ensure delivery of the MPCCD, the MVIA was placed as 2nd priority. As the MPCCD development matures, the plan is to transfer knowledge to support staff, thus enabling the development team to focus on advancing the MVIA detector. The Committee concurs with this approach, and notes that the MVIA is potentially a very good technology match, especially considering the collaboration with KEK and Lapis.

Achieving the desired performance, independent of radiation hardness, will be very challenging:
A 16-bit pixel, if such performance is indeed achieved, is not trivial. With two gain stages per pixel, each pixel will require individual calibration. With a full-size detector of $4x10^7$ pixels, consideration should be given to how such a detector will be calibrated.
The MVIA concept assumes uniform charge distribution over a (30 µm) pixel. With a suitable substrate, this assumption is not obvious. Simulation (at the device and

numerical level) together with measurements should be performed to confirm the viability of the concept.

Work should continue on the MVIA detector, but a set of minimum requirements together with guidelines as to when they should be met should be developed.

Further topics

Collaboration

Defining useful collaborations can optimize resources. The collaboration with Academia Sinica presents useful possibilities, but should be better defined and planned.

Data acquisition and Computing

Analysis, including algorithm development and on-line visualization, will make use of the staff and facilities of the supercomputing center in Kobe. Together with the now separate data acquisition group, good coordination is required – as efforts from all three of these groups are required to validate, diagnose and improve detector performance.

Miscellaneous

- A long-term, time-phased road map of goals and requirements will be helpful to define and prioritize future work.
- A “charge” for each Committee meeting, with specific topic(s), will help elicit more targeted feedback.
- The group is encouraged to publish their detector developments, and to present at appropriate conferences in order to maintain a high profile.
- Although on-site meetings are irreplaceable, for practical reasons short, focused “remote” (video, Skype, …) intermediate reviews should be considered.