Gas Based Detectors for FEL Photon Diagnostics.

Kai Tiedtke

Satellite Workshop on Photon Beam Diagnostics, 29 Jan. 2015
Outline.

- Intensity and Beam Position Monitor (GMD) @ FLASH
- Gas-Monitor-Detector for hard X-Rays (XGMD)
  - Radiometric comparison of the XGMD prototype @ SACLA
  - Measurements of the absolute number of photon of LCLS hard X-ray line *Brand - new*
- Online spectrometer (OPIS)@ FLASH
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Requirements for **Intensity** and **Beam Position** Detectors.

- cover full dynamic range: ~ 6 - 7 orders of magnitude from spontaneous emission to SASE in saturation
- on-line pulse resolved detectors (non-destructive with respect to the beam)
- low degradation under radiant exposure by FEL beam with a peak power of few GW; high linearity
- ultra-high vacuum compatibility

**No commercial detectors available!**

The *Atomic Photoionization Process* is a perfect candidate for non-destructive, pulse-resolved photon metrology tools.
Gas-monitor detectors for online intensity and beam position monitoring.

- Based on atomic photoionization => no degradation, indestructible
- Low particle density => transparent
- Calibrated in the PTB laboratory
  Uncertainty for the pulse energy: less than 10%

Reference number at the German Patent Office: 102 44 303
Equation behind the Gas-Monitor Detector.

\[ N_{\text{particle}} = N_{\text{photon}} \cdot \sigma(\hbar\omega) \cdot z \cdot \eta \cdot n = N_{\text{photon}} \cdot Q.E.(\hbar\omega) \]

- Number of particles detected (electrons or ions). Average photoionization charge needed to evaluate.
- Quantum Efficiency
- Cross Section
- Atomic Gas Density (requires temperature and pressure info)
- Detection Efficiency
- Charge accumulated by the detector
- Detector Acceptance Length
- Mean ion charge
- Elementary charge
- Number of particles detected

\[ N_{\text{particle}} = \frac{Q}{e \cdot \gamma} \]
FLASH GMD for the EUV energy range

Two gas monitor detector sets: before and behind the gas attenuator.
Beam position monitor

The BPM information can be used for a machine feedback in order to stabilise the beam.

Accuracy for on-line measurements of relative beam positions: ~ 20 µm
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see poster presented by A.A Sorokin
Missing photoionization cross section data and ion mean charged values for the hard X-ray regime.

In the framework of a German–Russian BMBF project and in collaboration with the PTB we measured the photoionization cross sections and mean charge values up to 30 keV at the VUV undulator beamline of MLS, the four crystal monochromator beamline (FCM), and the BAM line in 2012.
3rd generation GMD for European XFEL and SwissFEL - Intensity and beam position with an extended energy and dynamic range.

- Photon energy range: up to 20 keV
- Uncertainty for the pulse energy: < 10%
- Time resolution: < 200 ns
- Operating pressure: 10^{-6} mbar – 10^{-4} mbar
- Presently we are building 6 XGM for XFEL and 1 for PSI

- High extraction voltage of up to 20 kV has to be applied to prevent detection of highly energetic photoelectrons by the ion detector.
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New detector to solve the dynamic range problem

- It's a giant multiplier with 20cmx3cm open area
- CuBeO dynodes own design
- Gain: $10^7$
- Split electrode to measure beam position
- Robust
- Operating pressure: $10^{-8}$ mbar – $10^{-4}$ mbar

- Relative uncertainty (pulse to pulse): < 1% (for more than $10^{10}$ photon per pulse)
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Comparison between the XGMD pulse energy monitor with a cryogenic radiometer of AIST at SACLA

by DESY/PTB and RIKEN/AIST

November 21-23, 2011

Repetition rate: 10Hz
Pulse duration: 20fs
Peak power: 5GW

Repetition rate: 10Hz
Pulse duration: 20fs
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TABLE I. Average pulse energy of SACLA for different photon energies as measured with the CR and the XGMD and calibration coefficient of the SACLA BPM.

<table>
<thead>
<tr>
<th>Photon energy (keV)</th>
<th>Average pulse energy (μJ)</th>
<th>XGMD to CR measurement ratio</th>
<th>BPM spectral responsivity (μC/J)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CR</td>
<td>XGMD</td>
<td></td>
</tr>
<tr>
<td>4.4</td>
<td>32.26 ± 0.35</td>
<td>32.9 ± 2.0</td>
<td>1.020 ± 0.061</td>
</tr>
<tr>
<td>5.8</td>
<td>104.2 ± 1.3</td>
<td>106.6 ± 6.1</td>
<td>1.023 ± 0.060</td>
</tr>
<tr>
<td>9.6</td>
<td>95.3 ± 2.3</td>
<td>93.9 ± 6.1</td>
<td>0.985 ± 0.068</td>
</tr>
<tr>
<td>13.6</td>
<td>42.2 ± 1.1</td>
<td>40.8 ± 2.9</td>
<td>0.967 ± 0.072</td>
</tr>
<tr>
<td>16.8</td>
<td>0.96 ± 0.03</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

XGMD: uncertainties ~6%
Radiometer: uncertainties 1.1%~3.1% - operated by liquid helium at 4.2K

Measurements of the absolute number of photon of LCLS hard X-ray line

by DESY/PTB and LCLS/AIST
January 21-24, 2015

Measurement of the absolute number of photon of LCLS pulses with an XGMD

In-house Development

Sanghoon Song
Hard X-ray department

Collaboration

- Aymeric Robert
- Sanghoon Song
- Marcin Sikorski
- Roberto Alonso-Mori
- Diling Zhu
- Yiping Feng
- HXR staff
- Gabriella Carini : Detector
- Stefan Moeller : SXR
- Mark Hunter : CXI
- Hae Ja Lee : MEC

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Measurements of the absolute number of photon of LCLS hard X-ray line

by DESY/PTB and LCLS/AIST
January 21-24, 2015

Goal

Evaluate the absolute number of photon of LCLS hard X-ray line as a function of X-ray energy and operation mode of the machine

1. Transmission of the hard X-ray line (HOMS, other)
2. Cross Calibration of various Intensity monitor (XGMD, Radiometer, IPM, kapton monitor, laser power meter)
3. Brilliance
### Measurements of the absolute number of photon of LCLS hard X-ray line – Preliminary results

by DESY/PTB and LCLS/AIST

January 21-24, 2015

#### 9.0 keV

<table>
<thead>
<tr>
<th>Run</th>
<th>1st try</th>
<th>T (%)</th>
<th>XGMD (uJ)</th>
<th>C (uW)</th>
<th>after correcting factor (120*1.37), uJ</th>
<th>Ratio (XGMD/C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>Vac+Kaptor</td>
<td>4.1</td>
<td>35.5</td>
<td>3090</td>
<td>35.28</td>
<td>1.03</td>
</tr>
<tr>
<td>171</td>
<td>Vac+Kaptor</td>
<td>1</td>
<td>7.25</td>
<td>600</td>
<td>7.54</td>
<td>0.96</td>
</tr>
<tr>
<td>172</td>
<td>Vac+Kaptor</td>
<td>2</td>
<td>15</td>
<td>1300</td>
<td>14.84</td>
<td>1.01</td>
</tr>
<tr>
<td>173</td>
<td>Vac+Kaptor</td>
<td>3</td>
<td>22.4</td>
<td>1020</td>
<td>21.02</td>
<td>1.02</td>
</tr>
<tr>
<td>174</td>
<td>Vac+Kaptor</td>
<td>5</td>
<td>52.1</td>
<td>4380</td>
<td>50.01</td>
<td>1.04</td>
</tr>
<tr>
<td>175</td>
<td>Vac+Kaptor</td>
<td>6</td>
<td>65.1</td>
<td>5470</td>
<td>62.45</td>
<td>1.04</td>
</tr>
<tr>
<td>176</td>
<td>Vac+Kaptor</td>
<td>7.5</td>
<td>83.3</td>
<td>7020</td>
<td>80.15</td>
<td>1.04</td>
</tr>
<tr>
<td>177</td>
<td>Vac+Kaptor</td>
<td>9.1</td>
<td>107.5</td>
<td>8960</td>
<td>102.29</td>
<td>1.05</td>
</tr>
</tbody>
</table>

#### 6.0 keV

<table>
<thead>
<tr>
<th>Run</th>
<th>condition</th>
<th>T (%)</th>
<th>XGMD (uJ)</th>
<th>C (uW)</th>
<th>after correcting factor (120*3.01), uJ</th>
<th>Ratio (XGMD/C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>185</td>
<td>XPP att</td>
<td>100</td>
<td>245.6</td>
<td>9300</td>
<td>233.82</td>
<td>1.05</td>
</tr>
<tr>
<td>186</td>
<td>XPP att</td>
<td>52</td>
<td>120.7</td>
<td>4820</td>
<td>121.18</td>
<td>1.00</td>
</tr>
<tr>
<td>187</td>
<td>XPP att</td>
<td>78</td>
<td>50.8</td>
<td>2250</td>
<td>56.57</td>
<td>1.00</td>
</tr>
<tr>
<td>188</td>
<td>XPP att</td>
<td>15</td>
<td>25.5</td>
<td>1340</td>
<td>33.69</td>
<td>0.76</td>
</tr>
<tr>
<td>189</td>
<td>XPP att</td>
<td>7.7</td>
<td>15.5</td>
<td>1000</td>
<td>25.14</td>
<td>0.52</td>
</tr>
<tr>
<td>190</td>
<td>XPP att</td>
<td>4.7</td>
<td>7.5</td>
<td>690</td>
<td>18.85</td>
<td>0.43</td>
</tr>
<tr>
<td>212</td>
<td>XPP att</td>
<td>2</td>
<td>3.2</td>
<td>530</td>
<td>13.33</td>
<td>0.24</td>
</tr>
<tr>
<td>192</td>
<td>XPP att</td>
<td>78</td>
<td>50.8</td>
<td>1700</td>
<td>54.40</td>
<td>0.95</td>
</tr>
</tbody>
</table>

**Contribution from higher harmonics**
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Online Photoionization Spectrometer.

One can use the Ion and Electron TOF data to pinpoint the photon energies.

1 Ion time-of-flight spectrometer  
open multiplier detector  
electric fields (1-2kV) to extract photoions

4 Electron time-of-flight spectrometers  
micro channel plate detectors

μ-metal chamber  
$p_{\text{target}} < 3 \cdot 10^{-7}\text{hPa}$

Transmission: ~100%  
Signal recording by fast digitizers  
Capable of multi-bunch operation
OPIS wavelength measurement: center wavelength.
OPIS wavelength measurement: spectral width.

- Spectral width can be deduced from lines in the energy-converted photoelectron spectra.
- So far, information about the spectral distribution is limited.
OPIS: …towards single-shot measurements.

OPIS, PG measurements with Xe @ 11.60nm (25V retarding)  
400 shots = 40 seconds

Compare moving average of 20 FEL shots:  
PG: mean value of 20 single shot WL-values  
OPIS: WL determination from 20-shot average spectrum

Including OPIS correction by $\Delta \lambda = -0.028\text{nm}$  
derived from Auger line analysis

OPIS measurements reproduce wavelength fluctuations within $\Delta \lambda = 0.01 - 0.02\text{ nm}$
A Final Comparison (for FLASH)

<table>
<thead>
<tr>
<th></th>
<th>E-TOF</th>
<th>I-TOF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed of measurement</strong></td>
<td>Single shot capability (good signal quality conditions needed)</td>
<td>Single shot capability throughout the FLASH wavelength range</td>
</tr>
<tr>
<td><strong>Uncertainty of wavelength measurement</strong></td>
<td>0.05 nm Intrinsic calibration by means of Auger lines</td>
<td>0.1 nm -0.4 nm due to the uncertainty of partial cross section data?</td>
</tr>
<tr>
<td><strong>Expected “bonus” information</strong></td>
<td>Spectral distribution Higher harmonics</td>
<td>-</td>
</tr>
<tr>
<td><strong>Robustness</strong></td>
<td>Sensitive to electric and magnetic fields, beam stability</td>
<td>Like a rock</td>
</tr>
</tbody>
</table>
Conclusions

The XGM pulse energy monitor:

• Perfect agreement with cryogenic radiometer in the hard X-ray regime
• HAMP multiplier provides a huge dynamic range
• we already started the assembly of 7 devices for XFEL and SwissFEL

The OPIS Online spectrometer:

• characterized and calibrated in the whole wavelength range of FLASH during the last year
• Reliable spectrometer for FLASH 2

But we have to…

• improve its shot-to-shot capability
Acknowledgments

Many thanks to:

- **PTB**  
  A. Gottwald, M. Krumrey, and M. Richter

- **SwissFEL**  
  P. Juranic, L. Pattey, and R. Abela

- **SACLA**  
  M. Yabashi, K. Tono, T. Kudo, and T. Ishikawa

- **LCLS**  

- **AIST**  
  N. Saito, M. Kato, T. Tanaka, and T. Kurosawa

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  S. Molodtsov, T. Tschentscher, J. Grüner, W. Freund, and J. Buck
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Thanks for your attention.
OPIS: ...towards single-shot measurements.

OPIS, PG measurements with Xe @ 11.60nm (25V retarding)

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- OPIS, PG measurements with Xe @ 11.60nm (25V retarding)
  - 400 shots = 40 seconds
  - Compare moving average of 20 FEL shots:
    - PG: mean value of 20 single shot WL-values
    - OPIS: WL determination from 20-shot average spectrum
  - Including OPIS correction by $\Delta \lambda = -0.028$ nm derived from Auger line analysis