DepFET Direct Electron Detectors for time-resolved imaging applications

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(founded 2014)

We are part of:

Center for Free-Electron Laser Science
EDET team
Acknowledgements

HLL ➔ Ladislaw Andricek • Martin Hensel • Christian Koffmane • Jelena Ninkovic • Gerhard Schaller • Martina Schnecke • Florian Schopper • Thomas Selle • Johannes Treis • Andreas Wassatsch • Christian Zirr

KIT ➔ Ivan Peric et al.

USI ➔ Klaus Gärtner

MPSD ➔ Ibrahym Dourki • Djordje Gitaric • Sascha W. Epp • R. J. Dwayne Miller • Fabian Westermeier
**Static & Dynamic**

base-pairing dynamics and ubiquitous nature of DNA interactions

From 1 Hz frame rate we want to go 80 000 Hz frame rate.

Further Evolution in atom gazing: ……Solution Phase Dynamics

TEX nanocell with flow!

outside view

cross sectional view

Christina Müller: U Toronto
Sercan Kescin, Stephanie Manz: MPSD

300 keV Transmission Electron Microscope (TEM)
Experiments
Small scale & with e-

- keV FED – solid state
- keV FED – liquid phase
- keV FED – gas phase
- REGAE Diffraction
- keV time-resolved TEM
- REGAE Dynamic RTEM
Time-resolved imaging

Structural Dynamics in real and k-space

It is convenient to have to similar, but slightly different detectors for k- and real space
Different types of movies
Stroboscopic & real time

▶ Imposes different requirements on the detector!

- time resolution = high
- Repetition rate = high
  - real & k-space
- time resolution = very high
- Repetition rate = low
  - k-space (only)
Work on ➤ ASICS: switcher, DCD, DMC (DHP)
Sensor & pixel design: thickness, size, charge handling
System design: making the sum of components a useful unit, thermal design, Geant4 simulations of sensor response, mechanical design

Development basis

posponed

Sensors in Oct.

Edet_1k

Edet_80k
### Main differences

<table>
<thead>
<tr>
<th></th>
<th>EDet1K</th>
<th>EDet80K</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frame rate</strong></td>
<td>1000 Hz</td>
<td>80 000 Hz</td>
</tr>
<tr>
<td><strong>Data stream</strong></td>
<td>Continuous</td>
<td>Burst with 100 frames</td>
</tr>
<tr>
<td><strong>Read-out</strong></td>
<td>DCDxxx + DEPFET Movie Chip</td>
<td>DCDE + DEPFET Movie Chip</td>
</tr>
<tr>
<td><strong>Pixel arrangement</strong></td>
<td>512 x 512 (x 4)</td>
<td>512 x 512 (x 4)</td>
</tr>
<tr>
<td><strong>Shuter mode</strong></td>
<td>2-fold</td>
<td>4-fold</td>
</tr>
<tr>
<td><strong>Corr. double sampling</strong></td>
<td><strong>YES</strong></td>
<td>NO</td>
</tr>
<tr>
<td><strong>ADC resolution</strong></td>
<td>8 bit ?</td>
<td>8 bit</td>
</tr>
</tbody>
</table>
**EDet_80k**

DEPFET direct hit

- 1000 x 1000 px (4 chips)
- dead join region < 2 mm
- 60 x 60 mm² active area
- direct electron detection
- pixel size: 60 x 60 µm²
- Thickness 50µm (30 µm)
- > 200 primaries of 300keV per pixel
- full frame recording at 80kHz (for 100 frames) by 4-fold rolling shutter mode
- 8 bit ADC (DCD)
EDet_80k
DEPFET direct hit

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Pixel Size
Lateral Straggling

Spatial distribution of signal in the Si layer (No additional layers)
Thickness=60 µm; E_0=300 keV

Straggling well below pixel dimension (60 µm x 60 µm)
Statistics

- Thinner sensor -> less electrons created
- 300 keV primary electron generates $\approx 8000$ eh-pairs in 50µm Si and 80 000 eh-pairs in thick (500µm) Si.
- Most Probable Value gives useful statistics
Detector thickness
Thermal & stress issues

- closed liquid cooling cycle (-10 °C)
- thermal gradient < 10 K
- Deformation depends on material of support (brick):
  - titanium
  - poly-silicon
  - beryllium
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Charge Handling
Voodoo by Rainer Richter (HLL)

- On average: 1 e-h-pair/3.6 eV
- > 1M e-h pairs
- Significant charge handling increase
Charge Handling
8 Bit DCD

- DCD with selectable 4 gain settings: $k = \{0.1; 0.2; 0.5; 1\}$
- $k = 0.1$ (low gain -> high dynamic range)

![Graph showing charge handling](image)

1. LSB = 5900 eh

$\Delta bit << 0.5 \sigma(\text{poisson})$
Charge Handling
8 Bit DCD

- DCD with selectable 4 gain settings: \( k = \{0.1; 0.2; 0.5; 1\} \)
- \( k = 0.5 \) (higher gain \( \rightarrow \) single electron resolution)

\[ k = 0.5 \text{ 1 LSB} = 0.25 \mu A \]

\[ \Delta \text{bit} \ll 0.5 \sigma \text{(poisson)} \]

1. LSB = 1150 eh
TEM movie
Dynamic range limit: Speed is the goal…not beauty


0.4 e-/pixel (scaled)
40 e-/pixel (scaled)
3500 e-/pixel (scaled)
16000 e-/pixel (scaled)

100 eI/px (Poisson only)

0.5 μm
**EDet_80k**
DEPFET direct hit

- **direct electron detection**
- **1000 x 1000 px (4 chips)**
- **dead join region < 2 mm**
- **60 x 60 mm² active area**
- **pixel size: 60 x 60 µm²**
- **Thickness 50µm (30 µm)**
- **> 200 primaries of 300keV per pixel**
- **full frame recording at 80kHz (for 100 frames) by 4-fold rolling shutter mode**
- **8 bit ADC (DCD)**
Data stream

Use BELLE-II components where possible: How well do they fit the application

► > DH80k

80 kHz -> 80 GB/s (0.6 Tb/s) of data if operated continuously! (compare DE-CIX with 230 GB/s)

Solution: burst mode with movie of 100 frames. -> storage needed

A. Wassatsch
Most serious thread
Radiation Hardness

- Radiation tolerance about 10 Mrad Si-SiO interface
- for frames with 10M e- total, this would be 250M frames or 2.5 M movies or 250 TB
- We are investigating annealing processes to cure the trapped charges
- homogenous damage can be compensated by shifts in Gate voltage

**Charge loss. @Vgs = -3V, Vds=-5V**

- expected
- unirradiated
- irradiated (V_shift=2V)

**Operation window (100 pe- limit)**
Things I did not talk about

- Mechanical details
  - Cableing,
  - Flex leads
  - DAQ
  - Slow control and housekeeping

- System Integration

- Optical simulations
  - MDF etc.
<table>
<thead>
<tr>
<th>Last Milestone</th>
<th>Edet DCD (1\textsuperscript{st} gen) are delivered from engin. run (April ’16)</th>
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</thead>
<tbody>
<tr>
<td>Next important step</td>
<td>end of sensor production in August 2016 (10 wafers)</td>
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<tr>
<td>End 2016</td>
<td>1\textsuperscript{st} stage mechanical design prototype at hand</td>
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<tr>
<td>End 2016</td>
<td>submission of DMC chip (the DHP of Edet_80k)</td>
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<td>End 2016</td>
<td>Dynamic measurement on small det. structures</td>
</tr>
<tr>
<td>End 2016</td>
<td>First large matrix assembly by Nov 2016 – system test with DHP</td>
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<tr>
<td>End 2017</td>
<td>Full quadrant assembly</td>
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**EDET team**

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Thank you !!!