Review of Third Generation Light Sources

International Particle Accelerator Conference (IPAC’10)

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Won Namkung

Pohang Accelerator Laboratory (PAL)
POSTECH, Pohang 790-784, Korea
Outlines

• Brief History

• US Policy in 1984 and 2003

• 3rd Generation Light Sources in Operations

• Examples: SLS, SSRF, ALBA, NSLS-II, TPS, SESAME, PLS-II

• On Users and Technologies

• Summary
Brief History

- First observed in 1947 in GE Synchrotron by Edler et al.
- 1\textsuperscript{st} Generation: Used High-energy physics accelerators
- 2\textsuperscript{nd} Generation: Dedicated users’ facilities (1980s)
  (SRS, PF, NSLS, BESSY, Doris, SPEAR-II, Aladdin, …)
• 3rd Generation: Maximum use of insertion devices
  1990s: Big three-rings (ESRF, APS, Spring-8) and
         Medium four-rings (ALS, TLS, Elettra, PLS), ….
  2000s: (SLS, CLS, SPEAR-III, Soleil, Diamond, ASP, SSRF, ….)
  2010s: (SSRF, ALBA, PLS-II, NSLS-II, TPS, MAX IV, SESAME, ..)

• 4th Generation: Using SASE XFEL with Linacs (LCLS, SCSS, Euro-XFEL),
  and alternative advanced concepts (ERL and XFEL0)

Undulator

\[ \lambda \approx \frac{\lambda_u}{2\gamma^2} \left(1 + \frac{K^2}{2}\right) \]
www.lightsources.org

America => 18, Europe => 25, Asia and Oceania => 26
US-DOE Major Materials Facilities Committee (Eastman-Seitz Committee) recommended:

- 6 GeV Synchrotron Radiation Facility => APS (Argonne)
- Advanced Steady State Neutron Facility => ANS (cancelled)
- 1-2 GeV Synchrotron Radiation Facility => ALS (Berkeley)
- High-intensity Pulsed Neutron Facility => SNS (Oak Ridge)


*Note that it triggered the 3rd Generation construction race.*

Facilities for the Future of Science: A Twenty-Year Outlook
## Third Generation Light Sources in Operation (1993 – 1999)

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Energy (GeV)</th>
<th>Circumference (m)</th>
<th>Emittance (nm-Rad)</th>
<th>Current (mA)</th>
<th>Straight Section</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESRF</td>
<td>6.0</td>
<td>844.4</td>
<td>4.0</td>
<td>200</td>
<td>32 × 6.3 m</td>
<td>Operational (1993)</td>
</tr>
<tr>
<td>APS</td>
<td>7.0</td>
<td>1104</td>
<td>3.0</td>
<td>100</td>
<td>40 × 6.7 m</td>
<td>Operational (1996)</td>
</tr>
<tr>
<td>SPring-8</td>
<td>8.0</td>
<td>1436</td>
<td>3.4</td>
<td>100</td>
<td>44 × 7 m, 4 × 30 m</td>
<td>Operational (1997)</td>
</tr>
<tr>
<td>ALS</td>
<td>1.9</td>
<td>196.8</td>
<td>6.3</td>
<td>400</td>
<td>12 × 6.7 m</td>
<td>Operational (1993)</td>
</tr>
<tr>
<td>TLS</td>
<td>1.5</td>
<td>120</td>
<td>25</td>
<td>240</td>
<td>6 × 6 m</td>
<td>Operational (1993)</td>
</tr>
<tr>
<td>ELETTRA</td>
<td>2.4</td>
<td>259</td>
<td>7.0</td>
<td>300</td>
<td>12 × 6.1 m</td>
<td>Operational (1994)</td>
</tr>
<tr>
<td>PLS</td>
<td>2.5</td>
<td>280.56</td>
<td>12.0</td>
<td>200</td>
<td>12 × 6.8 m</td>
<td>Operational (1995)</td>
</tr>
<tr>
<td>LNLS</td>
<td>1.37</td>
<td>93.2</td>
<td>100</td>
<td>250</td>
<td>6 × 3 m</td>
<td>Operational (1997)</td>
</tr>
<tr>
<td>MAX-II</td>
<td>1.5</td>
<td>90</td>
<td>9.0</td>
<td>280</td>
<td>10 × 3.2 m</td>
<td>Operational (1997)</td>
</tr>
<tr>
<td>BESSY-II</td>
<td>1.7</td>
<td>240</td>
<td>6.1</td>
<td>200</td>
<td>8 × 4.9 m, 8 × 5.7 m</td>
<td>Operational (1999)</td>
</tr>
<tr>
<td>Siberia-II</td>
<td>2.5</td>
<td>124</td>
<td>98</td>
<td>200</td>
<td>12 × 3 m</td>
<td>Operational (1999)</td>
</tr>
</tbody>
</table>
Third Generation Light Sources in Operation
(1993 – 1999)
## Third Generation Light Sources in Operation (2000-2010)

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Energy (GeV)</th>
<th>Circumference (m)</th>
<th>Emittance (nm-Rad)</th>
<th>Current (mA)</th>
<th>Straight Section</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>New SUBARU</td>
<td>1.5</td>
<td>118.7</td>
<td>38</td>
<td>500</td>
<td>4 x 2.6 m, 2 x 14 m</td>
<td>Operational (2000)</td>
</tr>
<tr>
<td>SLS</td>
<td>2.4</td>
<td>288</td>
<td>5</td>
<td>400</td>
<td>3 x 11.7 m, 3 x 7 m, 6 x 4 m</td>
<td>Operational (2001)</td>
</tr>
<tr>
<td>ANKA</td>
<td>2.5</td>
<td>110.4</td>
<td>50</td>
<td>200</td>
<td>4 x 5.6 m, 4 x 2.2 m</td>
<td>Operational (2002)</td>
</tr>
<tr>
<td>CLS</td>
<td>2.9</td>
<td>170.88</td>
<td>22.7</td>
<td>300</td>
<td>12 x 5.2 m</td>
<td>Operational (2003)</td>
</tr>
<tr>
<td>SPEAR-3</td>
<td>3.0</td>
<td>234</td>
<td>18</td>
<td>500</td>
<td>12 x 3 m, 4 x 4.5 m, 2 x 7.5 m</td>
<td>Operational (2004)</td>
</tr>
<tr>
<td>SAGA-LS</td>
<td>1.4</td>
<td>75.6</td>
<td>7.5</td>
<td>300</td>
<td>8 x 2.5 m</td>
<td>Operational (2006)</td>
</tr>
<tr>
<td>SOLEIL</td>
<td>2.75</td>
<td>354.1</td>
<td>3.74</td>
<td>500</td>
<td>4 x 12 m, 12 x 7 m, 8 x 3.8 m</td>
<td>Operational (2007)</td>
</tr>
<tr>
<td>Diamond</td>
<td>3.0</td>
<td>561.6</td>
<td>2.7</td>
<td>300</td>
<td>6 x 11.3 m, 18 x 8.3 m</td>
<td>Operational (2007)</td>
</tr>
<tr>
<td>ASP</td>
<td>3.0</td>
<td>216</td>
<td>10</td>
<td>200</td>
<td>14 x 5.4 m</td>
<td>Operational (2008)</td>
</tr>
<tr>
<td>Indus II</td>
<td>2.5</td>
<td>172.5</td>
<td>58.1</td>
<td>300</td>
<td>8 x 4.5 m</td>
<td>Operational (2008)</td>
</tr>
<tr>
<td>SSRF</td>
<td>3.5</td>
<td>432</td>
<td>3.9</td>
<td>300</td>
<td>4 x 12 m, 16 x 6.5 m</td>
<td>Operational (2009)</td>
</tr>
<tr>
<td>ALBA</td>
<td>3.0</td>
<td>268.8</td>
<td>4.3</td>
<td>400</td>
<td>4 x 8 m, 12 x 4.2 m, 8 x 2.6 m</td>
<td>Operational (2010)</td>
</tr>
<tr>
<td>PETRA III</td>
<td>6.0</td>
<td>2304</td>
<td>1</td>
<td>100</td>
<td>20 x 4 m</td>
<td>Operational (2010)</td>
</tr>
</tbody>
</table>
Third Generation Light Sources in Operation
(2000-2010)
# New Third Generation Light Sources (After 2011)

<table>
<thead>
<tr>
<th>Light Source</th>
<th>Energy (GeV)</th>
<th>Circumference (m)</th>
<th>Emittance (nm-Rad)</th>
<th>Current (mA)</th>
<th>Straight Section</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>CANDLE</td>
<td>3.0</td>
<td>216</td>
<td>8.4</td>
<td>350</td>
<td>16 x 4.8 m</td>
<td>Planned</td>
</tr>
<tr>
<td>MAX IV</td>
<td>1.5/3.0</td>
<td>96 / 528</td>
<td>5.6 / 0.24</td>
<td>500</td>
<td>12 / 20 - straight sections</td>
<td>Ground breaking in 2010</td>
</tr>
<tr>
<td>PLS-II</td>
<td>3.0</td>
<td>280</td>
<td>5.8</td>
<td>400</td>
<td>12 X 6.8 m, 12 x 3.1 m</td>
<td>Construction (2011)</td>
</tr>
<tr>
<td>TPS</td>
<td>3.0</td>
<td>518</td>
<td>1.7</td>
<td>400</td>
<td>18 x 7 m, 6 x 12 m</td>
<td>Construction (2013)</td>
</tr>
<tr>
<td>NSLS-II</td>
<td>3.0</td>
<td>792</td>
<td>1.5</td>
<td>500</td>
<td>15 x 6 m, 15 x 9.3 m</td>
<td>Construction (2014)</td>
</tr>
<tr>
<td>SESAME</td>
<td>2.5</td>
<td>133</td>
<td>26</td>
<td>400</td>
<td>4 x 5 m, 8 x 3.5 m, 4 x 1.9 m</td>
<td>Construction (2014)</td>
</tr>
</tbody>
</table>

Talks at this conference:

- **TPS** MOOCMH01 C.-C. Kuo
- **PETRA-III** TUXRA01 K. Balewski
- **SSRF** WEOARA01 Z. T. Zhao
- **SESAME** WEOARA02 A. Nadji,
New Third Generation Light Sources
(2011 and after)
Emittance vs. Energy

Updated from Z. T. Zhao, SSRF
Circumference vs. Energy

Updated from Z. T. Zhao, SSRF
Number of ID Section vs. Emittance

Emittance (nm-rad)

Number of ID sections

3rd Generation

New 3rd Generation

Upgrade

PLS-II

NSLS-II

DIAMOND

SOLEIL

TPS

SSRF

SLS

NSRL

PFS

ELETTRA

ALS

PLS-I

SPEAR-3

CLS

NSRRC
SLS (1998-2001)

Energy: 2.4 - 2.7 GeV
Circumf. 288 m
Lattice: TBA
Emittance: 5.0 nm-rad
Current: 400 mA
Straight Sections: 3 x 11.7 m, 3 x 7.0 m, 6 x 4 m
Injection: Top-up only
Beam lines: 18

Courtesy: L. Rivkin
SSRF (2004-2009)

Energy: 3.5 GeV  
Circumf.: 432 m  
Lattice: DBA  
Emittance: 3.9 nm-rad  
Current: 300 mA  
RF Cavity: SC (3)  
Straight Sections: 4 x 12 m  
16 x 6.5 m  
Injection: Top-up  
Beam lines: 7 (Phase-I) 

Courtesy: Z.T. Zhao
ALBA (2003-2010)

- Energy: 3.0 GeV
- Circumf.: 268.8 m
- Lattice: DBA
- Emittance: 4.3 nm-rad
- Current: 400 mA
- RF Cavity: NC (6)
- Straight Sections: 8 x 2.5 m, 12 x 4.2 m, 4 x 8 m
- Injection: Top-up
- Beamlines: 7 (Phase-I)

Courtesy: D. Einfeld
TSP (2007-2013)

- **Energy:** 3.0 GeV
- **Circumf.:** 518.4 m
- **Lattice:** DBA
- **Emittance:** 1.6 nm-rad
- **Current:** 400 mA
- **RF Cavity:** SC (2)
- **Straight Sections:** 18 x 7.0 m
- **6 x 12.0 m**
- **Injection:** Top-up
Energy: 3.0 GeV
Circumf.: 792 m
Lattice: DBA
Emittance: 1.5 nm-rad
Current: 500 mA
RF Cavity: SC (2)
Straight
Sections: 15 x 6.6 m, 15 x 9.3 m
Injection: Top-up
Beamlines: 10 (Phase-I)
Synchrotron-Light for Experimental Science and Applications in the Middle East

Bahrain, Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestinian Authority, Turkey

SYNCHROTRON LIGHT SOURCE (SESAME)

www.sesame.org.jo

Courtesy: H. Winick
Physics Laboratory

Environmental science & Archaeology Laboratory

BessyI
0.8 GeV injector

Materials science Laboratory

Bio-Medical Laboratory

Energy; 2.5 GeV
Circumference; 133m
Emittance; 26 nm-rad
Space for 12 Insertion Devices

SESAME; in construction in Jordan
www.sesame.org.jo

Courtesy: H. Winick
Pohang Light Source
(2.5 GeV: 3rd Generation Facility)
## PLS –II (2009 - 2011)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PLS</th>
<th>PLS-II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy (GeV)</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Beam emittance (nm)</td>
<td>18</td>
<td>5.8</td>
</tr>
<tr>
<td>Beam Current (mA)</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>IDs</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Tune (H/V)</td>
<td>14.28 / 8.18</td>
<td>15.24 / 9.17</td>
</tr>
<tr>
<td>Natural Chromaticity (H/ V)</td>
<td>-23.36 / -18.19</td>
<td>-32.95 / -14.88</td>
</tr>
<tr>
<td>Harmonic Number</td>
<td>468</td>
<td>470</td>
</tr>
<tr>
<td>Circumference</td>
<td>280</td>
<td>281</td>
</tr>
<tr>
<td>RF voltage (MV)</td>
<td>NC/2.0</td>
<td>SC (3)/3.3</td>
</tr>
<tr>
<td>Lattice</td>
<td>TBA</td>
<td>DBA</td>
</tr>
<tr>
<td>Operation</td>
<td>Decay</td>
<td>Top-Up</td>
</tr>
<tr>
<td>Brightness</td>
<td>$\sim2 \times 10^{18}$</td>
<td>$\sim10^{20}$</td>
</tr>
</tbody>
</table>
Number of Users are increasing dramatically in the world. There were less than 10 users in Korea, when the PLS project started in 1988.
Nobel Prizes in Light Source Users

1997 Chemistry

John E. Walker, “Structure of F1-ATPase”

2003 Chemistry

Roderick McKinnon, “Structure of Cellular Ion Channels”

2006 Chemistry

Roger D. Kronberg, “Structure of RNA polymerase”

2009 Chemistry

Ada E. Yonath, “Structure and function of the ribosome”
There are many dramatic technological changes during the 3\textsuperscript{rd} Generation construction and operational experiences. For examples:

- Alignment technology (laser tracker)
- In-vacuum undulators (requires shorter straight sections)
- Computing capacity:
  - Simulation and CAD
- Networks and controls (no hard wires to control rooms)
- Advanced diagnostics
- SC cavities (higher RF voltage, and stability)
- Top-up operations (users’ strong demands)

- Experiences (no need for positron and more than 96\% availability)
Summary

- When 3\textsuperscript{rd} generation was conceived in 20-years ago, there was no demand from life science, but there was mainly for materials science.

- There are more new facilities under construction and planning, especially intermediate-size machines.

- Users are very much diversified and expanding rapidly to other research areas.

- The superconducting technology will share benefits in other large-scale scientific facilities.

- Starting with LCLS in 2009, more 4\textsuperscript{th} generation facilities (SCSS, Euro-XFEL, and others) will be followed. One may expect unforeseen results.
  
  - ERL and XFEL0 are other new approaches in competing with the 4\textsuperscript{th} generation machines.
Acknowledgements

Many thanks to

Z. Zhao (SSRF)
L. Rivkin (SLS)
F. Willeke (NSLS-II)
D. Einfeld (ALBA)
H. Winick (SESAME)
C.-C. Kuo and G. H. Luo (TPS)