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Development of X-ray Spectroscopy Detectors for Synchrotron Radiation Sources

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Introduction


Figure 1 High Energy Photon Source (HEPS)

- HEPS (**H**igh **E**nergy **P**hoton **S**ource) is the 4th-generation synchrotron radiation source in China.
- Brightness up to: 10^{22} photons/s/mrad²/mm²/0.1% BW
- Emittance superiority: 0.06 nm · rad
- Storage ring energy up to: 6 GeV
- It provides X-rays with energies up to 300 keV


Figure 2 the Platform of Advanced Photon Source Technology

- PAPS (the **P**latform of **A**dvanced **P**hoton **S**ource Technology) aims to develop and innovate new theories, methods, technologies, and equipment for X-ray optics and applications.
- PAPS not only serves the construction of the High Energy Photon Source, but also provides technical support, conditions, and team support for other advanced light source projects in China.

The HEPS/PAPS Detector System Project Team has conducted the key technological research and development for the unit and array Silicon Drift Detectors (SDD) in response to future synchrotron radiation requirements.

The key technologies mainly include:

- 8-inch semiconductor manufacturing process for unit and array SDD sensors;
- Ultra-low noise charge-sensitive front-end ASIC chip;
- Multi-channel digital processing readout electronics.
- Low temperature vacuum system integration technology.

The preliminary design and testing of unit and array detector system have been completed.

– **the single-unit SDD detector achieved an energy resolution of 140 eV@5.9 keV (-20℃);**
– **the 20-unit array-SDD detector reached an energy resolution of 300 eV@ 13.9 keV(-40℃). The maximum counting rate for a single channel can reach over 500kcps.**

Study of the SDD Sensor

Detector Design Specification:

- Pixel Radius: 2.2mm
- Pixel Array: 2×10
- Sensor Thickness: 650um
- Wafer Processing: ion implantation, 8-inch wafer
- Leakage Current:<10pA@233K

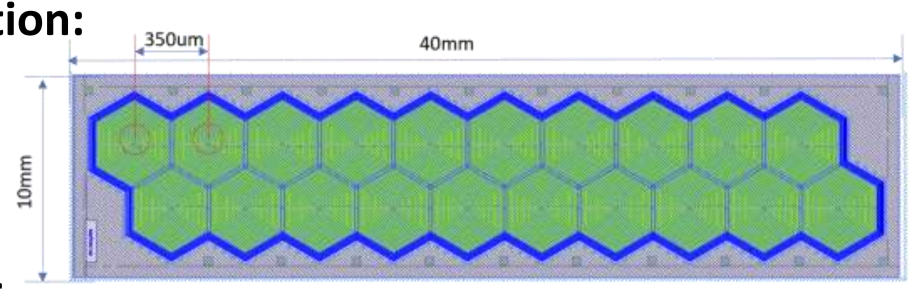

Figure 1 The size of SDD array


Figure 2 SDD array

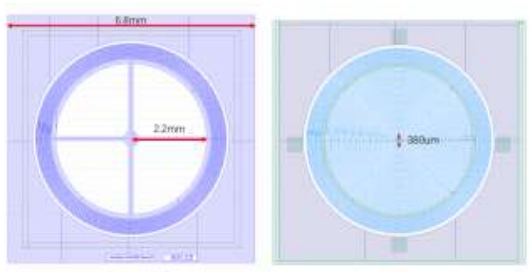
Figure 3 The size of unit sensor

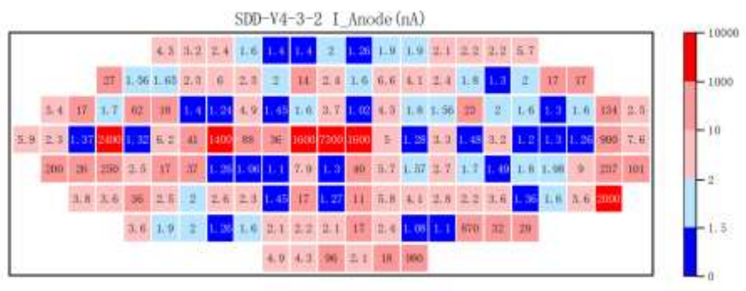

Figure 4 Distribution of leakage current of SDD unit at room temperature on the wafer

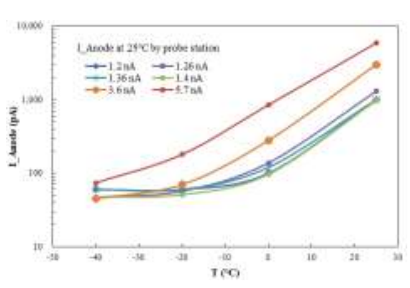
Figure 5 Curve of sensor leakage current with temperature variation

Design of charge-sensitive front-end ASIC

ASIC Design Specification:

- Collect variety: Electrons or holes
- Dynamic Range: 3.5V
- Gain: 40mV/fC
- Number of channels:1 and 8
- ENC~5e+6e/pF@293K

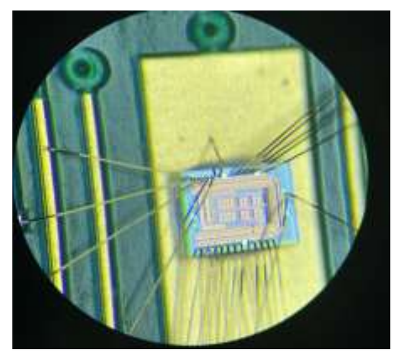
Figure 6 Chip under a microscope

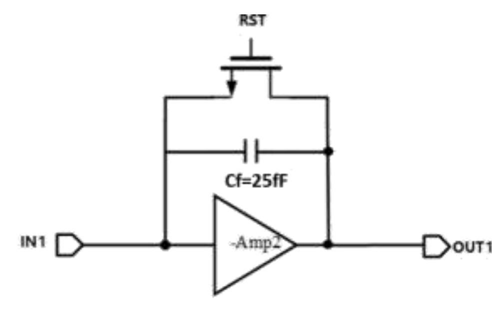

Figure 7 Basic design principles of ASIC

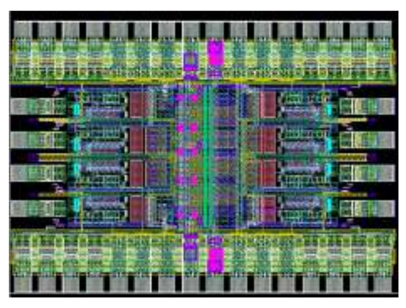
Figure 8 Schematic of an 8-channel chip

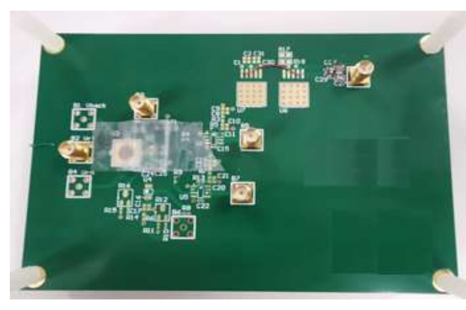
Figure 9 ASIC test board

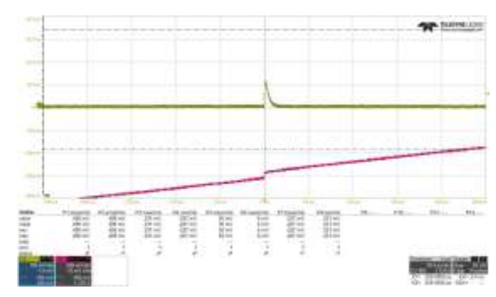
Figure 10 Signal output from chip
Red line: ASIC output; Yellow line: differential signal output
Figure 4 The array SDD system(20 channel)

Readout electronics and signal processing algorithms

Array readout electronics board:

- Number of Channels: 40/board
- Count Rate: 500kcps/ch
- Sample Rate: 65Mcps
- FPGA-based digital filtering and shaping algorithm
- gigabit network transmission


Figure 11 readout electronics(Each NIM accommodates 3 readout boards and 1 High voltage board)

Digital filtering shaping algorithm based on adaptive trapezoidal shaping

– **Fast Fourier transform (FFT) algorithm to calculate the decay constant.**
– **Calculate the trapezoidal flat top and adaptively adjust parameter M to achieve the best shaping result.**

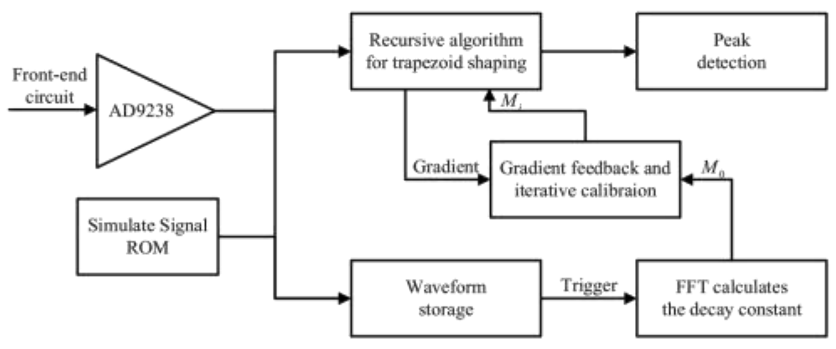

Figure 12 Block diagram of the adaptive shape system implementation

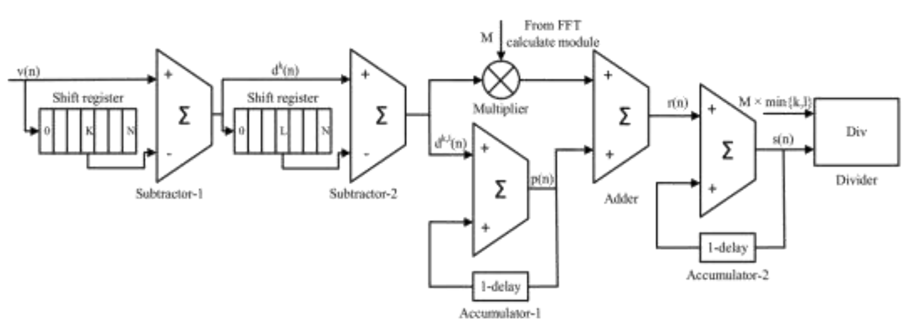

Figure 13 Block diagram of the recursive trapezoid shaping algorithm

System integration and test results

Large cavity encapsulation for array detector:

- Large-scale signal transmission using rigid-flex combined boards and micro-coaxial cables
- The cavity cooling temperature reaches 223K

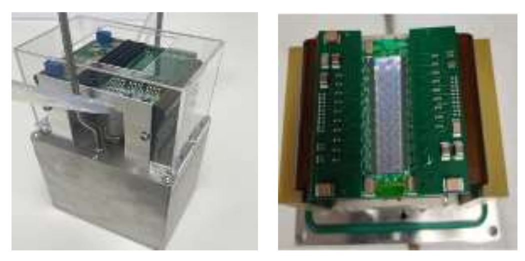
Figure 14 Array detector packaging

Unit detector in TO-8 package:

- Peltier cooling to -40℃

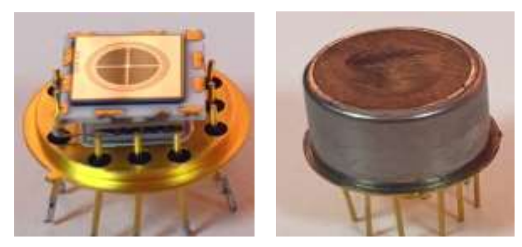
Figure 15 The unit SDD probe

The test results for unit and array detectors :

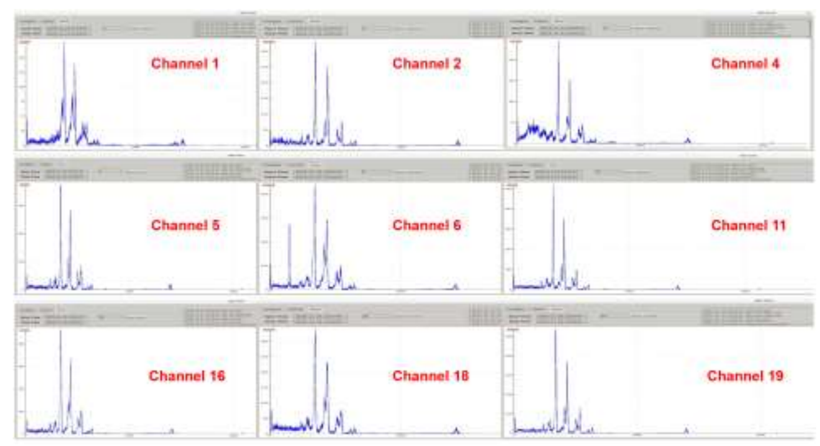

Figure 16 The energy spectrum obtained from the array detector test with Am241 (11 other unit detectors have high leakage current and cannot detect signals)

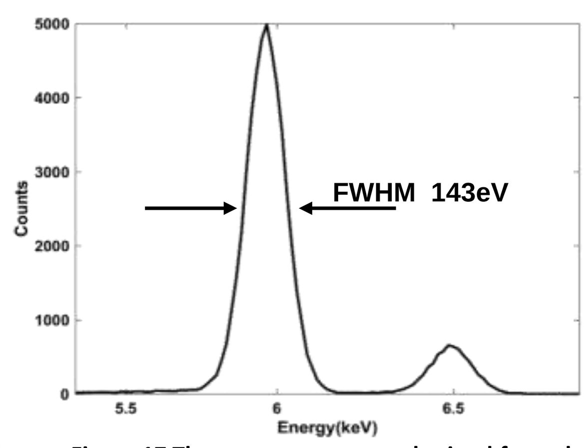

Figure 17 The energy spectrum obtained from the unit detector test with Fe55

Summary and Outlooks

China is currently constructing a fourth-generation High Energy Photon Source (HEPS), which is expected to be open to users by 2025. The development of array SDDs will play a crucial role in improving the efficiency of experiments at synchrotron light sources. We will continue to optimize the process and design to reduce sensor leakage current, enhance uniformity, and boost yield. Simultaneously, we will further refine the electronics to achieve superior energy resolution and higher counting rates.