Status of the Siberian Synchrotron Radiation Center

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The Budker Institute of Nuclear Physics where the Siberian Synchrotron Radiation Center (SSRC) is located remains the main site of synchrotron radiation (SR) and free electron laser (FEL) investigations in Russia. SSRC is the research center, which is open and free of tax for the research teams from Russia and from abroad.

The research, development and education program of SSRC included the following directions:
- research studies and development of new technologies with the use of synchrotron radiation from the VEPP-3 and VEPP-4M storage rings;
- construction of experimental equipment for works with SR as the beamlines, experimental stations, X-ray optics, monochromators, and detectors;
- development and construction of the accelerators - dedicated sources of synchrotron radiation, wigglers and undulators for another Russian and foreign centers;
- development of the free electron lasers and creation of the Siberian Center of Photochemistry;
- education and professional training of students and post-graduates.

1. Works at the experimental stations of SSRC.

There are two operating storage rings – SR sources presently available at SSRC: VEPP-3 (2 GeV) and VEPP –4 (up to 6 GeV). In 2003, the works with the use of SR were concentrated at VEPP-3, where there are 11 experimental stations located at 7 SR beamlines. The works with SR beams at VEPP-4M were stopped because of the high energy physics e+e- colliding beams experiments (carried out at a low energy of 1.5 GeV). In 2003, 2874 hours of the VEPP-3 operation time were allocated for SR experiments. In 2003, the research teams of about 60 research organizations and industrial firms including 14 Institutes of the Siberian Branch of Russian Academy of Science, 30 other Russian organizations and 16 from abroad took part in the works with SR beams.

On novel patterns of SSRC experimental program. At SSRC, traditionally for a long period of time we develop the X-ray diffraction cinema technique on the base of the BINP fast coordinate detectors and studies “in situ” with this technique with the resolution time of to a millisecond of a number of processes as the deformation and brake of materials, changes in a structure of alive muscle in the process of its contraction, high temperature synthesis, and various phase transitions. The next step in new developments was a unique submicrosecond diffractometry technique recently developed at SSRC [1], which allows to study the processes of detonation and behavior of matter in the detonation front. In 2003, we realized the experimental scheme that takes into account the spatial selfscanning of a process under study (the detonation, shock wave) and obtained the time resolution within 15 ns, which is by an order of magnitude shorter than the time interval between SR bunches from VEPP-3.

Another novel technique under development at SSRC is the scanning fluorescent analysis of the lake sediments for the reconstruction of the environment state in the far past. In particular, with the use of this technique we obtained the data on the climatic condition in the past within the intervals from hundreds to million years. It was suggested and tested a new technique for measuring high temperatures in the processes accompanied by the release of large amounts of heat as, for example, a combustion or SPHTS. The method uses a small test crystal placed inside the object under study, which provides a diffraction spot in the white SR beam. The diffraction spot size depends on the crystal size whereas it intensity is strongly dependent of temperature. With the use of the foilless channel of SR beam extraction from VEPP-3 we studied the photodesorption properties of the fundamentally new type of vacuum chamber for accelerators with the TiZrV getter layer cover on the inner surface. A new and promising field for applying of SR technique is a study of nanostructures. The newly developed XAFS method is designed for characterizing the structures of quantum dots. Among other works, it is worth mentioning the studies of the surface and structure of multiplayer X-ray optical components with the use of the new technique of the X-ray diffusion scattering and XAFS-studies of new catalysts for the fuel elements.

2. Development of new SR-sources.

25 years ago the development and creation of new SR source became an important field of the SSRC activity.

Kurchatov source of synchrotron radiation (KSRS) is specialized accelerator complex designed for generation of SR beams. The complex was completely developed and manufactured at the Budker Institute of Nuclear Physics and assembled by the BINP staff at the premises of the premises of the Russian Scientific Center "Kurchatov Institute", Moscow. In the course of development of the project, the conditions for minimum attainable horizontal emittance of the beam required for getting the radiation high brightness were first obtained. The obtained results enabled the development of the project of two dedicated SR sources: "Siberia-I" (with an electron energy of 450 MeV) and "Siberia-II" (at an energy of 2.5 GeV), which have been designed and manufactured at BINP and under operation at the Kurchatov Institute since 1983 and 1995, respectively.

Technological storage-ring complex "Zelenograd". The storage ring SR-source for the Russian research-industrial center of microelectronics in Zelenograd (near Moscow) have been designed and manufactured at BINP in the period 1990-1996. The primary goal of the center is the production of micromechanic elements by the X-ray lithography and LIGA-technology techniques. The design energy of the Zelenograd SR-source is 1.6 GeV with a possibility to increase it in future up to 2.5 GeV by installing the second accelerating cavity and with an increase in the RF cavity power. Unfortunately, in the period 1997-2001, the financing of the project was stopped. In 2002, the assembly and commissioning of all the systems of the project was renewed step by step. By present, the foreinjector is already assembled and commissioned and the current of 30 mA is obtained; the transfer channel to the small storage ring (booster) and the booster magnetic-vacuum system are assembled.

In addition, in 1999-2001, by the order of the Paul Scherer Institute, Willigen, (Switzerland) the magnetic system for the SR source of the third generation – the Swiss Light Source has been developed, manufactured and delivered to the customer. In total, 306 quadrupole and sextupole magnets with a mechanic tolerance for production of the magnet pole profiles of +/- ±15 μм and with the difference of the measured position of the lens magnetic axis no more than ±30 μм have been produced and installed at SLS.

In 2002, the Budker INP has designed, manufactured and delivered to Japan a prototype of the magnet for the SAGA storage ring and in the beginning of 2003 BINP got a tender on the production of the elements of the SR source magnetic system, which consists of 16 dipole magnets, 40 quadrupole lenses and 32 sextupole lenses. Despite the very strong delivery schedule, all the magnets have been manufactured and delivered to customer in the same 2003.

At present, BINP takes an active part in the development and creation of a new 1.2 GeV synchrotron - injector for FEL based on the electron storage ring at the Duke University (USA).

MARS Project. In 1997, a new concept of the SR-source of the fourth generation MARS (Multi-pass Accelerator Recuperator Source) was formulated in the Budker INP by N.Vinokurov, G.Kulipanov and A.Skrinsky and presented in their report at the 6-th International Conference on Synchrotron Radiation Instrumentation (SRI'97) in Japan /**2**/. The MARS SR Source was assumed to be realized not on the base of the storage ring but on the base of the microtron-recuperator. In this case, the one flight regime of radiation in the magnetic field is realized for each electron bunch and various diffusion phenomena have no time to increase beam emittance and an energy spread. In such an accelerator, the brightness of undulator radiation can surpass by two-three orders the brightness of the SR sources of the third generation in the range of wavelengths ~ 0.1-4 nm.

After five years of work on the project and discussions at a number of international conferences the present-day version of the project was finally formed with the following main parameters: maximum energy of electrons ~ 8 GeV, mean current up to 5-10 mA, horizontal emittance is less than 0.01 nm*rad, relative spread of energy in a beam ~ 0.001 %.

In 2002, we made the first step on the way of practical realization of the Project in Novosibirsk, namely, we started the work at a 14 MeV microtron recuperator on the experimental test of some technical solutions, which are put into the scheme of the MARS Project.

3. Insertion devices.

Budker INP has a big experience in the development and construction of insertion devices as the planar and elliptical wigglers, superbends, various types of undulators: electromagnetic undulators on the base of permanent magnets, hybrid ones with a tunable SR polarization, and others for the Russian and foreign SR and FEL centers.

Superconductive wigglers. Strong field wigglers or wavelength shifters (WLS) are installed in the straight section of the storage ring to enhance the performance of the machine for short wavelength users and to provide new possibilities for SR experiments. First in the world superconducting 20 pole wiggler have been assembled at the 1979 for the VEPP-3 storage ring. Last 10 years Budker INP has constructed new type superconducting wigglers and shifters for the number of storage rings around a world /**3**/. Some of them have record parameters among the same devises produced by other companies. Among them there are strong field 3-pole wavelength shifters for PLS, Korea (7.6 T, 1995), LSU-CAMD, USA (7.5 T, 1998), SPring-8, Japan (10.3 T, 2000), BESSY-II, Germany (7.5 T, 2000), BESSY-II PSF, Germany (7.5 T, 2001).

There are several reasons to install wigglers or shifters on a storage ring: (1) to shift the spectrum to the hard X-ray region by using a higher magnetic field of the wiggler (shifter); (2) to increase the photon flux due to many poles (multipole wiggler); (3) to obtain new features of radiation like polarization; (4) to obtain a flexibility for experiments, due to the possibility of changing the wiggler field during the experiment; (5) to decrease or increase the emittance of the beam in the storage ring; (6) to decrease the polarization time of the electron (positron) beam; and (7) generation of the intensive SR beams with photon energy 0.1 – 10 MэB and creation of the slow positron source of high brightness by conversion of gamma-ray into electron-positron pairs and positron moderation down to low energy (an example of realization is the installing of superconducting wiggler with magnetic field of 10 Tesla at the SPring-8).

In 2002-2003, we have carried out the works on the development and creation of the multipole superconducting wiggles for the foreign storage rings-SR sources. In particular, we have developed and manufactured the superconducting wigglers for generation of SR beams of high brightness: a 17-pole wiggler with a period of 14 cm and maximum field of 7.3 T for the storage ring BESSY-II by the order of the Hann-Meinter Institute (Berlin, Germany) and a 49-pole wiggler with a period of 6 cm and magnetic field of 3.5 T for the ELETTRA storage ring (Triest, Italy).

Superbend. In 2002-2003, we have developed and at the end of 2003 we have successfully tested at the stand a new type of the strong field superconducting SR - a superbend for BESSY-II (Germany), - a bending magnet with the magnetic field up to 9.35 T (turn on 11.25º). On the base of these magnets it is possible to construct the compact and inexpensive dedicated SR-sources for the Universities and industrial companies.

Elliptical wigglers and undulators for generation of radiation with tunable polarization. The elliptical wiggler and undulator designed for obtaining of ellipticaly polarized synchrotron radiation /**4**/ with rapid change of polarization sign was manufactured and tested at Budker INP in 1996 and 1998. In 1997 elliptical wiggler was installed at NSLS-II (BNL, USA) and undulator was installed in 1999 at SR source APS (Argonne National Laboratory, USA). The time required for switching of polarization sign is 5 ms.The four universal electromagnetic undulators ordered by Duke University (Northern Carolina, USA) have the separate power supply of the windings allows application of these undulators as planar, elliptic or spiral ones.

4. Free electron lasers.

The Siberian SR Center is one of the leaders in the field of FELs. Already in 1977, Budker INP staff N.A.Vinokurov and A.N.Skrinsky have proposed the new in principle FEL, and optical klystron (OK). In 1987, with the OK installed at the VEPP-3 storage ring we obtained the generation within the wavelength range of 2400-6900 angstrom, the world first FEL operated in the ultraviolet range of a spectrum.

The project of a powerful FEL based on the use of the accelerator-recuperator has been developed at BINP [**5**]. In 2003, the first stage powerful FEL was commissioned. The FEL provides a continuously retunable radiation in a submillimeter (terahertz) range of wave lengths (120-180 microns) with a mean power of 100 W. By 2006, it is planned to construct the second FEL at a power of the order of 10 kW in the infrared range: 3-20 microns. The Siberian Center of photochemical research is based on these two FELs.

The Budker INP takes part in the project of high-power IR FEL on the base of the superconducting linac at KAERI, Korea. In 2003, the RF-system of the machine has been commissioned. It consists of two cryomodules with 352-MHz superconducting cavities from CERN in a common cryostat, and two 50-kW 352-MHz generator modules, produced at Budker INP. The total RF voltage 10 MV was obtained on the cavities. Also the injection beamline from the injector to the cavities has been manufactured, assembled, and commissioned. A high-power 10-MeV SC linac, as an intermediate stage, has been commissioned. The full-scale project includes the second SC module, a backward track, and FEL installed on it. The scheme of the accelerator is energy-recovery linac. It's necessary to increase maximum RF-voltage up to 20 MeV on each module. In this case one can expect about 10 kW or more CW FEL emission in 6 – 20 μm wavelength region.

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