Percival CMOS Imager

Alessandro Marras
on behalf of the
Percival collaboration
The Percival collaboration & support

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PTB (in BESSY II ring):
C. Laubis

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A. Jewell, T. Jones, M. Hoenk, S. Nikzad
Motivation

- 1-photon resolution!
- 250 eV - 1 keV!
- low noise!
- high dyn range!
- many frame/s!
- high QE!
- no blind areas!
- many pixels! small pixels!
- 2-side buttable! (even more pixels)
The full PERCIVAL system

- Address
- Sampling
- ADC (12+1)
- Digital output (120 fps)
- P2M
  - 2M pixels
  - ~4×4 cm² sensor area
  - No gaps/blind areas
  - 2-side buttable
  - 27 um pixel pitch
  - Manufacture in progress, postproc. ~early 2017

- Layout stitching
- Voltage regulation
- Carrier board
- Mezzanine board
- Data management & storage
- FPGA
- 10GE
- DDR2 memory
- FPGA configuration
- SFP(+) 10GE
- Front end connector
- Power, DO/DC conv.
- Voltage regulators
- Slow control
- Triggers & slow communication
- Timing box
- Sensors

- 1-photon resolution
- 250 eV - 1 keV
- High dynamic range
- High QE
- Many frames/s
- No dead areas
- Any pixel size, small pixels
- 2-side buttable
- Even more pixels
The PERCIVAL prototype

**TestSensor 1.0/.1/.2**
- 33k pixels
- 6+4 pixel flavours
- \(\sim 0.4 \times 0.5 \text{ cm}^2\) sens. area
- 25um pixel pitch
- FSI & BSI
- FEL & Synchr. mode

**FPGA**

**Cryotiger**

**Vacuum vessel w. removable flanges**

\(\sim 10^{-6} \text{ mbar}\)

**Slow control PC** (Labview)

**FPGA acquisition PC** (24Gb RAM)
Monolithic: Collecting diodes & readout circuitry share the same substrate
TowerJazz 0.18um CMOS techn, over high-resistance thick epi
Coupled to handling wafer, back-thinned, back-illuminated: 100% fill factor
detector classification

Hybrid detector
- Sensor
- Bump bonding
- Readout & signal-processing circuits
- ASIC

Monolithic detector
- Front-Illuminated
  - Human eye
  - To signal-processing circuits
- Back-Illuminated
  - Octopus eye
  - To signal-processing circuits

Human eye

Octopus eye
Photodiodes and embedded circuitry are backthinned (~12um) and δ-doped epi Si. These photodiodes are monolithic, meaning they collect diodes and readout circuitry share the same substrate.

TowerJazz 0.18um CMOS techn, over high-resistance thick epi wafer, back-thinned, back-illuminated: 100% fill factor. Back surface delta-doped, post-processed: almost no entrance window.
delta-doping of back-surface

- Low Temperature Molecular Beam Epitaxy
- Effusion cells
- Device wafer
- High-res epi
- Evaporated atoms do not interact until they reach the wafer oxide (~1nm)
- MBE growth (few nm)
- Dopant down to single atomic layer
- Delta-doping of back-surface device wafer
- CMP + etching (doping-sensitive)
- Epi acts as etch-stop
- MBE growth of doped Si
- JPL
- Selective etching
- Exposed pad
- PAL
- DESY
- CFEL

References:
- Nikzad et al., IEDM14
- Hoek et al., KISS Workshop
The PERCIVAL core

slow controlPC

FPGA

double sampling (of reset level & integrated signal)

data reduction: streams out only one [the most suitable] of the multiple reading of integrated signal (+2 sel. bits)

upto 120 frame/s
Lateral Overflow

integration

annular-shaped partially-pinned photodiode

overflow capacitors

transistors

automatic selection of appropriate overflow Gm level (only relevant data streamed out)

and so on

readout
Lateral Overflow, dynamic range: test results

**Dynamic Gain Switch (Low Flux Detail)**
WO6-03TS1.2PIX, pix (120, 140) (D1), T=−40°C

**Dynamic Gain Switch (Full Overflow Range)**
WO6-03TS1.2PIX, pix (120, 140) (D1), T=−40°C

-Dyn. range: 3.5Me ~ 50k photons @ 250eV
Lateral Overflow, dynamic range: test results

dynamic gain switch (low flux detail)
W08-03TS1.2PIX, pix (120, 140) (D1), T=-40C

dynamic gain switch (full overflow range)
W08-03TS1.2PIX, pix (120, 140) (D1), T=-40C

dyn. range: 3.5Me ~ 50k photons @ 250eV
reasonably narrow pixel-to-pixel parameter dispersion
noise: test results

noise (low flux condition) compatible with most FEL frame rates
reasonably low parameter dispersion between different samples (also from different wafers)
noise: test results (high flux)

dynamic gain switch (full overflow range)
W08-03TS1.2PIX, pix (120, 140) (D1), T=-40°C

noise vs. overflow Gm level
W08-03TS1.2PIX, T=-40°C

Progr. config. min noise value
Progr. config. min noise range
Poisson limit (250eV photons)

PGA settings

integrated charge [e]
single pulse imaging @ FEL: test results

tests at BL2 (Flash)
single-pulse imaging (10Hz)
Low-Energy photons: test results

1-2keV tests at P04 (Petra III)
400eV tests at I10 (DLS)
100-300eV tests at Twinmic, Cipo (Elettra)

avg image, 10^x scale

charge [e]

position [um]

10^{-3}
10^0
10^1
10^2
10^3
10^4

E=400eV, d=10um, D=2.72m, norm. J0

1-2keV range
high dyn. range
250 1 keV
low noise
many frame/s
no blind ameas.
many pixels, small pixels
2-side bittable (even more pixels)

Percival
Lower-Energy photons: test results

91.84eV tests at BL2 (Flash)

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Charge Collection Efficiency: test results

measurement at I10 beamline (DLS)
Cipo beamline (ELETTRA)
P04 beamline (Petra III)
Charge Collection Efficiency: test results

more results will be available
at iWorld 2016 conference
## Summary

**P.E.R.C.I.V.A.L.**

(Pixellated Energy-Resolving Cmos Imager Versatile And Large)

<table>
<thead>
<tr>
<th>tests on prototypes</th>
<th>P2M</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Lateral Overflow</td>
<td>✓ 2M pixels</td>
</tr>
<tr>
<td>✓ low noise (~15e)</td>
<td>✓ ~4×4cm² sensible area</td>
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<tr>
<td>✓ high dynamic range (3.5Me – 50k ph.)</td>
<td>✓ no gaps or blind</td>
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<tr>
<td>✓ up to 120 frame/s</td>
<td>✓ 2-side buttable</td>
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<td>✓ compatible most FEL</td>
<td>✓ 27um pixel pitch</td>
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<tr>
<td>✓ tested 92eV-2KeV</td>
<td>✓ manuf. started ~spring 2016, FSI expected ~ fall/winter of 2016</td>
</tr>
<tr>
<td>✓ measured CCE (down to 50eV)</td>
<td>postproc. BSI ~spring of 2017</td>
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- 250 eV – 1 keV!
- low noise:
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- (even more pixels)
- high QE!
- no blind areas!
- promising

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- PAL
- DESY
- CFEL

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TS3 tests

- PLL: Operating up to 400MHz
- LVDS Stages: Operating at 800Mbits/s (limited by DAQ system)
The PERCIVAL prototype

- Sensor, cooling block
- periph board
- CMOS <-> LVDS, biases
- ~ Troom (Cu plane, braids)
- back flange
- SD board, mezzanine
- to vacuum pump
- front flange with beam opening
- to low-T cooling system (cryotiger)
  RT~ -40°C
Temperature effects

**dark current**

W08-03TS1.2PIX

- ○ T = +35°C (PGA = Bypass)
- × T = -40°C (PGA = Bypass)

**noise vs. Temperature**

W08-03TS1.2PIX

- ○ T = +35°C
- × T = -40°C
noise analysis

Programmable Gain Amplifier (to reduce noise when critical)
Dynamic range

**dynamic gain switch (full overflow range)**

**W08-03TS1.2PIX, pix (120, 70) (A1), T = -40C**

**W08-03TS1.2PIX, pix (40, 140) (E1), T = -40C**

**W08-03TS1.2PIX, pix (120, 140) (D1), T = -40C**
response to low-Energy photons
keV-Energy photons: test results

beam: 900 to 2100 eV
5 \times 10^{11} \text{ to } 1 \times 10^{13} \text{ ph/s (13\mu m Al filter)}

measurements at P04 beamline (Petra III)