Overview of Synchrotron Radiation (SR)

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http://www.postech.ac.kr/chem/mree
Outline

1. Introduction
   - AOFSSRR / Cheiron School
   - History of SR
   - SR

2. 1<sup>st</sup>-2<sup>nd</sup> Generation SR

3. 3<sup>rd</sup> Generation SR
   - Current Status of 3<sup>rd</sup> Generation SR Facilities
   - Applications in Science & Technology

4. 4<sup>th</sup> Generation SR
   - Current Status of 4<sup>th</sup> Generation SR Facilities
   - Applications in Science & Technology

5. Summary & Conclusions
AOFSRR Objectives

- To encourage regional collaboration in synchrotron radiation research and related subjects in Asia and Oceania.
- To promote advancement of synchrotron radiation research and related subjects in Asia and Oceania.
- To achieve the objective stated above, the AOFSRR shall hold a conference every year.
- The AOFSRR will also actively encourage any other activities that will promote synchrotron radiation research and related subjects in the region.

Specific Activities:
- Organize scientific collaboration meetings
- Exchange information of facilities and user groups
- Provide a framework for cooperative activities
AOFSRR Organization (2012)

**Executive Committee**
- President: Moonhor Ree (Korea)
- Vice president: Hongjie Xu (China)
- Past president: Keng Liang (Taiwan)
  - Secretary-general: Masaki Takata
  - Secretary-Treasurer: Richard Garrett

**Council**
- Member:
  - Australia (Keith A. Nugent; AS)
  - China (Hongjie Xu; SSRF)
  - India (P.D. Gupta; INDUS)
  - Korea (Moo-hyun Cho; PLS)
  - Japan (Junichiro Mizuki; JSSRR)
  - Singapore (Mark Breese; SSLS)
  - Taiwan (Shih-Lin Chang; NSRRC)
  - Thailand (Sarawut Sujitjorn; SLRI)

**Associate Member:**
- Malaysia (Sweep Ping Chia; Univ. Malaya)
- New Zealand (Richard Haverkamp; Massey Univ.)
- Vietnam (Tran Duc Thiep; Vietnam Acad. Sci. & Tech.)
- Indonesia (Suminar Pratapa; Inst. Technol. Sepuluh Nov.) - new

**Special Advisors to the President:**
- Osamu Shimomura (Japan)
- Herbert Moser (German)
- Sunil K. Sinha (USA)

**Guests**
(permitted by the Council)
Synchrotron Facilities in Asia/Oceania

BEPC (1991)
2.2-2.5 GeV

NSRL (1991)
0.8 GeV

SSRF (2008)
3.5 GeV

INDUS I (1999)
0.45 GeV

INDUS II (2006)
2.5 GeV

PLS (1994)
3.0 GeV

PAL-XFEL (2014)
10.0 GeV

UVSOR (1983)
0.75 GeV

PF (1982)
2.5 GeV

SPring-8 (1997)
8.0 GeV

SACLA (2012)
8.0 GeV

TLS (1993)
1.5 GeV

TPS (2013)
3.0-3.3 GeV

AS (2006)
3.0 GeV

SIAM (2004)
1.2 GeV

SSL (2001)
0.7 GeV
Human hair ~ 50-100 mm wide.
Synchrotron Radiation

When moving along a curved trajectory in a speed close to that of light, electrons emit electromagnetic radiation in tangential direction. This kind of radiation is called synchrotron radiation since it was first observed at a 70 MeV synchrotron radiation machine in 1947.

The curved trajectory can be created by bending magnet, wiggler and undulator magnets in accelerators.
1st-Gen. SR

2nd-Gen. SR

3rd-Gen. SR

4th-Gen. SR

mainly for particle physics

fully dedicated to SR

bending-magnet beamlines

Undulator, Wiggler beamlines

- 1970s

- 1980s

- 2000s

- 20x0s

1st-Man Made SR – GE Scientists “Betatron” in 1947

Quality of Photon Beam

Development of SR Sources

Coherent

Non-coherent beam

FEL ERL etc.
How a Synchrotron Works

4. Storage Ring
The booster ring feeds electrons into the storage ring, a many-sided donut-shaped tube. The tube is maintained under vacuum, as free as possible of air or other stray atoms that could deflect the electron beam. Computer-controlled magnets keep the beam absolutely true.

Synchrotron light is produced when the bending magnets deflect the electron beam; each set of bending magnets is connected to an experimental station or beamline. Machines filter, intensify, or otherwise manipulate the light at each beamline to get the right characteristics for experiments.

5. Focusing the Beam
Keeping the electron beam absolutely true is vital when the material you’re studying is measured in billionths of a metre. This precise control is accomplished with computer-controlled quadrupole (four pole) and sextupole (six pole) magnets. Small adjustments with these magnets act to focus the electron beam.

3. An Energy Boost
The linac feeds into the booster ring which uses magnetic fields to force the electrons to travel in a circle. Radio waves are used to add even more speed. The booster ring ramps up the energy in the electron stream to between 1.5 and 2.9 gigaelectron volts (GeV). This is enough energy to produce synchrotron light in the infrared to hard X-ray range.

2. Catch the Wave
The electron stream is fed into a linear accelerator or linac. High energy microwaves and radio waves chop the stream into bunches, or pulses. The electrons also pick up speed by "catching" the microwaves and radio waves. When they exit the linac, the electrons are travelling at 99.99996 per cent of the speed of light and carry about 300 million electron

1. Ready, Aim...
Synchrotron light starts with an electron gun. A heated element, or cathode, produces free electrons which are pulled through a hole in the end of the gun by a powerful electric field. This produces an electron stream about the width of a human hair.

Source: University of Saskatchewan Paradigm Media Group Inc.
SR Applications in Science

• Spatial Science vs. Time-Domain Science
• Spectroscopy Science
• Scattering Science
• Microscopy (Imaging) Science
• Science & Technology Fields:
  Physics, Chemistry, Materials, Biology, Medicine,
  Pharmaceutics, Environmental, Agriculture, Information
  Technology, Displays, Mechanical Engineering ……….
  (almost all fields of Science and Technology)

* SR Users are more than 100,000 in the world.
Properties of Synchrotron Radiation

- **Broad spectrum:** from infrared to hard X-ray;
- **Wide tunability** in photon energy (or wavelength) by monochromatization: sub eV up to the MeV Range;
- **High Brilliance and high flux:** many orders of magnitude higher than that with the conventional X-ray tubes;
- **Highly collimated:** radiation angular divergence angle proportions inversely to electron beam energy ($1/\gamma$);
- **High level of polarizations:** linear, circular, elliptical;
- **Pulsed time structures:** tens of picoseconds pulse;
- …
Synchrotron Radiation Facilities

- Over the past 40 years, design and construction of dedicated SR facilities have been continuously carried out all over the world. Currently there are about 50 SR light sources in operation and about 23 of them are third generation light sources;

- Before 1970s, first generation light sources, attached to high energy machines, were parasitically operated;

- From the mid-1970s to the late 1980s, second generation light sources were designed and constructed as dedicated SR user facilities;

- From the mid-1980s, third generation light sources have been designed and constructed with low emittance beam, undulators and Wigglers;

- Since the Mid-1990s, the construction of intermediate energy third generation light sources has been the focus of efforts worldwide;

- Meanwhile compact synchrotron radiation facilities have been designed and constructed.

- Since the late 1990s, fourth generation light sources (so-called free electron lasers) have been started designing and construction.

- Since the last 2000s, energy recovery linac (ERL) light sources have been started designing and construction.
Synchrotron Radiation Facilities (in operation)

Asia-Oceania : 26    Europe : 25    America : 18

www.lightsources.org
3rd Generation Light Sources

- 3rd generation light sources, based on advanced undulators, Wigglers, and low emittance storage ring, are currently the main working horses. According to the storage ring energy, it can be classified into low-, high- and intermediate energy light sources;

  - High energy third generation light sources (>4GeV): ESRF (6 GeV), APS (7 GeV), Spring-8 (8 GeV);
  - Low energy ones (<2.5GeV): ALS, Elettra, TLS, BESSY-II, MAX-II, LNSL, … ;
  - Intermediate energy ones (2.5 ~ 4.0GeV): PLS/PLS-II, ANKA, SLS, CLS, SPEAR3, Diamond, SOLEIL, INDUS-II, ASP, SSRF, ALBA, NSLS-II, TPS, MAX-IV, … ;

- In addition, further advanced third generation light sources, diffraction limited or ultimate, are under investigations and studies. Notably, progress is very encouraging in upgrading the high energy physics accelerators into advanced third generation light sources, such as the PETRA-III in operation at DESY and the PEP-X proposal at SLAC.
Intermediate Energy Light Sources

- The pioneering third generation light sources generated bright radiation based on fundamental and lowest harmonic spectral line of undulator:
  - High energy machines were optimized at 5-25keV for hard X-ray science;
  - Low energy ones were designed & optimized for VUV and soft X-ray sciences;

- As undulator technology well developed, its theoretical brilliance can be achieved at higher harmonics, this leads to a few of outstanding properties of intermediate energy light sources;
  - The photon beam properties in the 5-25keV range generated with intermediate energy light sources are comparable with those from high energy machines;
  - Up to 11th-15th harmonics are currently used at operating machines;
  - Circumference ranges from 100+ m to ~800m depending on budget;
  - Low construction and operation costs make it a cost effective light source right for meeting the regional needs;
3rd Generation Light Sources around the World

M. Ree

Cheiron School-2012
### 3rd Generation Light Sources in Operation (1)

<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>1. ALS</td>
<td>1.9</td>
<td>196.8</td>
<td>6.3</td>
<td>400</td>
<td>12×6.7m</td>
<td>Operation (1993)</td>
</tr>
<tr>
<td>2. ESRF</td>
<td>6.0</td>
<td>844.4</td>
<td>3.7</td>
<td>200</td>
<td>32×6.3m</td>
<td>Operation (1993)</td>
</tr>
<tr>
<td>3. TLS</td>
<td>1.5</td>
<td>120</td>
<td>25</td>
<td>240</td>
<td>6×6m</td>
<td>Operation (1993)</td>
</tr>
<tr>
<td>4. ELETTRA</td>
<td>2.0/2.4</td>
<td>259</td>
<td>7</td>
<td>300</td>
<td>12×6.1m</td>
<td>Operation (1994)</td>
</tr>
<tr>
<td>5. PLS</td>
<td>2.5 (3.0)</td>
<td>280.56</td>
<td>18.6 (5.8)</td>
<td>200 (400)</td>
<td>12×6.8m (+ 12×4.2m)</td>
<td>Operation (1995) (2011)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. APS</td>
<td>7.0</td>
<td>1104</td>
<td>3.0</td>
<td>100</td>
<td>40×6.7m</td>
<td>Operation (1996)</td>
</tr>
<tr>
<td>7. SPring-8</td>
<td>8.0</td>
<td>1436</td>
<td>2.8</td>
<td>100</td>
<td>44×6.6m, 4×30m</td>
<td>Operation (1997)</td>
</tr>
<tr>
<td>8. LNLS</td>
<td>1.37</td>
<td>93.2</td>
<td>70</td>
<td>250</td>
<td>6×3m</td>
<td>Operation (1997)</td>
</tr>
<tr>
<td>9. MAX-II</td>
<td>1.5</td>
<td>90</td>
<td>9.0</td>
<td>200</td>
<td>10×3.2m</td>
<td>Operation (1997)</td>
</tr>
<tr>
<td>10. BESSY-II</td>
<td>1.7</td>
<td>240</td>
<td>6.1</td>
<td>200</td>
<td>8×5.7m, 8×4.9m</td>
<td>Operation (1999)</td>
</tr>
<tr>
<td>11. Siberia-II</td>
<td>2.5</td>
<td>124</td>
<td>65</td>
<td>200</td>
<td>12×3m</td>
<td>Operation (1999)</td>
</tr>
<tr>
<td>12. NewSUBARU</td>
<td>1.5</td>
<td>118.7</td>
<td>38</td>
<td>500</td>
<td>2×14m, 4×4m</td>
<td>Operation (2000)</td>
</tr>
</tbody>
</table>
### 3rd Generation Light Sources in Operation (2)

<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>13. SLS</td>
<td>2.4-2.7</td>
<td>288</td>
<td>5</td>
<td>400</td>
<td>3×11.7m, 3×7m, 6×4m</td>
<td>Operation (2001)</td>
</tr>
<tr>
<td>14. ANKA</td>
<td>2.5</td>
<td>110.4</td>
<td>50</td>
<td>200</td>
<td>4×5.6m, 4×2.2m</td>
<td>Operation (2002)</td>
</tr>
<tr>
<td>15. CLS</td>
<td>2.9</td>
<td>170.88</td>
<td>18.1</td>
<td>500</td>
<td>12×5.2m</td>
<td>Operation (2003)</td>
</tr>
<tr>
<td>16. SPEAR-3</td>
<td>3.0</td>
<td>234</td>
<td>12</td>
<td>500</td>
<td>2×7.6m, 4×4.8m, 12×3.1m</td>
<td>Operation (2004)</td>
</tr>
<tr>
<td>17. SAGA-LS</td>
<td>1.4</td>
<td>75.6</td>
<td>7.5</td>
<td>300</td>
<td>8×2.93m</td>
<td>Operation (2005)</td>
</tr>
<tr>
<td>18. ASP</td>
<td>3.0</td>
<td>216</td>
<td>7-16</td>
<td>200</td>
<td>14×5.4m</td>
<td>Operation (2007)</td>
</tr>
<tr>
<td>19. DIAMOND</td>
<td>3.0</td>
<td>561.6</td>
<td>2.7</td>
<td>300</td>
<td>6×8m, 18×5m</td>
<td>Operation (2007)</td>
</tr>
<tr>
<td>20. SOLEIL</td>
<td>2.75</td>
<td>354.1</td>
<td>3.74</td>
<td>500</td>
<td>4×12m, 12×7m, 8×3.8m</td>
<td>Operation (2007)</td>
</tr>
<tr>
<td>21. SSRF</td>
<td>3.0</td>
<td>432</td>
<td>3.9</td>
<td>300</td>
<td>4×12m, 16×6.5m</td>
<td>Operation (2009)</td>
</tr>
</tbody>
</table>
# New 3rd Generation Light Sources in Operation, Commissioning, Construction and Plan

<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>22. Indus-2</td>
<td>2.5</td>
<td>172.5</td>
<td>58</td>
<td>300</td>
<td>8×4.5m</td>
<td>Operation</td>
</tr>
<tr>
<td>23. PETRA-III</td>
<td>6.0</td>
<td>2304</td>
<td>1.0</td>
<td>100</td>
<td>1×20m, 8×5m</td>
<td>Operation</td>
</tr>
<tr>
<td>24. ALBA</td>
<td>3.0</td>
<td>268.8</td>
<td>4.5</td>
<td>400</td>
<td>4×8m, 12×4.2m, 8×2.6m</td>
<td>Operation</td>
</tr>
<tr>
<td>25. SESAME</td>
<td>2.5</td>
<td>133.12</td>
<td>26</td>
<td>400</td>
<td>8×4.44m, 8×2.38m</td>
<td>Construction</td>
</tr>
<tr>
<td>26. TPS</td>
<td>3.0</td>
<td>518.4</td>
<td>1.6</td>
<td>400</td>
<td>6×12m, 18×7m</td>
<td>Construction</td>
</tr>
<tr>
<td>27. CANDLE</td>
<td>3.0</td>
<td>216</td>
<td>8.4</td>
<td>350</td>
<td>16×4.8m</td>
<td>Planned</td>
</tr>
<tr>
<td>28. NSLS-II</td>
<td>3.0</td>
<td>792</td>
<td>2.1</td>
<td>500</td>
<td>15×9.3m, 15×6.6m</td>
<td>Commissioning</td>
</tr>
<tr>
<td>29. MAX IV</td>
<td>3.0</td>
<td>287.2</td>
<td>0.8</td>
<td>500</td>
<td>12×4.6m</td>
<td>Construction</td>
</tr>
<tr>
<td>30. TSRF</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>Planned</td>
</tr>
</tbody>
</table>
SR Applications in Science

- Spatial Science vs. Time-Domain Science
- Spectroscopy Science
- Scattering Science
- Microscopy (Imaging) Science
- Science & Technology Fields:
  Physics, Chemistry, Materials, Biology, Medicine,
  Pharmaceutics, Environmental, Agriculture, Information
  Technology, Displays, Mechanical Engineering ...........
  (almost all fields of Science and Technology)
• There are dramatic increased demands from life science research, for example, big three statistics (ESRF, APS, Spring-8) in structural biology.

• One may note that cases of PLS and TLS are also outstanding results.

• The overall users are about 100,000 in the world.
Scientific Demands

Coherency
- Atomic and nanoscale imaging (Cells & Viruses, Nano-materials etc.), Others

Femto-second science
- Real-time reaction with high repetition rate
  (Chemical reaction, Photo-induced phase transition etc.)

Nano beam
- Condensed matter physics under extreme conditions

Performances

Brilliance: brighter by 2 orders
Pulse width: shorter by 2 orders

compared to those of 3rd generation SR

New Light Source
- X-Ray Free Electron Laser (XFEL)
- Energy Recovery Linear-Accelerator (ERL)

4th Generation SR
X-Ray Free Electron Laser (XFEL)

Self Amplification of Spontaneous Emission (SASE)
## XFELs around the World

<table>
<thead>
<tr>
<th>Project</th>
<th>Type</th>
<th>Location</th>
<th>Country</th>
<th>e-Beam (GeV)</th>
<th>Photon (nm)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEUTL</td>
<td>SASE</td>
<td>APS</td>
<td>USA</td>
<td>0.22</td>
<td>660-130</td>
<td>Since 2001</td>
</tr>
<tr>
<td>TTF I</td>
<td>SASE</td>
<td>DESY</td>
<td>Germany</td>
<td>0.3</td>
<td>125-85</td>
<td>Since 2002</td>
</tr>
<tr>
<td>SDL DUV-FEL</td>
<td>HGHG</td>
<td>SDL/NSLS</td>
<td>USA</td>
<td>0.145</td>
<td>400-100</td>
<td>Since 2002</td>
</tr>
<tr>
<td>FLASH (TTF)</td>
<td>SASE</td>
<td>DESY</td>
<td>Germany</td>
<td>1.0</td>
<td>12 - 6</td>
<td>Since 2006</td>
</tr>
<tr>
<td>SCSS Prototype</td>
<td>SASE</td>
<td>SPring-8</td>
<td>Japan</td>
<td>0.25</td>
<td>150-50</td>
<td>Since 2006</td>
</tr>
<tr>
<td>LCLS</td>
<td>SASE</td>
<td>SLAC</td>
<td>USA</td>
<td>14.5</td>
<td>0.15</td>
<td>in 2009</td>
</tr>
<tr>
<td>SACLA</td>
<td>SASE</td>
<td>SPring-8</td>
<td>Japan</td>
<td>8</td>
<td>0.1 (0.05)</td>
<td>in 2011</td>
</tr>
<tr>
<td>Euro XFEL</td>
<td>SASE</td>
<td>DESY</td>
<td>Germany</td>
<td>17.5</td>
<td>0.05</td>
<td>in 2014</td>
</tr>
<tr>
<td>PAL XFEL</td>
<td>SASE</td>
<td>Pohang</td>
<td>Korea</td>
<td>10</td>
<td>0.06</td>
<td>in 2014</td>
</tr>
<tr>
<td>PSI XFEL</td>
<td>SASE</td>
<td>PSI</td>
<td>Swiss</td>
<td>5.8</td>
<td>0.1</td>
<td>(in 2016)</td>
</tr>
<tr>
<td>SPARC</td>
<td>SASE</td>
<td>INFN Frascati</td>
<td>Italy</td>
<td>0.15</td>
<td>500</td>
<td>in 2007</td>
</tr>
<tr>
<td>FERMI</td>
<td>HGHG</td>
<td>Trieste</td>
<td>Italy</td>
<td>1.2</td>
<td>10</td>
<td>in 2011</td>
</tr>
<tr>
<td>DUV/Soft X-ray</td>
<td>HGHG</td>
<td>SINAP</td>
<td>China</td>
<td>0.8-1.3</td>
<td>&gt;3</td>
<td>approved</td>
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<tr>
<td>Soft X-ray FEL</td>
<td>HGHG</td>
<td>BESSY</td>
<td>Germany</td>
<td>2.3</td>
<td>64 - 1.2</td>
<td>proposal</td>
</tr>
<tr>
<td>SPARX</td>
<td>HHG</td>
<td>INFN Frascati</td>
<td>Italy</td>
<td>1 - 2</td>
<td>1.5</td>
<td>proposal</td>
</tr>
<tr>
<td>4GLS</td>
<td>HGHG</td>
<td>Daresbury</td>
<td>GB</td>
<td>0.6</td>
<td>100 - 19</td>
<td>proposal</td>
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<tr>
<td>ARC-EN CIEL</td>
<td>HHG</td>
<td>Saclay</td>
<td>France</td>
<td>0.7</td>
<td>1</td>
<td>proposal</td>
</tr>
</tbody>
</table>
### Functions of XFEL(SASE), XFEL-O & ERL

<table>
<thead>
<tr>
<th></th>
<th>average brilliance</th>
<th>peak brilliance</th>
<th>repetition rate (Hz)</th>
<th>coherent fraction</th>
<th>bunch width (ps)</th>
<th># of BLs</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>XFEL (SASE)</strong></td>
<td>~10^{22-24}</td>
<td>~10^{33}</td>
<td>100~10K</td>
<td>100%</td>
<td>0.1</td>
<td>few</td>
<td>One-shot measurement</td>
</tr>
<tr>
<td><strong>XFEL-O (Option)</strong></td>
<td>~10^{27}</td>
<td>~10^{33}</td>
<td>~1M</td>
<td>100%</td>
<td>1</td>
<td>few</td>
<td>Single mode FEL</td>
</tr>
<tr>
<td><strong>ERL</strong></td>
<td>~10^{23}</td>
<td>~10^{26}</td>
<td>1.3G</td>
<td>~20%</td>
<td>0.1~1</td>
<td>~30</td>
<td>Non-perturbed measurement</td>
</tr>
<tr>
<td><strong>3rd-SR</strong></td>
<td>~10^{20-21}</td>
<td>~10^{22}</td>
<td>~500M</td>
<td>0.1%</td>
<td>10~100</td>
<td>~30</td>
<td>Non-perturbed measurement</td>
</tr>
</tbody>
</table>

(brilliance: photons/mm²/mrad²/0.1%/s @ 10 keV)
Applications of XFEL in Science

- Coherent beam source
- Higher flux beam source
- Smaller size beam source
- Pulse beam source (~ fs)

Ultra-small
Nature
- Flea
- Human hair ~30 μm wide
- Red blood cells & white cell ~5 μm
- Viruses ~200 nm

Technology
- Head of a pin ~1 mm
- Micro gears 10-100 μm diameter
- DVD track 100 μm
- 1 μm Electrodes connected with nanotubes
- Carbon nanotube ~2 nm diameter
- Atomic correl ~14 nm diameter

Ultra-fast
Nature
- Hydrogen transfer time in molecules is ~1 ns
- Spin processes in 1 Tesla field is 10 ps
- Shock wave propagates by 1 atom in ~100 fs
- Water dissociates in ~10 fs
- Bohr period of valence electron is ~1 fs

Technology
- Computing time per bit is ~1 ns
- Optical network switching time per bit is ~100 ps
- Laser pulse width ~1 fs
- Shortest laser pulse is ~1 fs
- Oscillation period of visible light is ~1 fs

X-Ray Laser

4th Generation (XFEL, ERL)
3rd Generation
2nd Generation
1st Generation
X-ray Tube
Summary and Conclusions

- The development of third generation light source is still active and growing. There will be about 8 new ones operational before 2015.

- Intermediate energy light sources, such as Diamond, SOLEIL, ASP, Indus-2, ALBA, SSRF, CANDLE, NSLS-II, TPS, MAX-IV have been the focus of the recent development, the cost-effective feature makes them very suitable for meeting regional scientific needs of doing cutting-edge studies in various fields.

- Future development is very promising, not only the high energy physics machines will be converted to advanced light sources, like PRTRA-III and PEP-X, but also the ultimate storage ring light source is also very competitive.

- Two 4th generation facilities (XFEL) are in operation and more facilities are coming soon, and thus one may expect unforeseen results. ERL and XFELO are other new approaches in competing with the 4th generation machines.

- Users are very much diversified and expanding rapidly to other research areas.
SR Source is so essential for your researches in the highest quality!
M. Ree’s Group (POSTECH)

1. Research Fields

**<Polymer Physics>**
- Nanostructures and Morphology
- 3D Single Molecule Structure
- Polymer Chain Conformation
- Surface, Interfaces
- Electric, dielectric, optical, thermal, mechanical properties
- Sensor properties

**<Polymer Synthesis>**
- Functional polymers
- Structural polymers
- Polypeptides, DNA, RNA

2. Group Members

16 Ph.D. candidates
2 Postdoctors
2 Technicians
4 Scientists (PLS: Coworkers)

Scattering / Reflectivity:
Synchrotron X-Ray, Neutron, Lasers

- Polymers for Microelectronics, Displays, & Sensors
- Polymers for Implants & Biological Systems
- Proteins & Polynucleic acids (DNA, RNA)

http://www.postech.ac.kr/chem/mree