LIGHT SOURCE
& BEAMLINES

Control of bunch length of the UVSOR storage ring

Hiroyuki HAMA, Shiro TAKANO and Goro ISOYAMA
UVSOR Facility, Institute for Molecular Science, 38 Myodaiji, Okazaki 444

An extremely short bunched beam realized in an electron storage ring would give various advantages to experimental studies with synchrotron radiation. The short bunched beam extends a region of study in time-resolved experiments, and gain of a free electron laser on a storage ring increases due to a high peak current in such a beam. Moreover, emission of coherent synchrotron radiation[1)], which has not been reported on storage rings[2,3)], would be hopefully detected. We have conducted an experiment to control bunch length by means of changing the momentum compaction factor α on the UVSOR storage ring at an electron energy of 600 MeV. The storage ring has been regularly operated at an operating point of Q_x=3.16 and Q_y=2.64 with α=0.035, where the natural bunch length is approximately 260 ps (2σ) at the energy of 600 MeV[4)]. The bunch length is proportional to the square root of α, which can be varied by changing the dispersion function because it is proportional to an integral of the dispersion function in bending magnets. The UVSOR ring has the magnet lattice called as the double bend achromat. It is possible to vary the dispersion function while the horizontal and vertical betatron wave numbers are maintained at constant values. We can make the dispersion function negative in a part of a bending magnet such that α is reduced due to cancellation in the integral.

Relying on a model calculation with a computer program for linear lattice calculation, we carried out the experiment. Prior to the experiment, magnet parameters of the model were adjusted to reproduce the measured α and the betatron numbers at the injection point. According to the calculation, the momentum compaction factor can be varied as the dispersion function at the center of long straight section η^{cal}_{LSS} is changed. At the regular operating point, η^{cal}_{LSS} is estimated to be approximately +0.38 m. As η^{cal}_{LSS} become smaller, α decreases and becomes zero at η^{cal}_{LSS}=-0.825 m, which is the unstable point for the synchrotron oscillation. The beam was injected at η^{cal}_{LSS}=+0.3 m throughout the experiment, which is close to the regular operating point. The storage ring was operated in a single bunch operation in order to avoid any effects from coupled bunch instability. After the injection, excitation currents of the quadrupole magnets were changed synchronousely to reduce α using the same procedure for beam accelaration, which is supported by a computer control system.

We measured the following three diffrerent parameters relevant to the bunch length and the momentum compaction factor. (1)Bunch length was measured by the single photon counting method using a photomultiplier consisted of micro-channel plates. Time spectra of synchrotron radiation emitted from a bending magnet were obtained with the standard technique using a time-to-amplitude converter and a pulse height analyzer. (2)A signal from a pickup electrode was processed by a spectrum analyzer, and the synchrotron oscillation frequency f_s was measured. Even at a small beam current, a collective synchrotron oscillation due to instability was observed as sidebands of the RF frequency signal in the frequency spectrum, though the intensity was very weak. (3)Horizontal beam displacement Δx of the beam was measured as a function of the RF frequency. Then α was obtained using a relation $\Delta x=\eta(\Delta p/p)=\eta\alpha^{-1}(-\Delta f/f)$, where η is the value of dispersion function at the position monitors and $\Delta p/p$ and $\Delta f/f$ are relative deviations of the momentum and the RF frequency from central values.

As shown in fig. 1, we successfully controlled the bunch length from 300 ps down to approximately 40 ps (twice the standard deviation). The bunch length estimated from f_s was in good agreement with the bunch length measured directly, and both of them were in agreement with the model calculation. We, however, observed a strong nonlinear dependence of Δx and also f_s on the RF frequency in the low α region. Such nonlinearity is considered to be due to an effect of second order term of $\Delta p/p$ in α, which probably originated from different focusing forces of Q-magnets given to off-momentum particles. Taking into account the second order term, we analyzed the data using relations $\Delta l/l=\alpha_1(\Delta p/p)+\alpha_2(\Delta p/p)^2$. We obtained the value of $\alpha_2=-0.15$ at the operating point with $\eta^{cal}_{LSS}=-0.8$ m, while an estimated value by the calculation was +0.52. This discrepancy can be explained by taking account of an effect of the sextupole magnetic field on the nonlinearity. In the experiment, the natural chromaticities were compensated with the sextupole magnets, but the second order term was probably overcorrected. Actually we could supress the nonlinearity by reducing the magnetic field of the focusing sextupoles.

Figure 2 shows the experimental results of α and calculated values, which are in good agreement. By suppressing the second order term, we obtained he lowest α of 0.00025 from the measurement of f_s so far, which corresponds to the bunch length of 25 ps.

References

1) F. C. Michel, Phys. Rev. Lett. 48 (1982) 580.
2) J. Yarwood et al., Nature 312 (1984) 742.
3) G. P. Williams et al., Phys. Rev. Lett. 62 (1989) 261.
4) A. Lin et al., to be published in Jpn. J. Appl. Phys.

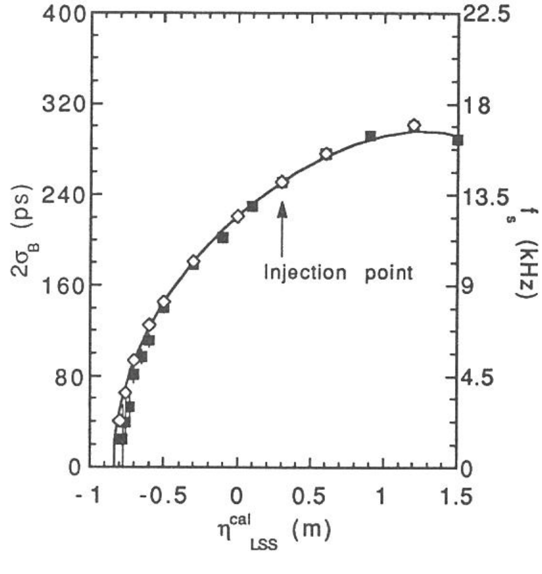

Fig. 1. Measured bunch lengths and synchrotron oscillation frequencies of several operating points, which are denoted by squares and diamonds. The right-han axis for f_s is normalized to be visible as same magnitude of bunch length. Theoretical bunch length is indicated by the line.

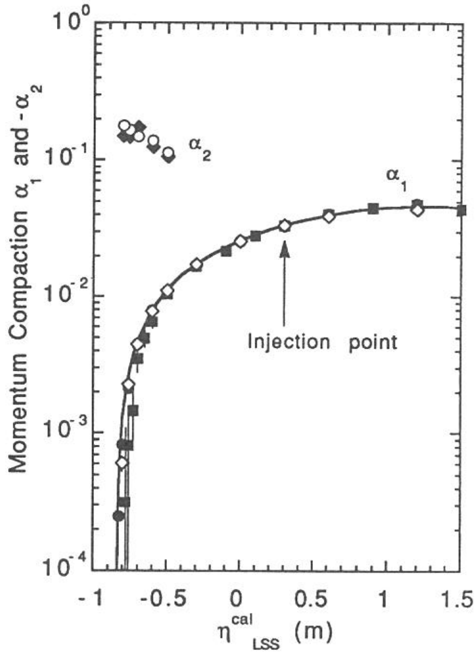

Fig. 2. Experimental result of momentum compaction factors. Values deduced from the data of bunch lengths are denoted by squares. Solid and open circles denote α_1 and α_2 deduced from the data of displacements. Diamonds represent those but from the data of synchrotron oscillation frequencies.

Free Electron Laser Experiment with an Optical Klystron on the UVSOR Storage Ring

Shiro TAKANO, Hiroyuki HAMA and Goro ISOYAMA

UVSOR Facility, Institute for Molecular Science,

Myodaiji, Okazaki 444

An experimental study of a free electron laser (FEL) in the visible region is in progress on the UVSOR storage ring. The present goal is to achieve lasing at a wavelength around 488 nm with the electron energy of 500 MeV. As the initial step of the project, an FEL gain was measured with a transverse undulator of nineteen periods with the period length of 11.1 cm made of permanent magnet.[1)] The measured peak gain was 8×10^{-4} at the stored beam current of 10 mA/bunch, which was in good agreement with the theoretical calculation. It was concluded that the UVSOR storage ring had sufficient performance relevant to the FEL project.

In order to obtain an FEL gain as high as possible within the limitation imposed by length of a long straight section where the undulator was installed, we have remodeled the undulator to an optical klystron (OK).[2)] The central three periods of the undulator have been removed and replaced by a three pole wiggler. The OK consists of two identical undulator sections of eight periods, called as an energy modulator and a radiator, respectively, separated by a dispersive section of 37 cm long, called as a buncher. The parameter N_d of the dispersive section, which is the number of optical wavelengths (488 nm) passing over electrons in the dispersive section, can be changed in the range from 60 to 85 when the magnet gap of the dispersive section is varied.

The vertical magnetic field along the longitudinal axis of the OK is measured with a Hall probe. Figure 1 shows the measured magnetic field and the calculated electron trajectory in the horizontal plane. The magnetic field imperfection originating from magnetization errors in strength and in angle of magnet blocks is well compensated, so that there is no accumulated distortion of the orbit due to erroneous kick in angle when electrons travel along the OK. Figure 2 shows a spontaneous emission spectrum for N_d = 83 measured at a low beam current of less than 1 mA/bunch. The fine structure peculiar to radiation from an OK is evident, which arises from interference of radiation from the two undulator sections.

In order to check the performance of the OK, an FEL gain is measured by the method similar to that employed in the previous experiment with the conventional undulator.[1)] The light at the wavelength of 488 nm from an Ar ion laser is modulated in polarization at a frequency of $f_{mod} \sim 2.8$ kHz by an Pockels' cell, injected into the OK, and detected with a PIN silicon photodiode after it interacts with the electron beam. As the storage ring is operated in single bunch mode, the gain signal appears at the combined frequency of the revolution frequency of the electrons f_{rev} and the modulation frequency f_{mod}. The signal is processed by a fast lock-in amplifier locked at $f_{rev}+f_{mod}$. The measured gain is shown in Fig. 3 as a function of N_d. The measured peak gain is about 0.4 % for the average beam current of 10 mA/bunch, which is in agreement with calculation. The gain of the OK is about five times larger than that of the conventional undulator.

An optical resonator of 13.3 m long is installed for oscillation experiment. Radii of curvature of the front and rear mirrors are 8 m and 6 m, respectively. An oscillation experiment is now in preparation.

References

1) S. Takano, H. Hama, G. Isoyama and A. Lin: UVSOR activity Report 1990, p.4; S. Takano, H. Hama, G. Isoyama, A. Lin and N. A. Vinokurov: submitted to Jpn. J. Appl. Phys.

2) N. A. Vinokurov and A. N. Skrinsky: preprint 77-59 of the Institute of Nuclear Physics, Novosibirsk, 1977.

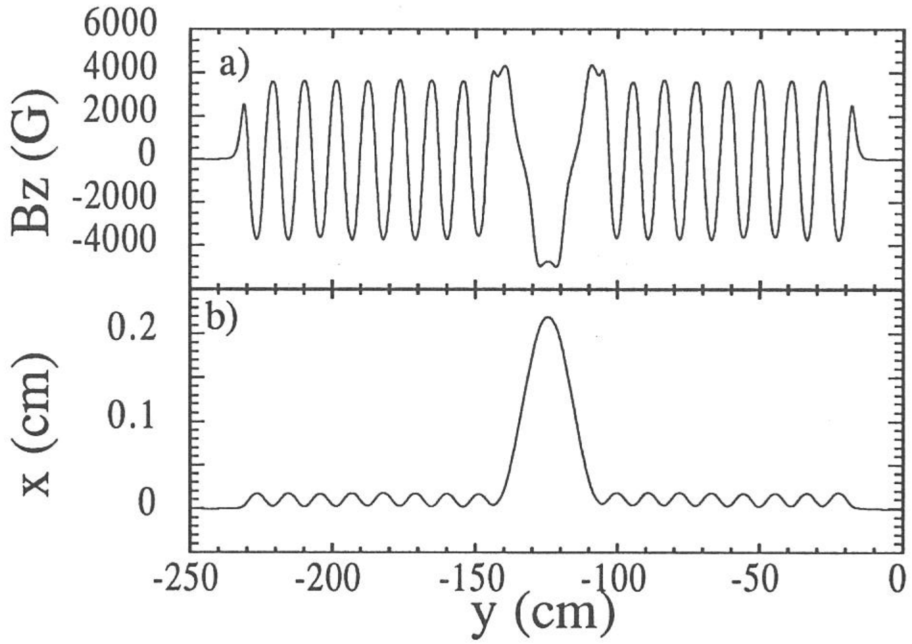

Fig.1 a) Vertical magnetic field in the optical klystron.
b) Calculated electron orbit in the horizontal plane.

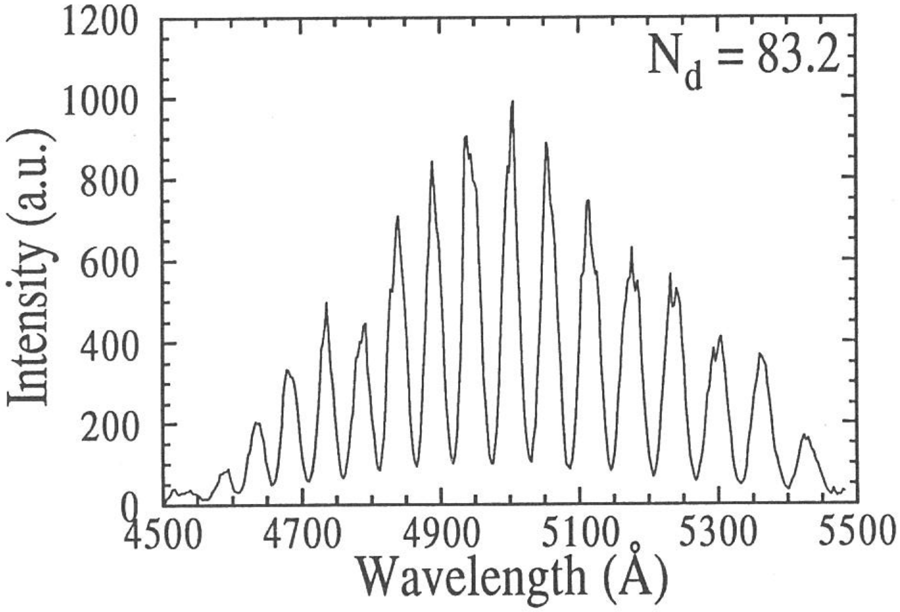

Fig. 2. Spontaneous emission spectrum of the optical klystron.

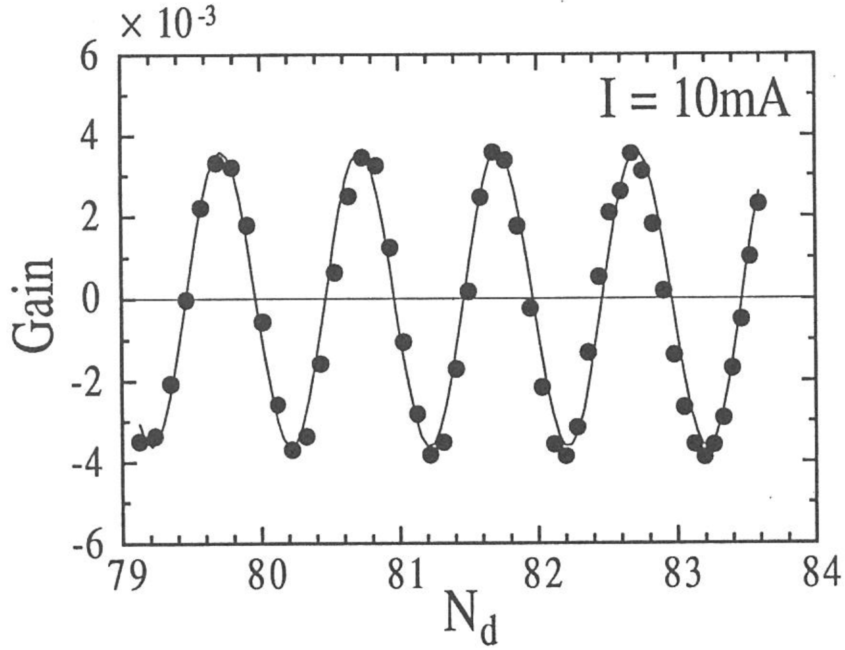

Fig. 3. Gain of the optical klystron as a function of N_d.

Computer Control System for the UVSOR Storage Ring

Noriichi KANAYA*, Hiroyuki HAMA, Jun-ichiro YAMAZAKI,
Osamu MATSUDO and Goro ISOYAMA

** Photon Factory, National Laboratory for High Energy Physics, 1-1 Oho, Tsukuba 305*
Institute for Molecular Science, 38 Myodaiji, Okazaki 444

Since the construction of the UVSOR accelerator system, the storage ring as well as the booster synchrotron had been operated by a manual control system. We sometimes met difficulties with the control system to improve the performance, especially, of the storage ring. In order to overcome the difficulties, a new control system based on mini-computers was recently installed for a part of the accelerator system, that is, for the storage ring and the beam transport line from the synchrotron. We employed Micro VAXs with the VMS operating system as the computers for control and mainly the CAMAC interface for connecting components of the accelerator system with the computers The new system has been working quite well.

The computer system consists of two min-computers (Micro VAX 3400) with four shared hard disks, which are used for communication between the computers, two work stations (VAX Station 3100) for operator's terminals and seven CRTs for status monitors, which are connected to the computers by a local network (DECNET) through two terminal servers (DEC Servers) They constitute a local cluster structure via the network. One of the mini-computers is used for control of the storage ring, and the other for the beam transport line. The latter computer will be also used for control of the synchrotron and the injector linac in the future. If one of the min-computers malfunctions due to a system failure, it is possible to control all the system by the other computer though the response time of the system is degraded.

The main interface between computers and accelerator components we adopted is CAMAC. There are six crates for the storage ring and two crates for the beam transport line, which are connected serially to each computer by an optical link. We mainly use parallel input and output modules to control devices; 24-bit change-of-state input register modules (Kinetic Systems 3473), 24-bit isolated input gate modules (3471), 48-bit digital output register modules (3072) and 16-bit input gate/output register modules (3063). Additionally, we use 32-channel 16-bit scanning analogue-to-digital converter modules (3516) for analogue inputs. Status data are read by the 3473 modules, though an interruption function (LAM) is not used for the moment, and numerical data are read by the 3471 modules. They are read or written in the BCD format. Since approximately 70 DC power supplies with relatively small output capacity are necessary for steerings, sextupoles, skew quadrupoles and correction coils of bending magnets and quadrupole magnets, we employed the 3063 modules which can be connected to the power supplies directly by single cables. The CAMAC modules are electrically isolated from controlled devices. Some devices are connected to the computers by GPIB interface or RS232C interface.

In order to use most of the existing power supplies which were controlled by remote control boxes in the control room, interface boxes were made and inserted between the power supplies and the CAMAC interface. Since we use the same electrical and logical levels for the CAMAC modules, those of each power supply are converted to the standard ones for the CAMAC modules in the interface box. An exception is the DC power supplies for small magnets and coils, which are directly connected to the CAMAC modules one to one. They were newly built and replaced old ones.

The control program was made by Digital Equipment Corporation Japan. The standard tools of the X-window (DEC-Window) are used for the man-machine interface, which runs on the workstations. The control screen has a hierarchical structure. The main control window is a summary screen, on which operational and error status of the accelerator system is displayed, routine operations of the system such as starting-up, injection, acceleration, and so on are conducted, and sub-summary screens of the lower level such as for the magnet power supplies and the RF system of the storage ring are called. From a sub-summary screen, we can get access to control screens for individual devices. It is also possible on the sub-summary screen to set numerical values to the devices. Any of the screens can be displayed on the CRTs, the program for which is written by GKS.

The routine operations of the system are defined in the form of files, which consists of conduct files and data files. When one of the routine operations is selected by an operator, the program first reads a conduct file, in which names of data files are written, and then reads the data files written in the conduct file. In a data file, names and setting values of devices are written. The data file has a sub-structure called as pages, which is divided by the symbol of end of step (EOS). The control program reads commands written in a page, successively performs them, and waits till all the commands are completed. Then it proceeds to the next page. It is possible to write any numbers of data files in a conduct file. Owing to this control file system, it is possible to change operation modes without changing the control program.

Since the UVSOR accelerator system is running for user experiments, the control system was replaced stepwise during relatively short shutdown periods in 1991. The longest one was four weeks. In order to avoid unscheduled shutdown due to the new control system, the special care was taken so that anytime we could go back to the old control system if a malfunction of the new control system happened. Fortunately, there was no such an accident. We will extend the system to cover all of the accelerators in the future.

CONSTRUCTION OF BL-4A BEAM LINE AND ITS FACILITIES

Shinri SATO, Yuji UKISU, Eiken NAKAMURA, Toshio KINOSHITA, Atsunari HIRAYA, and Makoto WATANABE
Institute for Molecular Science, Myodaiji, Okazaki 444, Japan

In recent years, VUV surface photochemistry, especially SOR photochemistry has received increasing attention because of its potential applications to microelectronics, e.g., photo-CVD, microlithography, photo-etching, etc. Fundamental researches on VUV surface photochemistry are, however, far behind its technological researches due partly to lack of suitable light source. BL-4A beam line was constructed for the fundamental study on photochemistry of solid surfaces and of adsorbed molecules.

Figure 1 shows a schematic diagram of BL-4A beam line. The SOR light is focused by a prefocusing mirror onto a sample in a reaction and analysis chamber (RAC). Unfocused light is also available. Although the beam line has no spectrometer, wavelength region of the SOR light can be selected by a thin metal-film or a glass cut-off filter. RAC is equipped with some surface-science facilities; polarization-modulation reflection absorption FTIR spectroscopy (PM-IRAS) for molecular structure analysis of adsorbed species, a quadrupole mass spectrometer for gas analysis, Auger electron spectroscopy (AES), X-ray photoelectron spectroscopy (XPS) for surface chemical analysis, an ion sputtering gun for sample cleaning, a gas-handling system, and a sample load lock for a quick exchange of sample. RAC is pumped by a turbo molecular pump and an ion pump, and its base pressure is less than 1 x 10^{-9} torr. A sample holder attached to an XYZT precision manipulator can be cooled with liquid nitrogen and heated by electric heater. The temperature of the sample can be elevated at a constant rate for temperature-programmed desorption (TPD) technique.

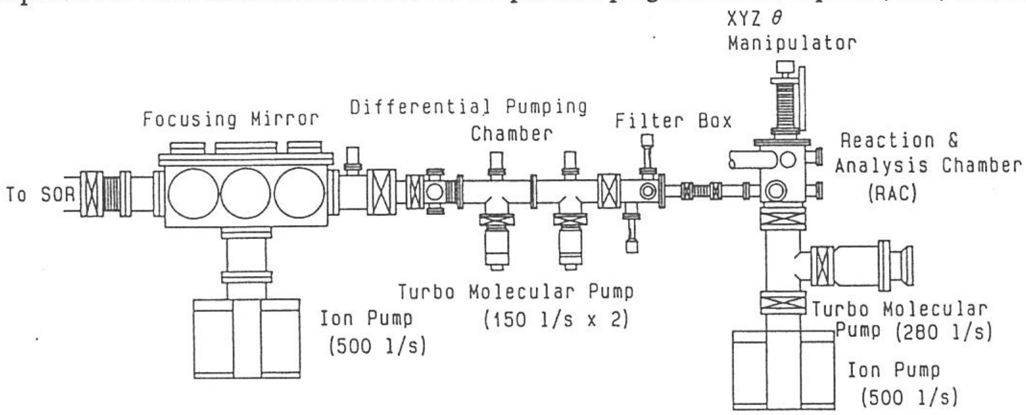

Figure 1. Schematic diagram of BL-4A beam line.

Figure 2 shows a schematic diagram of PM-IRAS which is carried out at the level of SOR beam. When P-polarized IR beam is incident to sample surface (metal surface in principle) at a high incident angle nearly 90°, the beam interacts efficiently with molecular vibration perpendicular to the surface, while S-polarized IR beam not. Therefore, PM-IRAS gives information of surface species alone even if gas-phase species are present, and serves for improvement in S/N ratio. In this system, PM is carried out at 64 KHz by a wire-grid polarizer and a photoelastic modulator.

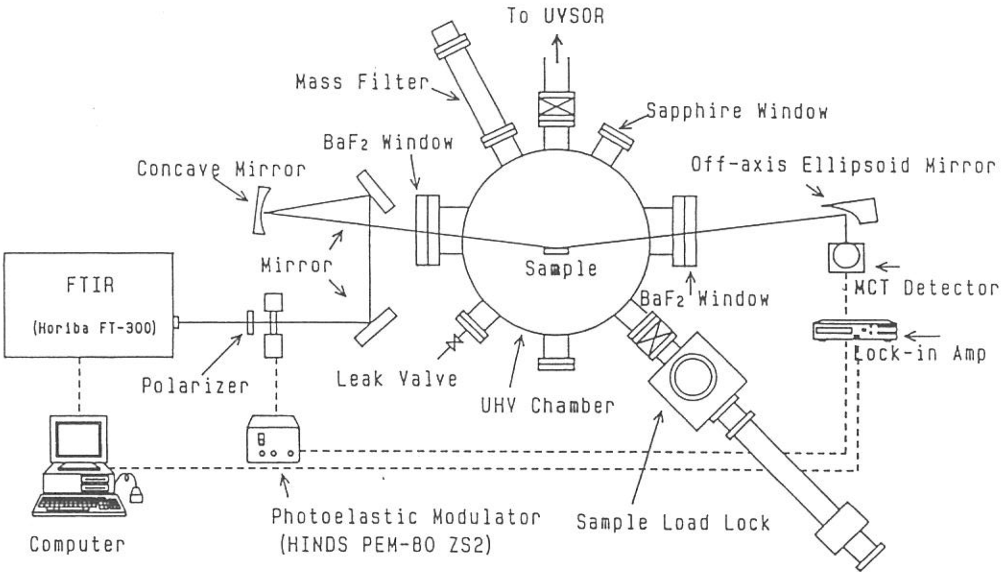

Figure 2. Schematic diagram of PM-IRAS system at the lower level of RAC.

Reflected IR beam from the sample is detected by a HgCdTe (MCT) detector cooled with liquid itrogen. A difference signal between P- and S-polarized beams is amplified by a lock-in amplifier and subjected to Fourier-transform calculation, while a reference spectrum is recorded without the lock-in amplifier. BaF_2 windows of RAC were specially made for IR spectroscopy in an ultra high XPS, AES, and sample cleaning are carried out at the upper level of RAC, to which the sample is transferred by the manipulator. A schematic diagram of the upper level system is shown in Fig. 3. An X-ray gun has dual anodes of Mg and Al, and an electron analyzer is VSW CLASS 150, specification of which is as follows: Energy range, 10 - 5000eV; Detector, Mulch-channel detector (Resistive anode PSD); Noise, 50meV (peak to peak); Sensitivity, 450Kcps at 0.9eV FWHM (Ag $3d_{5/2}$).

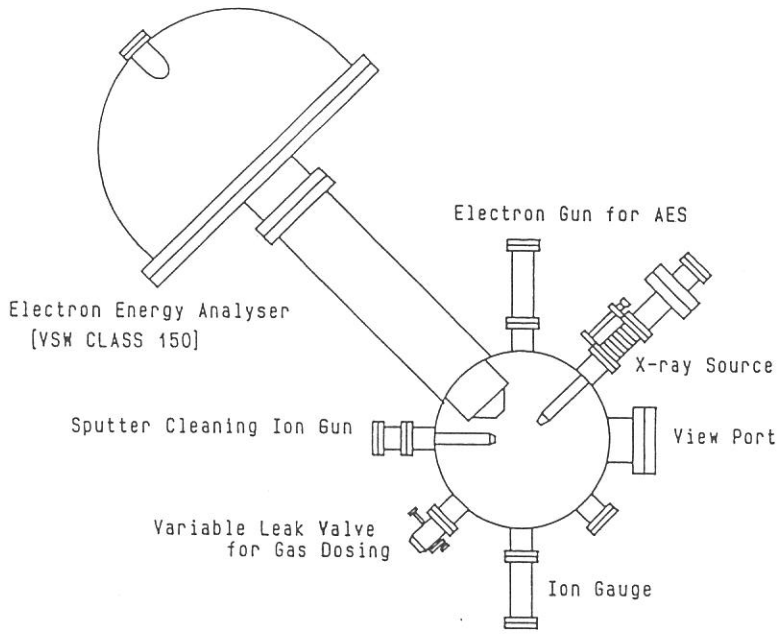

Figure 3. Schematic diagram of the upper level of RAC.

Design of an Instrument for Far-Infrared Microspectroscopy using a SR Source

A. Ugawa, H. Ishii,[+] K. Yakushi, H. Okamoto, T. Mitani,
M. Watanabe, K. Sakai, K. Suzui, and S. Kato.
Institute for Molecular Science, Okazaki 444 Japan.
[+]Department of Chemistry, Faculty of Science, The University of Tokyo, Bunkyo-ku, Tokyo 113 Japan.

A design of a microspectro-photometric system using a synchrotron radiation (SR) source are described. The system covers the wide spectral range of 50-13000 cm^{-1}, being under construction at the UVSOR BL6B beam-line. The optical system, which is designed mainly for reflectance measurement, is schematically drawn in Fig. 1. The optical system constitutes of four components: 1) *Beam Line Optics (BL6B)* in ultra-high vacuum with interchangeable four windows, 2) *Fourier-Transform Interferometer* of vacuum type, 3) *Infrared Microscope* Spectra-Tech IR-PLAN, which will be placed in dry and CO_2 free atmosphere, and 4) *Si Bolometer* cooled by liquid helium. Preliminary experiments in the mid-infrared region (500-5000 cm^{-1}), as shown in Fig. 2, have qualitatively confirmed the theoretical calculation that the synchrotron radiation is more intense than a blackbody (T = 1200 K) when a microspectro-photomeric technique is applied, which is due to natural collimation and high brilliance of SR source. The SR as an infrared source exhibits its advantage on measuring the spectra of small single crystals especially in the far-infrared region.

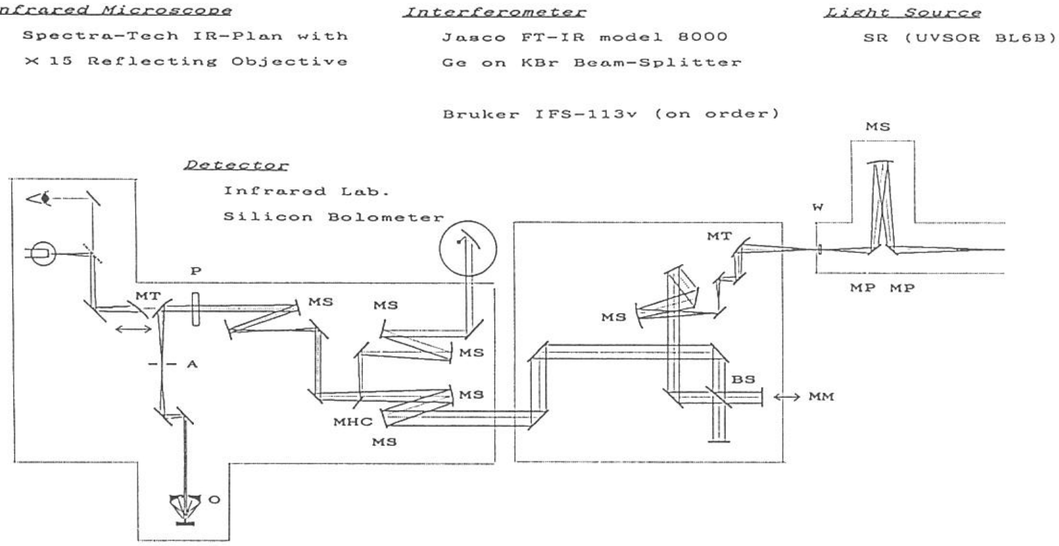

Fig. 1. Schematic drawing of the optical system.

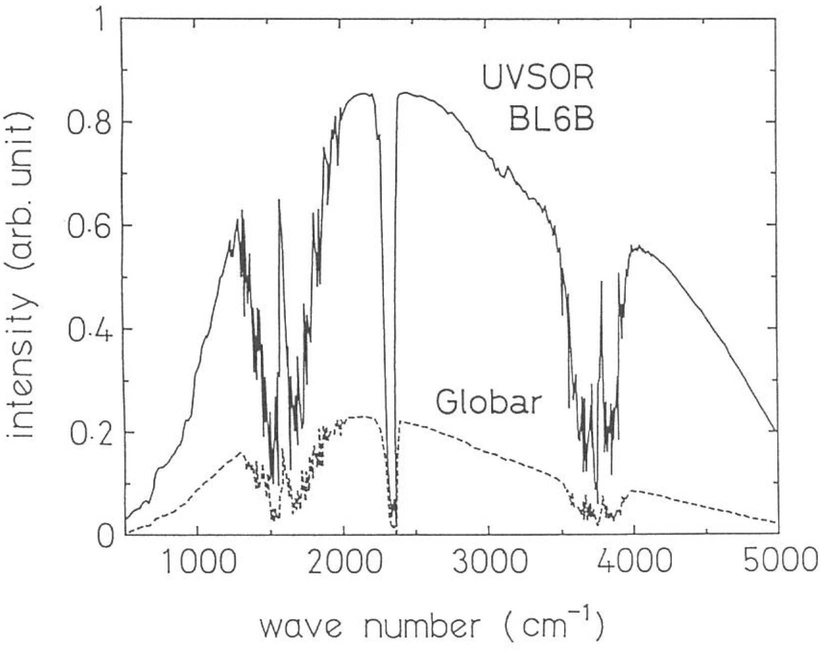

Fig. 2. Power spectrum of the SR (BL6B) and black body.

CONSTRUCTION OF AN APPARATUS FOR STUDIES OF SURFACE PHOTOCHEMICAL PROCESSES, III ON BL4B

Haruhiko OHASHI,* Eiken NAKAMURA, Toshio KINOSHITA, Atsunari HIRAYA, Makoto WATANABE, and Kosuke SHOBATAKE
Institute for Molecular Science, Myodaiji, Okazaki 444 Japan
** Visiting Student from Toyohashi Univ. of Technology, Toyohashi, 440 Japan*

An apparatus has been constructed on for studies of surface photochemical processes of semiconductor materials. The processes to be studied are synchrotron radiation-excited etching of semiconductor material surfaces and epitaxial growth of crystalline semiconductor film at low temperatures. A long focusing mirror (550 mm x 30 mm) was installed 2.31 m downstream from the source point and the focussed synchrotron radiation, which is deflected by 4°, is irradiated upon a sample surface 4.50 m downstream from the center of the mirror. It would be worth to describe the characteristics of the mirror installed here. From ray tracing calculations it was shown that the focussing behavior is improved quite a lot by using an elliptically bent cylindrical mirror.[1] Therefore the mirror surface is shaped to be circular in the vertical direction (radius: R_v =11.1 cm) and elliptical in the horizontal direction. Mechanically a long cylindrical mirror was bent by pressing it on an elliptically machined surface.

The beamline was designed such that one can also carry out experiments with unfocussed SR as it is directly radiated from the source point, despite of the low intensity levels compared with the focussed SR, because its absolute intensity and spectral profile can be theoretically estimated. Furthermore since the focused SR beam crosses with the unfocussed beam 3.02 m downstream from the center of the focussing mirror, one has to only rotate apparatus around the crossing point and realign SR beam.

The schematics of the apparatus is shown in Figure 1. It consists of a reaction chamber, two differential pumping chambers, DPC-1 and DPC-2, and a light chopper chamber. To the reaction chamber are attached a differential pumping chamber, DPC-1 from its upstream side, a stock chamber which keeps samples on top of it, and an ESCA (VSW Scientific Instrum., Model Class 150) analyzer chamber from the side of the reaction chamber. The samples on the sample holder are inserted in the leak chamber, and transfered to the stock chamber after the leak chamber is pumped down to low enough pressure. Thus the stock chamber and reaction chamber are not exposed to air. The base pressure of the stock chamber is 2,0 x 10^{-10} Torr and that of the reaction chamber is at present 1.0 x 10^{-9} Torr without baking. The chambers are pumped with magnetically suspended turbomolecular pumps. It is planned that from the downstream side of the reaction chamber will be connected a molecular beam chemistry apparatus II (MBC-II) which is being modified to detect desorbed species from a SR-irradiated surface using a rotatable mass spectrometer detector with an electron bombardment ionizer. In the mean time experiment is underway to detect desorbed species from the irradiated surface in another reaction chamber using a mass spectrometer detector.

References

1. A. Hiraya, et. al., *Rev. Sci. Instrum.* **63**, 1264 (1992).

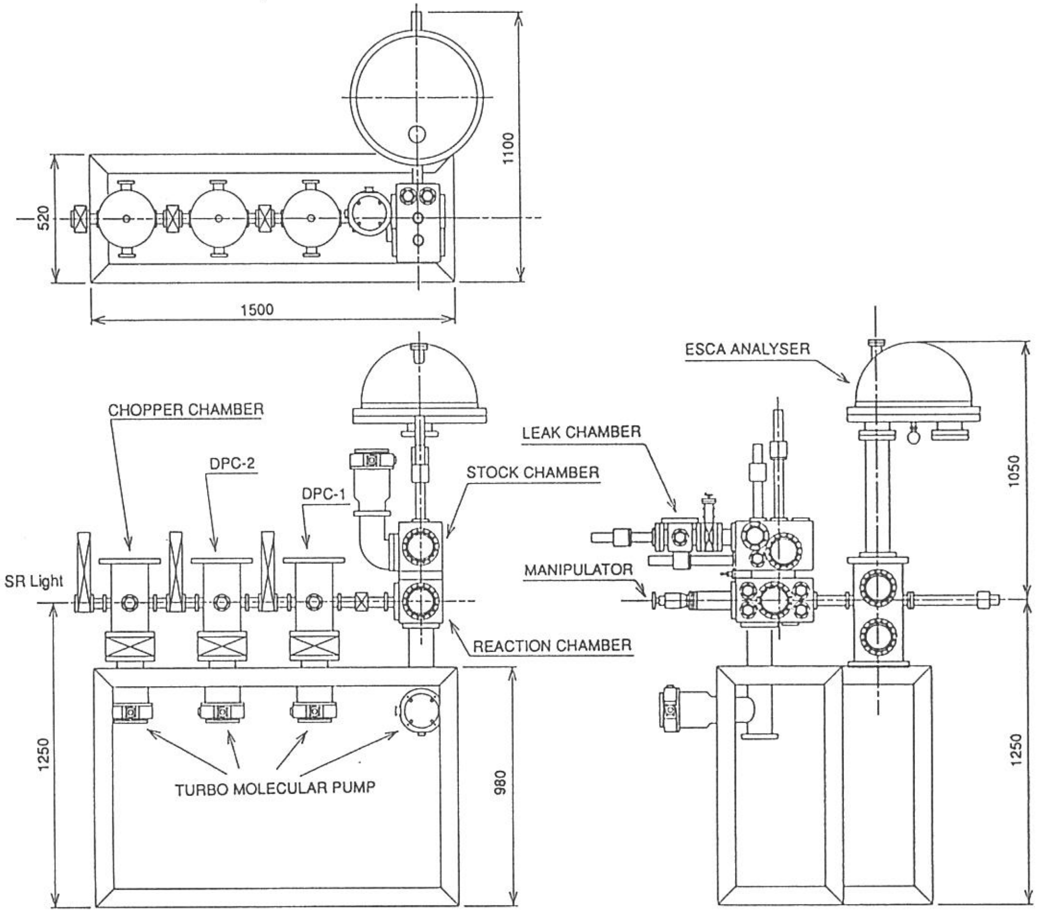

Figure 1. Schematic drawings of the apparatus constructed on Beamline BL4B for studies of surface photochemical processes. Top: downward view, bottom left: side view (note that the SR is radiated from the left), bottom right: side view facing the light beam source.