First test of a diamond detector at European XFEL

Wolfgang Freund
X-ray Photon Diagnostics group (XPD)
European XFEL GmbH

ADAMAS workshop, December 9th 2019

Co-authors:
MID team: Wei Lu, Alexey Zozulya, Ulrike Bösenberg, Anders Madsen
XPD: Jan Grünert
Facility Layout (photon part)

<table>
<thead>
<tr>
<th>Source</th>
<th>Scientific instruments</th>
<th>Main energy range [keV]</th>
<th>Extended energy range [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SASE1</td>
<td>SPB, FXE</td>
<td>5 – 20</td>
<td>3 – 20</td>
</tr>
<tr>
<td>SASE2</td>
<td>MID, HED</td>
<td>5 – 20</td>
<td>3 – 36</td>
</tr>
<tr>
<td>SASE3</td>
<td>SQS, SCS</td>
<td>0.45 – 2</td>
<td>0.26 – 3</td>
</tr>
</tbody>
</table>

- LINAC
- SASE2
- SASE1
- SASE3

- XTD1
- XTD2
- XTD3
- XTD4
- XTD6
- XTD9
- XTD10

- XS2
- XS3

- electron tunnel
- electron switch
- electron bend
- photon tunnel
- undulator
- electron dump

European XFEL

Wolfgang Freund, X-ray Photon Diagnostics
FEL beam properties (SASE1 and SASE2 undulators)

- Transversal highly coherent beam
- Photon energy 5-20 keV
- Pulse energy from a few µJ to ~ 2 mJ (~ $10^{12}$ photons)
- Pulse length ~ 50 fs
- Due to SASE process: strong fluctuations from shot to shot

Example of three adjacent FEL pulses – each pulse can have different LASER modes (after monochromator)
X-ray photon diagnostics at European XFEL

Measurement of beam properties

- Invasive diagnostics (Imagers, MCP detector, K-mono, …)
- Gas based online diagnostics
  - XGM (X-ray Gas Monitor), main instrument for pulse energy and avg. beam position
  - PES (Photoelectron spectrometer, 16 TOF)
- Solid-state online diagnostics (minimally invasive)
  - Single-shot spectrometer (HIREX)
  - Backscatter monitors
  - Diamond screens
  - **Diamond detectors**

![X-ray Gas Monitor (XGM)](image1)
![PES](image2)
![HIREX single shot spectrometer](image3)
![SR-imager](image4)
![MCP-detector](image5)

![Filter Ch. & IMGTR](image6)
![Pop-in Monitor](image7)
![K-mono](image8)
![European XFEL](image9)
Diamond detectors for X-ray photon diagnostics

First diamond detector projects started already in 2012 with tests at Elettra and LCLS (*). We are now relaunching the detector project. The goal is to build a detector setup for single-shot intensity and position detection in the hard-X-ray beamlines.

Requirements:

- High pulse energy → radiation hard and robust against single shot damage
- High repetition rate (4.5MHz) → detector speed
- Beam position jitter → measurement accuracy between 10 and 100 µm (depending on position)
- Intensity jitter → relative accuracy better 1% and high dynamic range
- Continually in beam path → minimal interference with beam
- e.g. use ins split and delay units for adjustment of beam path → small detector
- Fast feedback to accelerator → pulse resolved detector

Duolateral diamond detector

Detector fabricated at CEA Saclay (M. Pomorski)

Images courtesy M. Pomorski

Detector assembly

- Tested diamond sample EG-6 processed by Michal Pomorski, CEA (40 µm single crystal CVD, electronic grade)
- DLC layer: surface resistance of 350 Ω and 750 Ω
- Al contacts at the edges

Why using a duo-lateral and not a four-quadrant detector?
- SASE-FEL strongly jitters in energy, position, shape: non-gaussian beam with large deviation from the center → no reliable measurement (4-quadrant)
- FEL is highly coherent: non-homogenous contacts introduce wavefront distortion (probably pure carbon contacts could be used)
First diamond detector test at European XFEL

Wolfgang Freund, X-ray Photon Diagnostics

Measurement setup

- Beam parameters:
  - 9.3 keV x-rays
  - max. 1.1 mJ per pulse (~ $7 \times 10^{11}$ photons)
  - Pulse length ~ 50 fs
  - 4.5 MHz repetition rate
  - Beam diameter approx. 1 - 2 mm (not focused)

- Setup:
  - Fast oscilloscope (50 GS/s) or ADC board (108 MS/s) with pulse stretcher
  - Up to 30 dB attenuators at the 50 Ohm inputs
  - no amplifiers
First diamond detector test at European XFEL

Wolfgang Freund, X-ray Photon Diagnostics

Measurements

- MID instrument in SASE2 (Materials Imaging & Dynamics)

- Commissioning beamtimes:
  - February 2019 with 7.5 keV / 30 µJ beam
  - before first user run, beam was not stable, test of instrumentation
  - July 2019 with 9.3 keV / 1.2 mJ beam
  - good beam conditions, DAQ problems

- Difficult to get fully supported user beamtimes for our detector development
First diamond detector test at European XFEL

Wolfgang Freund, X-ray Photon Diagnostics

Pulse shape at low intensity

- Beam condition: 7.5 keV, 30 µJ, repetition rate 1.1 MHz
- Detector directly connected to oscilloscope, signal from front side
- Best timing with 30-50 V bias
Pulse shape at low intensity

- Beam conditions and setup as before
- Signal readout via bias-Tee from backside
- Similar signal as before, but some overshoot after the main peak → optimization of electronics
Pulse shape at high intensity / high rep-rate

- Measured signal vs bias voltage
- 9.3 keV, 1.1 mJ, 2 bunches @ 4.5 MHz

![Diamond BPM channel Right](image1.png)
![Diamond BPM channel Top with Bias-T](image2.png)
Pulse shape at high intensity / high rep-rate

- Beam: 9.3 keV, 1.1 mJ, 4.5 MHz
- Detector:
  - right channel without Bias-T
  - 100 V bias on back side
- Longer pulse trains: 10 to 200 pulses
- Memory effect at 4.5 MHz: detector system doesn't recover from last pulse → exponential decay
- At 1.1 MHz this effect was negligible
Conclusions and outlook

- Detectors worked well at low pulse energy. Saturation effects at higher intensity (> 100 µJ).

- Need faster detectors:
  - Lower surface resistance of electrodes (may compromise position accuracy)
  - Test of four-quadrant detector with carbon electrodes
  - Thin detectors ~ 10 µm

- Diamond detectors could be used for beam stability high speed feedback systems

- Need a small series of detectors for MID split-and-delay-unit, which must be compact and UHV compatible (e)
Thank you for your attention
First diamond detector test at European XFEL

Wolfgang Freund, X-ray Photon Diagnostics

SPARE SLIDES
Measurements at LCLS from 2013

- 50 µm diamond
- Contact resistance 125 kΩ and 2.6 kΩ
- Beam:
  - 8.8 keV
  - Max. 10 µJ
First diamond detector test at European XFEL

Wolfgang Freund, X-ray Photon Diagnostics

Measurements at LCLS from 2013

1D-position scans / moved DD on x-y-stage in x-direction

- 300 µm diamond
  3.4 kΩ/8.2 kΩ
- 3 different x-positions
- Slits: 100 x 100 µm
- Attenuation: 10⁻² (transm.)
- Bias: +200 V at front
- Single shot data
- Averaged position accuracy better 5 µm

![Graph showing measurement results with CH1 and CH2 axes, and parameters such as ∆X = 120µm, Slope=1 → center position.](image)
Measurements at LCLS from 2013

1D-position scans / moved DD on x-y-stage in x-direction

- 300 µm diamond
- 5 µm stepwidth / 1mm range
- Slits: 100 x 100 µm
- Attenuation: 10^{-2} (transm.)
- Bias: +200 V at front
- Average of 1000 shots/step

![Graph showing detector x position vs. response]