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Design of the first full-scale HYLITE, a charge integration pixel detector readout chip for XFEL

Introduction of SHINE, STARLIGHT and HYLITE

Figure 1 Location of SHINE (Top View)

- **SHINE (Shanghai HIgh repetitioN rate XFEL and Extreme light facility) is the first hard X-ray Free Electron Laser facility in China.**
  - **Photon Energy: 0.4~25 keV**
  - **Repetition Frequency: 10 kHz (Up to 1 MHz)**
- **STARLIGHT (SemiconducTor Array detectoR with Large dynamIc ranGe and cHarge inTegrating readout) is a new pixel array detector designed for SHINE.**

Specs	Parameters
Sensor	500 μm silicon PIN
Pixel Size	100μm × 100μm
Array Size	128 × 128
Dynamic range	1 ~ 10000 ph./pulse/pixel @12 keV
Frame rate	12 kHz (continuous readout)
Detector	A 4M pixel detector in vaccum, quadrant movable

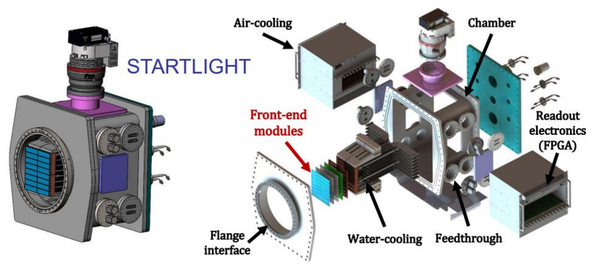
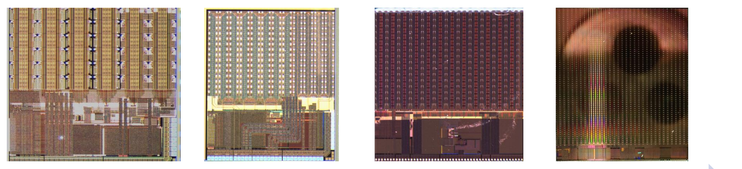


Figure 2 The STARLIGHT Detector System

- **HYLITE (High dYnamic range free electron Laser Imaging deTEctor) is the charge-integration pixel readout chip of STARLIGHT.**



HILITE0.1	HYLITE0.2	HYLITE200S	HYLITE200F
• Tapeout: 2020.10 • Pixel size: 200μm×200 μm • Array Size: 6×12	• Tapeout: 2021.1 • Pixel size: 100μm×100 μm • Array Size: 16×24	• Tapeout: 2022.3 • Pixel size: 200μm×200μm • Array Size: 16×25 • Full Function Verification	• Tapeout: 2022.6 • Pixel size: 200μm×200μm • Array Size: 64×64 • First Full-Scale Chip

Chip Design

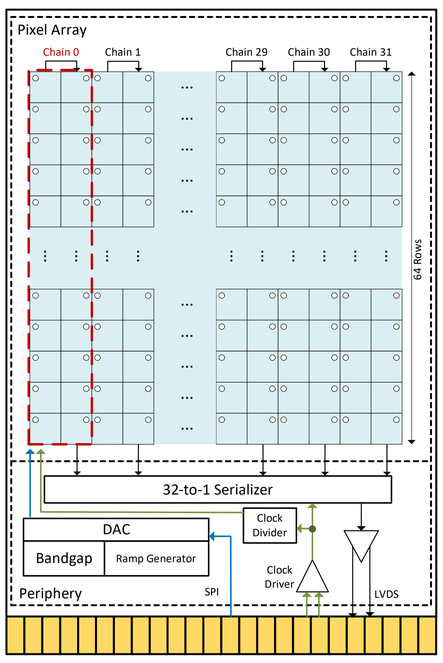


Figure 3 Block Diagram of the HYLITE200S Chip

- **HYLITE200F: The first full-scale chip of HYLITE.**
  - **Array Size: 64×64**
  - **Pixel Size: 200 μm×200 μm**
  - **ENC in the High Gain Mode: ~360 e-**
- **Working in Pump-Probe mode, synced with the beamline.**
- **Three Gains**
  - **Automatic Gain Switching**
  - **Dynamic range of 10^4 ph. @12 keV with single-photon resolution**

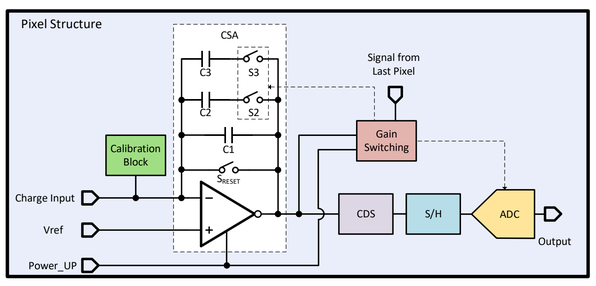


Figure 4 Block Diagram of the HYLITE Pixel Structure

- **Three Working Phases**
  - **Analog Phase: Charge integration**
  - **Conversion Phase: A-D Conversion by in-pixel single-slope ADC**
  - **Readout Phase: Pixels organized as 32 shift chains; single LVDS output port**
- **Maximum Frame Rate @ 400 MHz external clock: 6.3 kHz**
- **Power down feature involved**
  - **Total average power: 34 μW/pixel**
    - **Analog: 21.96 μW (@ 1 μs analog power-up time)**
    - **Digital: 14.76 μW**

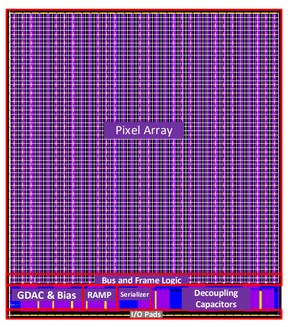


Figure 5 Pixel Layout of HYLITE200F

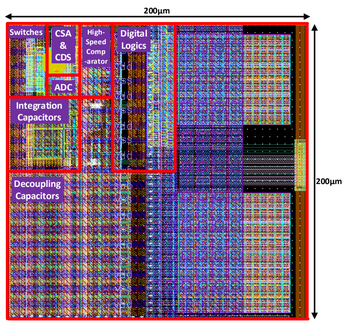


Figure 6 Chip Layout of HYLITE200F

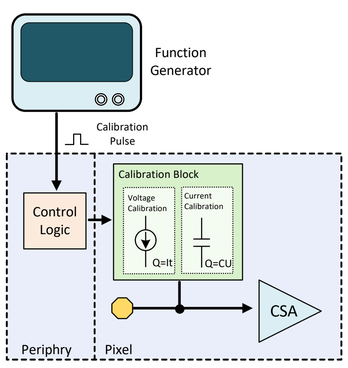


Figure 7 Chip Test Sources

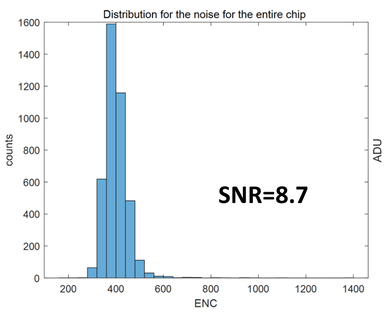


Figure 8 Noise Test Result

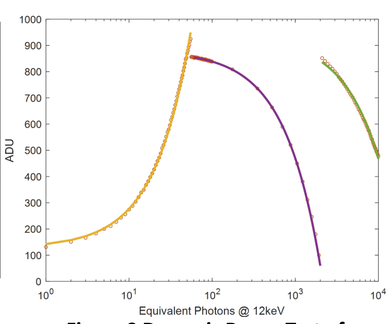


Figure 9 Dynamic Range Test of 10000 Photons

Wafer Test

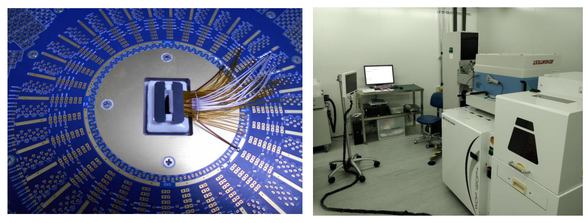
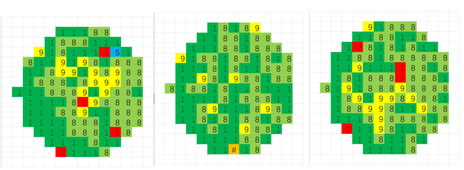


Figure 10 The wafer probe card and test environment of HYLITE200F



- **Average yield of 5 wafers: 84.8%**

Prototype Modules

Figure 11 Modules of 2×8 & 2×2 Chips

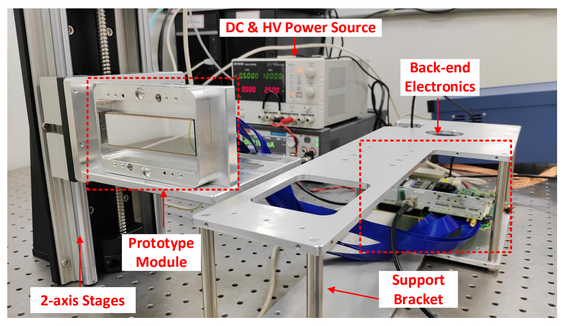


Figure 12 Test environment of prototype modules

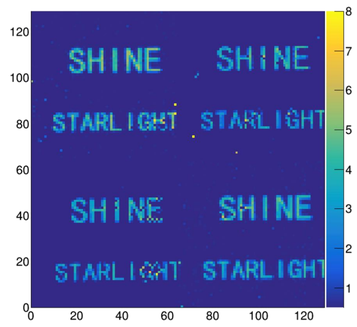


Figure 13 Imaging test with a "SHINE STRALIGHT" mask, module of 2×2 Chips

- **Sensor: 500 μm silicon PIN**
- **Bump-bonding**
  - **Copper Pillar technology**
  - **Minimum pad clearance: 60 μm**
- **Three types of prototypes are manufactured**
  - **Single Chip (Fully tested, referring Poster #15)**
  - **2×2 Chips (Preliminarily tested)**
  - **2×8 Chips (Under tested)**
- **Functionality of the detector is verified.**

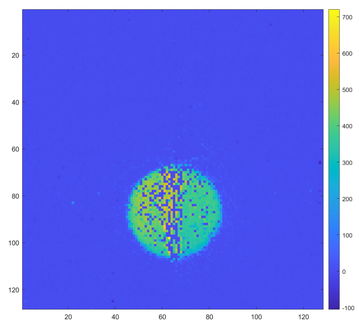


Figure 14 Imaging test with a light dot, module of 2×2 Chips

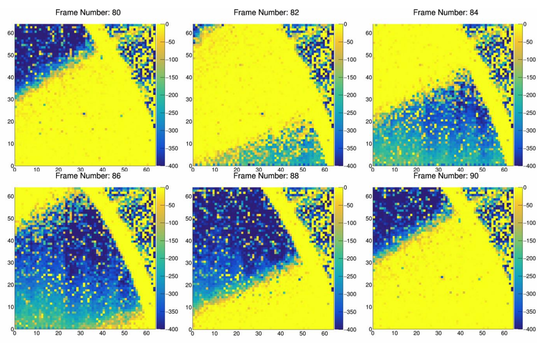


Figure 15 Imaging of a rotating chopper@100Hz, the frame rate is 1kHz

Summary and Outlooks

HYLITE is a charge-integration readout chip designed for STARLIGHT, a pixel array detector for SHINE. In this poster, we present the designs of the first full-scale chip of HYLITE, HYLITE200F, and the corresponding prototype modules. Functionality of the front-end module is verified via preliminary imaging test, while the bump-bonding process still needs to be improved. Meanwhile, the second full-scale chip with a pixel pitch of 100 μm has been manufactured and will be tested soon.

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