THE RECENT PROGRESS OF SIAM PHOTON LABORATORY

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Abstract

The experimental work with the Siam Photon Source has been carried out on the elucidation of the final states in the 3p-3d resonant photoemission on Ni(111). Angle-resolved photoemission measurements for the energy band mapping both for the surface and bulk states have been made as well. The maximum stored current in the storage ring is 216 mA. The beam lifetime at a stored current of 100 mA is about 7 hrs. Various pieces of noise causing the beam instability have been removed. Defects in 64 coils of quadrupole magnets of the storage ring have been giving rise to frequent strong beam instability, large COD, the non-uniform distribution of the betatron function, low injection efficiency and a short beam lifetime. Temporary replacement of the worst 4 coils has drastically improved the machine performance. Complete replacement of all defective coils and installation of an undulator will be performed soon. Design work for the undulator beam line is underway.

INTRODUCTION

For expressing "something about synchrotron light of Thailand" we have been using the word, *Siam Photon*, in a way like the *Siam Photon Project*. The accelerator complex of the Siam Photon Source of the National Synchrotron Research Center (NSRC) of Thailand is composed of a 40 MeV injector linac, a 1 GeV booster synchrotron, and a 1 GeV light source storage ring. The designed light source structure is described elsewhere [1-8]. The accelerator complex comprises second-hand machines. The storage ring has been reformed. The original accelerator complex was owned by the SORTEC Laboratory in Tsukuba, Japan and donated to NSRC. In this sense the Siam Photon Source has distinctive aspects of used machine. The components of the dismantled machines were transported to Siam Photon Laboratory of eight years ago.

The SORTEC injector linac, the SORTEC booster synchrotron and the SORTEC low energy beam transport (LBT) line between the linac and the synchrotron are used in the Siam Photon Source in their original structures without being reformed. The electron beam is bent twice horizontally in the LBT line. In the vertical plane, the electron beam is not deflected, since the linac and the synchrotron are on the same floor. The LBT line has the magnet lattice structure of the double bend achromat (DBA). At the center between the two bending magnets, a slit is inserted and it defines the energy of the electron beam coming out of the LBT line. It works as an energy analyzer slit. The line is equipped with a Faraday cup for the measuring the total beam intensity and the spectrum of the electron beam energy.

The original SORTEC storage ring has the design optimized for the microlithography research and not quite suitable for various kinds of scientific research. Thus, the storage ring structure was modified so that the electron beam with a small size generates more brilliant light suitable for the scientific use. The new storage ring has four long straight sections for insertion devices and the natural emittance of the beam is one seventh as small as that of the original SORTEC storage ring. Reformed items are as follows:

1. The magnet lattice was changed from the quadrupole doublet lattice similar to the FODO lattice to the DBA lattice. By the lattice structure reform the beam emittance and the betatron function were reduced considerably.
2. A certain number of quadrupole magnets, sextupole magnets and steering magnets were added to complete the DBA lattice. The beam adjustment can be performed in an easier way.
3. Four long straight sections for insertion devices were inserted. Because of this, the reformed storage ring has a circumference of 81.3 m, which is almost double as large as that of the original SORTEC ring. The designed natural emittance is 72 π-nm-rad.
4. The machine control system was renewed [4, 5]. The new machine control system is composed of personal computers (PC's) and programmable device controllers (PLC's). In the machine control room, three PC's are installed. One of three is for the control server (CNT-SRC) and the other two are for the data acquisition server (ACQ-SRV). In addition to these four PC's are installed and used as the operational terminal equipment. Two of the additional computers are used to control the admittance to the controlled access areas and to record the personal histories of stay in the controlled access areas. We installed the device control stations (DCS's) in the various rooms where many power supplies and on-site controllers are placed. The ordinary Ethernet is used for LAN connecting the computers and DCS's. PLC's are used for the connection purpose. A hub is located in the control room. DCS's and PLC's are connected to the hub with optical fibers with 100 Base T cable.

5. The vacuum chambers were renewed. Because the magnet lattice structure was changed, the vacuum chambers must be changed. New vacuum chambers are made of aluminum. The background pressure is as low as 10^{-11} Torr. Beam position monitors of the button type were installed in the chambers.
6. The structure of the high-energy beam transport (HBT) line connecting the synchrotron with the storage ring was reformed. In this part, the electron beam is deflected twice in the horizontal direction by quite small angles. The HBT line in the original SORTEC machine is placed on the same level floor as that for both storage ring and synchrotron. The HBT line is bent by large angles in the horizontal plane. In the Siam Photon Source, the electron beam is not deflected by large angles and the beam line appears to be almost straight in the horizontal plane. Instead the electron beam is deflected twice by large angles in the vertical plane. Thus, not only bending magnets were replaced but a few focusing magnets and a few steering magnets were added.
7. The linac, the synchrotron, and the beam transport lines are installed underground. This facilitates the radiation shielding and the beam injection from the inside of the storage ring. By this, we can use all the space around the storage ring for optical experiments.
8. Using one of the straight sections a planar undulator of the Hallback type will be installed in the storage ring. It has only one pair of magnet array.

BRIEF HISTORY

The Siam Photon Project has progressed as follows:

- March 1996: The Siam Photon Project started.
- May 1996: NSRC was founded.
- January 1997: Components of dismantled SORTEC accelerator complex have arrived at NSRC and stored in a warehouse.
- February 1998: The construction of the building of the Siam Photon Laboratory started.
- November 1999: The building construction was completed.
- December 1999: Machine reassembling work and beam line construction started.
- June 2001: The machine and the beam line have been completed.
- December 2001: First successful electron filling in the storage ring was achieved.

During the period of the machine construction, the progress of the machine construction delayed by one year owing to financial difficulties.

PRESENT STATUS

After the first beam storage in the storage ring, work for improving the machine performance, such as enhancement of the beam stability, the injection efficiency, the beam lifetime, and the stored current, has been carried out. The beam line and the attached experimental station were precisely aligned and adjusted during this period. By the end of January 2004, the maximum stored current reached 216 mA. The beam lifetime at a stored current of 100 mA is about 7 hrs. This value is that of the design goal.

As the first experiment using the beam line, the measurements 3*p*-3*d* resonant photoemission and angle-resolved photoemission for the energy band mapping on clean Ni(111) were carried out. The results will be mentioned later [12].

A planar Hallback type undulator has been built. Generated light covers the spectral range from 20 eV to 600 eV using the 1st and 3rd harmonics bands. If we use the 5th harmonics band, we can expand the available spectral range up to 800 eV. The period length is 64 mm and total length is 2.5 m. A C-shaped frame for the magnet support is employed. The inspection of the performance to clear the specifications has shown that the undulator is formed very well. No mechanical deformation was found when the magnet gap was changed continuously. The magnet gap can be changed by computer control. The software prepared by NSRC works well to change the magnet gap smoothly.

The vacuum chamber in the undulator part of the storage ring was specially designed to increase the conductance. The minimum magnet gap is 26 mm. The gap inside the vacuum chamber at the part where the electron beam exists is very narrow. Therefore, the conductance for residual gases along the beam direction is low. On the other hand, the metal surface area where outgasing occurs is large. Thus, the pressure in the chamber may be high. In order to avoid this situation, we designed the vacuum chamber consisting of a tube with a large diameter with the narrow gap portion to attach it. There is a wide aperture at the border between the two parts of the chamber. The vacuum chamber in the undulator part is made of stainless steel. Danfysik has constructed the undulator and the vacuum chamber. It will soon be installed into the storage ring.

TROUBLE SHOOTING

Since the original SORTEC machine was built 14 years ago and the dismantled components remained unused over 5 years, some component elements such as power supplies and controllers are found not to work properly. During the course of the reassembling work, all the components were examined carefully and broken parts were either replaced or repaired.

After the machine construction had been completed, we have spent more than two years for the commissioning of the machine and improving the machine performance. Some of problems we had encountered were reported already [8,13]. Among the problems we had to overcome, three issues were very serious.

One of the three issues was the non-uniform floor settlement [13]. This occurred both in the linac-synchrotron room and in the storage ring room. We repeated machine alignment as the measures. The irregular floor subsidence stopped in two years after the completion of the building construction. We consider that this irregular subsidence of the floor is caused by the use of bad quality piles to support the floor and the defects in the design of the foundation.

The second serious problem was the breakdown of the synchronous pulse generator in the machine control system. The synchronous pulse generator and other injector timing control systems are installed in the main control room. An installed battery supplying power to the circuit boards had died and the memories in a board had disappeared. The battery was renewed and the memories were re-installed. Then we found that a built-in computer to control the system had been broken. Thus, the SORTEC timer system was abandoned and a new timer system has been built. We used the design developed by KEK and SPring8.

The third one is the beam instability and most serious. It occurred in the linac and the storage ring. The linac beam instability was caused by occasional fluctuations of the electron beam energy. If the electron energy changes, the location of the electron beam moves after the beam passes through the first bending magnet in the LBT line. Since the location of the analyzer slit is fixed, the beam movement is converted to the fluctuations of the beam intensity. The change in the electron energy was partly caused by the accumulation of various pieces of the degradation of the components in the microwave electrical circuit. Some of the problems were attributable to the inappropriate circuit design and the use of improper circuit components. The adjustment of the control circuit was found to be imperfect. Large noise arising from the breakdown discharge in the high voltage circuit for the electron gun prevented the proper operation of various monitors. The result of this is that the fine-tuning of the controls and power supplies circuit could not be carried out.

As cures, most of the defects have been removed; the fine tuning of the controls and the power supplies was carried out; a voltage amplifier had been installed at each beam current monitor for increasing the output signals; the emission current from the electron gun has been increased. These actions enhanced the injection efficiency. Now, the fluctuations of the beam energy have been fixed within the level that does not affect the injection efficiency. At present, noise cannot be removed completely, although it does not make crucial influence on the machine performance. The work to replace the cathode of the electron gun is underway.

The occasional beam fluctuation in the beam injector part become conspicuous as the intensity fluctuation of the electron beam coming out of the HBT line. Thus the cause for this can exist in the synchrotron. Noise picked up by the power supply to the quadrupole magnets of the synchrotron made the quadrupole magnet operation unstable. The noise has been removed by installing filters between the power supply and DCCT monitors. Another problem leading to the beam instability was the degradation in the circulator of the microwave circuit. Some parts were renewed.

In this way, the beam injection to the storage ring is performed with the considerably stable incoming beam at present.

The beam instability in the storage ring was such that the location of the electron beam in the storage ring moved quite frequently and the beam was lost suddenly. This caused large COD that could not be corrected. The beam lifetime was short. We had to correct the beam position with very strong steering magnet fields at certain points of the ring. The intensities of γ-rays emitted from some points in the ring were very high. By careful inspections, we found that all power supplies to magnets and the control circuit for the RF acceleration system was working fine without any problems.

Then we measured the machine parameters in order to investigate whether the electrons are traveling properly in the storage ring or not. Then, as a result, we found the quite abnormal distribution of the betatron functions with the very large magnitudes of the betatron functions at a few points along the electron orbit. This explained the observed anomalous features of the stored beam. The beam scraping may have occurred. Abnormal focusing forces must cause the anomalous beam position.

We inspected the characteristics of the quadrupole magnets and found that the short-circuit occurred between coil-layers of many quadrupole magnets. The defects of the quadrupole magnets explained the observed fact that the electron beam could not pass through the centers of quadrupole magnets. We have replaced the worst four coils with new ones. This drastically improved the machine performance. The construction of 64 coils to replace old coils has been completed.

PHOTOEMISSION EXPERIMENTS

Details of the structures of beam lines which have been built are described elsewhere [9-12]. TOYAMA built the machnical components. Karls Zeiss supplied the optical elements such as mirrors and gratings. They are made of silicon crystals. The photoemission experimental station has been completed by VACUUM GENERATORS.

Only two optical beam lines have been installed in the light source system. One of the beam lines is for the electron beam monitoring with visible synchrotron light. Synchrotron light is guided to an optical system with a telescope and a TV camera where the image of the light source is finely obtained. We assume that the image represents the cross sectional view of the electron beam. The changes of the shape and location of the image are taken to be those of the electron beam. This observation is conveniently used for the beam diagnosis.

Another beam line is for photoemission experiments [9-12]. The monochromator used is of the constant deflection angle type with the non-linearly varied line spacing plane grating. An average resolving power of 5,000 is attained. Monochamatized light is focused on a sample as a small spot. No optical element is installed in the front-end part, i.e. the area inside the radiation shield wall in the building. Measuring the locations of the Fermi edge of an Au film at various photon energies we carried out the photon energy calibration of the monochromator. The corresponding readouts of the rotary encoder attached to the grating system were compared with the kinetic energy values at the Fermi edge. The photoemission measurement system consists of a UPS angle-resolved photoemission energy analyzer, an Auger electron energy analyzer (CLAM), a helium discharge tube and a head-on type x-ray tube. The system is also equipped with a sample holder and manipulator. A separate sample preparation chamber is also installed. The x-ray tube is for XPS measurements. Ultraviolet light from a helium discharge tube is used for the calibration of the energy analyzer system.

As the light beam application experiments, we have carried out photoemission measurements on a clean Ni(111) surface both in the angle-integrated mode and the angle-resolved mode.

In the angle-integrated mode measurements, we focused our attention on the change of the final states as the excitation energy is varied. The change in the final states shows up as the change of the spectral band shape. If the excitation energy is high enough, the spectral band shape does not depend on the excitation energy and resulting spectra have the shape of the super Coster-Krönig (sCK) electron spectrum. If the excitation energy falls into the region where the complete 3*p*-3*d* resonance occurs, resulting spectra have the shape of that of two hole bound state spectrum. In the intermediate energy region, spectral band shape varies continuously depending on the excitation energy. We attribute this to the change of the final states where the role of the excited spectator electron is important.

In the optical ground state of Ni, the screening of 3*d* holes by conduction electrons (4*s* electrons) makes the number of 3*d* holes per ion be fluctuating. They energy is supplied by phonons. On average, one 4*s* hole and one 3*d* hole form the ground state $4s3d^9$. The fluctuation also generates the state with no 4*s* hole and two 3*d* holes. The two hole state is often referred to as the two hole bound state in the sense that two 3*d* holes occur at a lattice site. If the optical excitation removes a 3*d* electron, the fluctuating screening makes the resulting state to be two 4*s* holes plus one 3*d* hole or one 4*s* hole plus two bound 3*d* holes. This is found in the observed photoemission EDC curves. If the sCK transition occurs after the excitation of the 3*p* electron, the final valence state can be the state with one 4*s* hole plus three 3*d* holes or two 4*s* holes plus two bound holes. If one hole in the valence state is removed by the core electron excitation, the two hole bound state can be brought about with higher probability. This is a sort of the final state interaction. What we observe in the excitation energy dependence of the photoemission band shape is the process to diminish the 3*d* holes in the intermediate state.

In the study of the angle-resolved mode, the obtained spectra are used for the energy band mapping. At present, the surface energy bands are traced. The measurements were carried out by changing the polar angle of the emission direction. Although the amount of the obtained data is not sufficient at present, the agreement of the observed data and those of theoretically calculated band is fair.

FUTURE PROSPECT

Since the light source has started working well, we will move our primary effort to the construction of new beam lines and experimental stations. We wish to fill the experimental hall with beam lines and experimental stations as planned. The urgent task is to build the undulator beam line. We are now carrying out the design work for this beam line.

On the other hand, existing beam line will be used for the research of surface electronic structures of transition metals, such as Ni(111), Cr(100), Cr(110) and Cu(100) and Cu(110). Studies of deeper core level excitations will also be made. Outside users are coming to use the experimental stations. A few groups trying to use the facility appear to be interested in transition metals, semiconductors, and polymers. In the future, one more beam line for the VUV-SX spectroscopy will be built.

We are now carrying out the design study of the x-ray beam line for superconducting magnet wiggler. In this work, the design work for the experimental station for protein crystallography is included. For x-ray generation, we are still carrying out the feasibility studies.

In addition to protein crystallography, x-ray experiments under consideration are ordinary X-ray diffraction experiments, XAFS measurements and materials characterization. The design work of the associated beam line has not yet started.

For the machine performance improvement such as computer controlled operating point adjustment, increase in the beam injection efficiency, and automatic COD correction, continuous efforts will be carried out. The conceptual design work for the superconducting wiggler has not started yet.

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