SR activity in the Siberian Synchrotron and Terahertz radiation center

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Synchrotron and Free electron laser Radiation: generation and application
SFR-2016
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Budker Institute of Nuclear Physics Novosibirsk
SSTRC History
SSTRC
Main directions

- SR applications activity
- FEL developing, building, maintenance and upgrading
- FEL radiation applications in the terahertz rage
- Developing and fabrication superconducting insertion devices
- Developing and fabrication magnetic elements for accelerators
- Developing of the new light source for SSTRC
- SR and FEL conferences organization
- Education activity
- International collaborations
Light sources in the SSRTC

1. Girocon (430 MHz)
2. LINAC (50 MeV)
3. Convertor
4. Synchrotron (350 MeV)

ROKK-1M
Detector KEDR
## SR sources

<table>
<thead>
<tr>
<th></th>
<th>VEPP-3</th>
<th>VEPP-4M Low Energy</th>
<th>VEPP-4M High Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy, GeV</strong></td>
<td>2</td>
<td>1.8</td>
<td>4</td>
</tr>
<tr>
<td><strong>Circumference, m</strong></td>
<td>72</td>
<td>366</td>
<td></td>
</tr>
<tr>
<td><strong>Lattice type</strong></td>
<td>FODO</td>
<td>FODO</td>
<td></td>
</tr>
<tr>
<td><strong>Emittance, nm rad</strong></td>
<td>~300</td>
<td>25</td>
<td>120</td>
</tr>
<tr>
<td><strong>Max. current, mA</strong></td>
<td>100</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td><strong>Number of bunches</strong></td>
<td>1-2</td>
<td>1, 2, 4, 8</td>
<td>1, 2, 4, 8</td>
</tr>
<tr>
<td><strong>SR devises</strong></td>
<td>Wave length shifter (2 T)</td>
<td>Bending magnet (0.38 T)</td>
<td>Multipole wiggler (1.3 T x 5 poles)</td>
</tr>
<tr>
<td><strong>Optic function in irradiation point</strong></td>
<td>$\beta_x, \beta_y, \eta_x, \text{m}$</td>
<td>$9.64, 7.9, 0.9$</td>
<td>$9.7, 7.9, 1.16$</td>
</tr>
<tr>
<td><strong>Source size in irradiation point</strong></td>
<td>$\sigma_x \times \sigma_y, \text{mm}$</td>
<td>$0.9 \times 0.3$</td>
<td>$2.3 \times 0.1$</td>
</tr>
<tr>
<td><strong>Critical energy, keV</strong></td>
<td>5.3</td>
<td>0.8</td>
<td>13.8</td>
</tr>
<tr>
<td><strong>Number of beamlines</strong></td>
<td>8</td>
<td>1</td>
<td>1 (3 stations)</td>
</tr>
</tbody>
</table>
### Time for SR applications work (hours)

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light source</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VEPP-3</td>
<td>1956</td>
<td>1197</td>
<td>1221</td>
<td>2028</td>
<td>1530</td>
<td>2076</td>
<td>660</td>
<td>1056</td>
</tr>
<tr>
<td>VEPP-4M</td>
<td>240</td>
<td>432</td>
<td>294</td>
<td>180</td>
<td>48</td>
<td>348</td>
<td>150</td>
<td>492</td>
</tr>
</tbody>
</table>

### SR operation mode time, hours

- VEPP-3
- VEPP-4M

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>VEPP-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VEPP-4M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
VEPP-3 synchrotron radiation beamlines

0a - LIGA-technology and X-ray lithography
0b - Fast dynamic process (detonation etc)
2 - Precise diffraction and anomalous scattering
3 - X-ray fluorescence analysis
4 - High pressure diffraction
5a - X-ray microscopy and microtomography
5b - Time resolved diffraction
5c - Small angle scattering
6a - Time resolved luminescence
6b - Precise diffraction-2
7 - SR monitoring station
8 - EXAFS-spectroscopy
VEPP-4 SR beamlines

1. «Cosmos» (metrology in VUV and soft X-ray range 10–2000 eV)
2. Phase contrast microscopy, microtomography and hard X-ray fluorescence
3. «Vzryv-2» (nanosecond diagnostics)
4. «High presure» - assembling
5. “Plamya” beamline - developing
6. Precise difractometry (planning)
“LIGA” station at VEPP-3

Single microbeam SR or microbeams array are used for Direct X-ray lithography for Fabrication of deep LIGA structures.

Samples of high aspect ratio microstructures: micro-lamellae, micro-grid, array columns

Electron lithography. SEM Hitachi Type II + Nanomaker for microstructure forming in the thin PMMA layers (2-3 µm) for fabricating intermediate template for the soft X-ray lithography.
Mosaic refractive lenses with big aperture

<table>
<thead>
<tr>
<th>E, keV</th>
<th>F, cm</th>
<th>h, µm</th>
<th>l, µm</th>
<th>m</th>
<th>N</th>
<th>Micro structures number, total</th>
<th>Aperture, µm</th>
<th>Calc.tr. transparency</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>20</td>
<td>15</td>
<td>26</td>
<td>5</td>
<td>43</td>
<td>102168</td>
<td>1290</td>
<td>0.40</td>
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<tr>
<td>15.8</td>
<td>52</td>
<td>12</td>
<td>31</td>
<td>8</td>
<td>242</td>
<td>470448</td>
<td>5820</td>
<td>0.29</td>
</tr>
<tr>
<td>15.8</td>
<td>52</td>
<td>12</td>
<td>31</td>
<td>8</td>
<td>121</td>
<td>118096</td>
<td>2904</td>
<td>0.44</td>
</tr>
<tr>
<td>25</td>
<td>10</td>
<td>20</td>
<td>41</td>
<td>2</td>
<td>33</td>
<td>24684</td>
<td>1320</td>
<td>0.62</td>
</tr>
</tbody>
</table>

![Graph showing transparency vs. distance](image-url)
Beamline 2 Anomalous scattering

The main parameters of the station:
- Monochromator: "Channel cut» Si, c working plane (111)
- Energy range: 7-20 keV
- Slits Ta
- Beam on the sample size 0.1 ÷ 2 × 5 mm²

The diffractometer:
- Scanning angle range 2Ω = -10 ÷ 140 °
- Minimum scanning step 0.001 °
- Sample: Flat washer ø30 mm or cylindrical capillary ø0.5 ÷ 1 mm
- Detection systems: PMT scintillator NaI (Tl)
- One-coordinate detector OD-3M-350

Realized methods:
- Diffraction with high angular resolution;
- Diffraction in grazing incidence (Grazing Incidence Diffraction);
- Small-angle diffraction (diffraction on long-structures);
- Obtain the radial distribution of the electron density functions;
- Diffraction using the resonance scattering near the absorption Zn K-edge.

Model object - zinc-aluminum spinel. Record the contrast values of the diffracted intensity at different radiation energies.
Beamline 3, Scanning $\mu$SRXRF
Confocal polycapillary X-ray optics

Spatial resolution about 10 $\mu$m
3d reconstruction

Elements distribution in the cross-section of the human hair

Microfluid insertions

Lenses adjustment stages

X-ray polycapillary lenses

sample
Beamlibe 3. SRXRF. Lake bottom sediments analysis.

- Rb/Sr ratio, climatological indicator
- Profiles reproducibility
- Join of tree profiles
Equipment for XRD experiments with high pressure and high temperature
Beamline 4, VEPP-3

High pressure diamond anvil cell and general view for the diffraction experiment

Stability of hydrocarbon compounds at high pressures and temperatures and implications for the deep structure of the Earth and planets

Poly cyclic aromatic hydrocarbons - important components of inclusions in the deep minerals and meteorites

Pressure dependence of the unit cell volume of naphthalene $\text{C}_{10}\text{H}_8$ at 298-773 K.

Murchison meteorite
Aromatic hydrocarbons predominate in hydrocarbon matter of meteorites (Pering, 1971, Science)

Polyphase inclusions hydrocarbons in diamonds from deposits north-east Siberian platform (Томилиenko и др., 2001, Доклады РАН).

Molecule naphthalene

Structure and anisotropic compressibility naphthalene 0-6 GPa

View in the chamber and the paten of powder sample at $P \approx 3$ GPa
The equation of state of explosives

Diamond anvil

Shockwave experiment

Experimentally obtained curve equation of state of shockwave loading TATB and compression in the diamond anvils

Limit of a shockwave experiment

SR
**Beamline 5a. X-ray microscopy and microtomography**

**Main layout**

**Monochromator**

Channel cut monochromator: Si (111)

1 - sample 2 - first asymmetrical crystal, 3 - second asymmetric crystal, 4 - Detector

**Experimental hatch**

**Two dimensions detector “Photonic Science”**

Effective range: 62 x 41 mm²
The scintillator: Gadolinium oxysulfide
Energy range: optimum 5 - 35 keV
Range of registration: 65536 (16-bit)

**Imaging schemes**

(a) - without magnification, (b) - scheme using asymmetrically cut crystals

**The main parameters of the station**

**Monochromator:**
Two crystals, silicon, (+ n, -n) c working crystallographic plane (111)
The range of photon energies of monochromatic radiation: 5-45 keV
Spatial resolution
In the circuit without increasing: 50 μm
In the circuit with increasing 2 μm

**Experimental hatch**

1 - sample 2 - first asymmetrical crystal, 3 - second asymmetric crystal, 4 - Detector

**Testing of the X-ray transparent coatings**

**Density distribution in the explosive**

**Minerals distribution in geological samples**

**X-ray topography on natural diamonds**

**Archaeological research**

**Minerals distribution in geological samples**

**Testing of the X-ray transparent coatings**

**Density distribution in the explosive**

**Minerals distribution in geological samples**

**Archaeological research**

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**Testing of the X-ray transparent coatings**

**Density distribution in the explosive**

**Minerals distribution in geological samples**

**Archaeological research**
Dedication
Research of the phase and structural transformation during chemical reaction by using X-ray diffractometry

Main parameters:
Monochromator: cut silicon single crystal Si (111)
Energy: ~ 8.2 keV

One-coordinate detector OD-3:
Angle range: ~ 30 degrees (at a distance of up to 350 mm of the sample)
Channel: ~ 0.01 °
The number of channels: 3328
Minimum time frame - 1 ms
Maximum load: 10 MHz

XY detector MarCCD
Pixel Size - 80 * 80 mm
The diameter of the working area - 165 mm
The minimum reading time - 2 sec

Formation 3D-structure of the silver nanoparticles produced by the decomposition of the carboxylate

Phase transformation dynamics in the Self-propagating high temperature synthesis (SHS) in the mechanical composite materials

NiO + Al + Ni –AlNi3
SiO2+Al -> Si + Al2O3

... and during formation mixed organic crystals

Meloxycame

Amber acid
The main parameters of the station Monochromator: 
A single-crystal, with the beam deflection in the vertical plane at an angle of approximately 30°; Crystals: Ge (111), Si (111), Si (220); The discrete set-energy radiation: 7.162 keV, 7.460 keV, and 12.183 keV collimator: Slits output; beam on the sample size 0.5 × 5 mm2 detection systems: One-coordinate detector OD-3M-350: The range of angles 30°, resolution 0.01°, the time resolution of 1 ms. 

XRD patterns of corundum, obtained at different photon energies in a fixed detector position 

Realized methods 
Diffractometry with time resolution at high temperatures (up to 1400 °C in air to 2000 °C in vacuum); 
Diffractometry with time resolution in a reaction medium (up to 900 °C at gas pressures from 0.1 mbar to 10 bar);
A study of low-interest Ni-Au catalysts for the conversion of biomass fermentation products for alternative energy. Bio fuel

Research applied Pd-Au catalyst raw material processing systems from renewable resources for pharmacology and medicine.

It was found that the structure of the shell of the active component Pd-Au catalysts, leading to high process selectivity.

It was established that the method of CVD beta-diketonate complexes Hf and Al nanocrystalline film obtained solid solutions of mixed oxides.

It is shown that the active catalyst Ni-Au component has features of the structure causing high catalytic activity.
Multipole wiggler on VEPP-4 for hard X-ray applications

SR beam extraction from 7-pole wiggler VEPP-4M: $E = 1.8$ GeV (left) and $E = 4$ GeV (right), $I = 40$ mA, $B = 1.3$ T (May 2012).
New stations on the wiggler beamline from VEPP-4 storage ring
Phase contrast imaging with using Laue Talbot interferometer

\[(\Delta \phi = \pi/2)\]

\[nL_T = n \frac{p_\phi^2}{2\lambda}\]

\[p_\alpha = p_\phi\]
Phase contrast microscopy

(a) – Absorption contrast, (б) – Differential phase contrast $\partial \Phi(x)/\partial x$, (в) – phase contrast $\Phi(x)$, (г) – Tomographic reconstruction of three-dimensional structure of strawberries set phase projections.
Cytopathic effects nanoparticles at microbeams irradiated human glioblastoma cell culture

VEPP-4 SR experimental hall

CLINIC
Primary Culture
tumor

CRYOBANK

Microbeams radiation therapy

% deceased cells U87

in vitro

in vivo

Days

% deceased cells U87
Detonation Diamond nucleation: scale effect

- The scheme of SAXS experiment during detonation of explosive trotyl/hexogen.

- It was found that an increase in the mass of explosives leads to increases in the produced diamonds mass. Accordingly, increases the rate of formation of diamonds. However, the dependence of the diamonds mass versus the mass of explosive is nonlinear. Also, there is non-linear dependence of the formation rate of diamonds versus the weight of the explosives. Thus, we observe a scale effect.

- Interpretation: the dependence of chemical reactions from the detonation conditions (diameter), the formation of larger diamonds in the detonation of explosives with large diameters.
ITER: plasma discharge on the diverter. Material behavior. Model experiment with laser pulse heating

Now we are preparing an experiment to study the behavior of the crystal lattice of the material of the fusion reactor first wall in a plasma discharge on the diverter.
Soft X-ray and VUV metrology station

Optics layout

Gratis monochromator for VUV range
Spectral range: 5 - 100 eV
Spectral resolution: 0.3-2%
The angle of incidence: 70°
The lattice period: 1/300 mm
Plating: Gold
The fixed position of the output beam in the scanning process - 14 mm

Soft X-ray monochromator
Spectral range: 80-3000 eV
Spectral resolution: 0.1-10%
The range of angles of incidence: 10°- 85°
Mirrors: Y / Mo, Fe / C, W / Si;
Crystals: mica, RbAP, KAP
Adjust the angle of the second mirror: ± 10°
The fixed position of the output beam in the process of scanning the spectrum

Reflectometry system in the experimental volume
It allows to work with mirrors, crystals and diffraction gratings. Investigation of the reflection coefficients, rocking curves, quality focusing systems, etc.

The calorimeter. Absolute detector for absolute measurement of beam power of 300 mW or more
Measurement accuracy - 2-5%
The detector is calibrated to the national metrological center German PTB using a cryogenic radiometer. Calibration accuracy - 1%.

Two coordinate detector from Lebedev Institute (Moscow)

Sensitivity map measurements
Map sensitivity photodiode FDUK-100UV after local irradiation dose of 1.8 MGrey (123 J / cm²)

Calibration meter solar activity for a geostationary satellite "Electro-L №3" Customer - Institute of Applied Physics (Moscow)

Certified measurement procedure

The spectral sensitivity of the reference detector SPD silicon photodiode development PTI (St. Petersburg)

The top graph - the calibration data (+) and approximation of data (solid line) of the model function. The lower graph shows the difference between (x).
New light source for SSRC

Problems

- Currently used storage rings are not dedicated for SR generation, thus the SR parameters are not satisfying for modern requirements
- VEPP-3 and VEPP-4 are intensively used for high energy physics experiments, thus SR experiments have a low priority in operation time sharing rules
Reasons for creation new source in Novosibirsk

- Siberian Synchrotron Radiation Center (SSRC) unifies many SR users from different scientific organizations. Most popular modern scientific techniques are realized on SSRC beamlines.

- Good geographical location of the Novosibirsk Scientific Center provides effective applications of SR methods for institutes and universities from Siberian region.

- BINP stuff has a big experience for development and fabrication of the modern acceleration elements as well as facilities (including light sources), so possibility to make such source for own needs is evident.

- Great experience of BINP in developing and fabrication of superconducting insertion devices for SR centers also gives some additional kicks for SR source project.
Proposal history
Compact light source with superconducting dipoles

Основные параметры
π=55.8 м
Qx/Qz = 4.10/3.67
C_x/C_z = -26.78/-9.64
J_x=1.038
α=4.74 \times 10^{-3}
δE/E=1.33 \times 10^{-3}
ε_x = 10.2 nm rad
ΔE = 180.2 keV/turn
τ = 2.38 ms
Proposal history
2.2 GeV light source
New light source in the VEPP-4 tunnel

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>3 GeV</td>
</tr>
<tr>
<td>Beam current</td>
<td>Up to 500 mA (2.5 mA/bunch)</td>
</tr>
<tr>
<td>Emittance</td>
<td>~ 1 nm rad</td>
</tr>
<tr>
<td>Injection</td>
<td>500 MeV</td>
</tr>
<tr>
<td>Circumference</td>
<td>~ 360 m</td>
</tr>
<tr>
<td>IDs</td>
<td>10 Wigglers and undulators</td>
</tr>
<tr>
<td>RF</td>
<td>180 MHz, currently used</td>
</tr>
</tbody>
</table>
Ring structure
ID section

11.85 m

8°

7 m
## Cost estimation

<table>
<thead>
<tr>
<th>Component</th>
<th>Price, k$</th>
<th>Quantity</th>
<th>Total cost, M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipoles</td>
<td>30</td>
<td>70</td>
<td>2.1</td>
</tr>
<tr>
<td>Quadrupoles and sextupoles</td>
<td>15</td>
<td>400</td>
<td>6</td>
</tr>
<tr>
<td>Power suppliers</td>
<td>1000</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Diagnostic</td>
<td>1000</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Vacuum chamber, 1 m</td>
<td>2</td>
<td>360</td>
<td>0.72</td>
</tr>
<tr>
<td>Vacuum system (pumps and power suppliers)</td>
<td>1000</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Transport channels</td>
<td>2000</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Injection system (kickers, septum)</td>
<td>500</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Insertion devices</td>
<td>1000</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Beamline (frontends, shutters, hatches)</td>
<td>2000</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Civil engineering works</td>
<td>2000</td>
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<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>43.32</strong></td>
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Thank you for attention