THE MEXT 21ST CENTURY COE PROGRAM BASED ON PORTABLE SYNCROTRONS NAMED MIRRORCLE

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Abstract

The Synchrotron Light Life Science Centre of Ritsumeikan University seeks the next generation life science beyond genomics and proteomics by the unique portable synchrotrons named MIRROCLE. MIRRORCLE-6X generates brilliant hard x-rays in spite of its 6-MeV electron energy. The power of IR/FIR beam from MIRRORCLE-20 is much higher than any synchrotrons by its unique mirror system introduced to collect the synchrotron light from whole arc of the electron orbit. Unique applications are also described

OWERVIEW OF THE COE PROGRAM

The Synchrotron Light Life Science Centre granted by the MEXT 21st Century COE Program [1] seeks unique Life Science. The overview and the target of our project are drawn in Fig.1. We study the dynamics and behaviours of the living specimens in each level such as protein, cell, organ, etc. by developing new research instruments based on portable synchrotrons.

Yamada and collaborators have succeeded in developing two tabletop synchrotron light sources having 15 cm orbit radius for brilliant IR radiation named MIRRORCLE-20 [2,3] as seen in Fig. 2(a) and for hard x-ray productions, named MIRRORCLE-6X [4] as seen in Fig. 2(b). MIRRORCLE20 provides the IR rays much brighter than any other SR sources. The IR radiation from the entire electron orbit of exact circular is collected, which reaches 10W/mm^2 in average. The IR synchrotron light spectrum is cantered at 10 μm wavelength and covers from few to 100 μm.

The unique beam line is the dispersive type IR irradiation system. We are able to place specimens along 15 cm long focal plane, where one to 0.5 % band monochromatic IR-rays are available through 30 of 1mm slits by using a grating monochrometer. The powerful CW white beam of SR is in some extent more useful compared with the monochromatic pulse beam of free-electron laser. Detection of IR rays is another task, but we are able to detect chemical products due to the specific wavelength IR irradiation onto the specific proteins or DNA in water. We will find switches, which trigger the protein's functions [5].

Changes in the characteristics of water by the specific IR irradiation are one of the important research subjects to understand the meaning of heat in human body.

Scanning micro FT-IR will be another beam line to be prepared in the next stage. Behaviours of cells will be studied under IR or FIR irradiation in few μm spot.

Characteristics of cancer tumour or cholesterol under IR-rays irradiation are another subject to be studied. We will find specific wavelength, which heat up cancer tumor selectively, or resolve cholesterol. If these wavelengths are not absorbed by the skin or water, we may open up new medical treatment opportunity

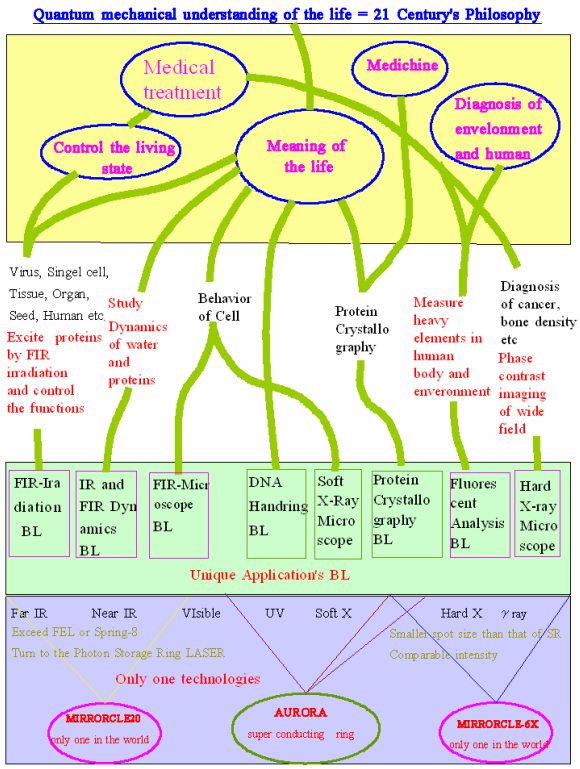

Figure 1: Top column shows the destination of the project. The second column describes proper targets of the project. The third column is devoted for specific beam lines to be prepared. The bottom line indicates unique synchrotron light sources dedicated for IR, soft x-ray, and hard x-ray.

IR/FIR project by MIRRORCLE-20

MIRRORCLE-20, which has 15cm orbit radius, is under operation at the injection of 40 Hz repetitions with 20 mA peaks current. Since the circumference is extremely short 600 mA is stored by one shot of injection. We found that the injection efficiency is nearly 100%. Last two years MIRRORCLE-20 has been operated for x-ray production to perform the x-ray imaging [6], the irradiation experiments of cancer cells, the x-ray fluorescent analysis of heavy elements and so on. The activities of the x-ray experiments are now shifted to MIRRORCLE-6X. MIRRORCLE-20 injection system, which enables to accommodate complex mirror system in the vacuum chamber, is modified for IR/FIR

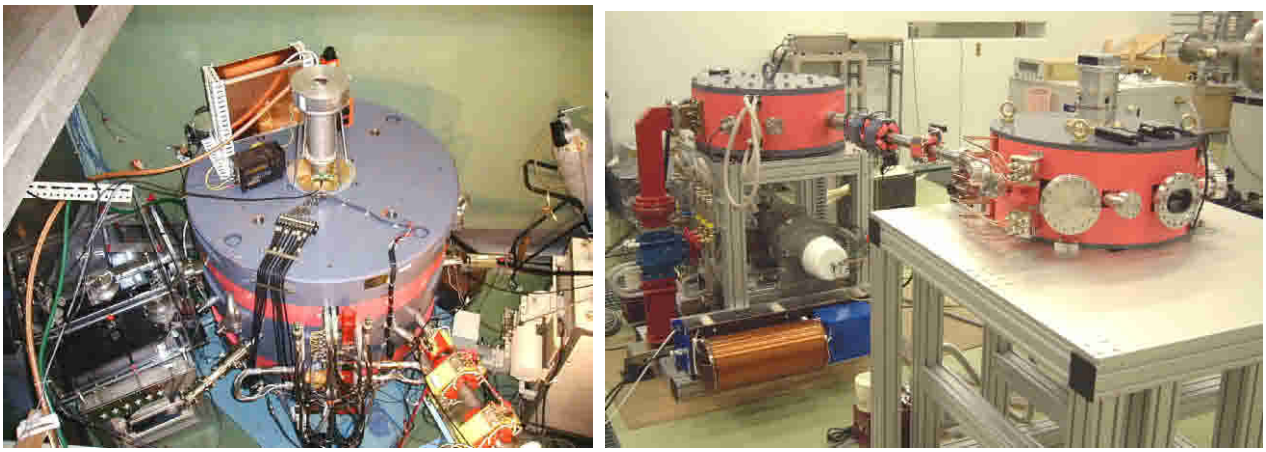

Figure 2: MIRRORCLE-20 (left) and MIRRORCLE-6X (right) are the portable exact circular synchrotrons using normal conducting magnet.

Mirror System, which Focuses All the SR Emission into One Point

Another key issue is the special mirror system. The designed beam optics is somewhat different from usual SR beam line optics used for the synchrotron light sources. The complex mirror system collects all radiations emitted from the whole arc of the exact circular 15 cm diameter electron orbit by an exact circular mirror and a quasi-ellipsoidal mirror as seen in Fig. 3. The extracted IR beam can be parallel with spot size of 10x3 mm^2 wide. This mirror system is placed in the vacuum chamber under the magnetic field. We have observed 20mW of integrated IR radiation without the circular mirror. With the circular mirror 120mW is expected..

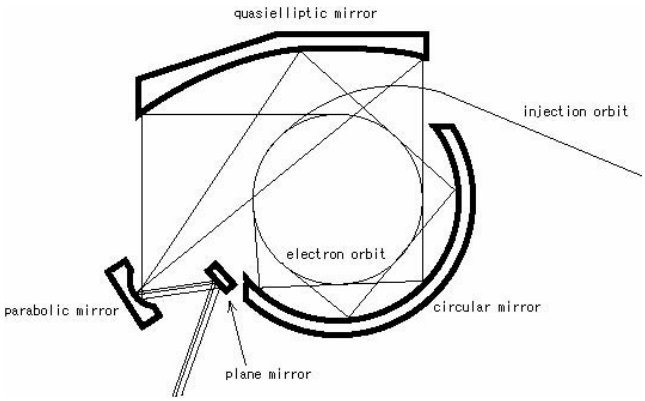

FIGURE 3: The special mirror system is composed of the circular mirror concentric to the electron orbit, quasi-elliptic mirror, which focuses the radiation in to one point, parabolic mirror which makes parallel beam to be extracted.

Grating monochrometer type irradiation system is under construction, which has 15 cm long focal plane and 1 to 0.5% band width/mm. Four gratings cover wavelengths from 5 to 25μ m.

Hard X-ray project by MIRRORCLE-6X

According to the success of the hard x-ray generation by MIRRORCLE-20, MIRRORCLE-6X has been designed. The 6 MeV instead of 20 MeV is chosen for suppressing neutron generation, but still to be relativistic electron energy, which gives 82-mrad x-ray divergences. The micron order x-ray source point size, 100 mA injector peak current, and 400 Hz repetitions reserve the 10^{11} order photon brilliance. The total flux of 10^{12} photons is much brighter than that of any synchrotron light sources, which is quite advantageous to the imaging and the x-ray microscope. The magnification of 7.6 times is available at 1 m distance.

Multi-layer X-Ray Mirror for the Protein Crystallography

The protein crystallography, x-ray fluorescent analysis, and x-ray microscope beam lines are the primarily target of our COE program. The 10^{11} order brilliance must be sufficient to start the protein crystallography, but we are going to introduce 8sets of multi-layer cylindrical x-ray mirror system as shown in Fig.5, which focuses x-ray beam into 0.1 mmϕ spot. The x-ray intensity will be enhanced by 10^4 if the mirror surface is made ideally. Replica method will be introduced for the cylindrical mirror fabrication.

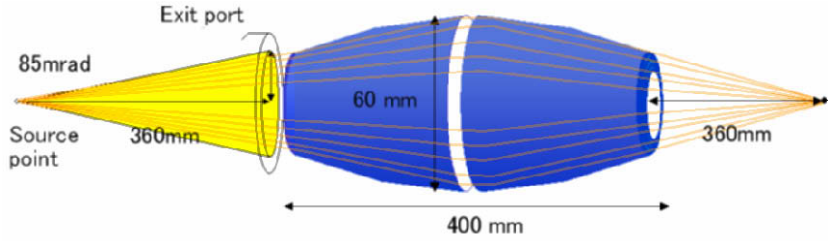

FIGURE 4: Eight sets of multi-layer cylindrical mirrors will be made by the replica method. Mother body must have the surface roughness less than nm and the shape tolerance less than 1μm.

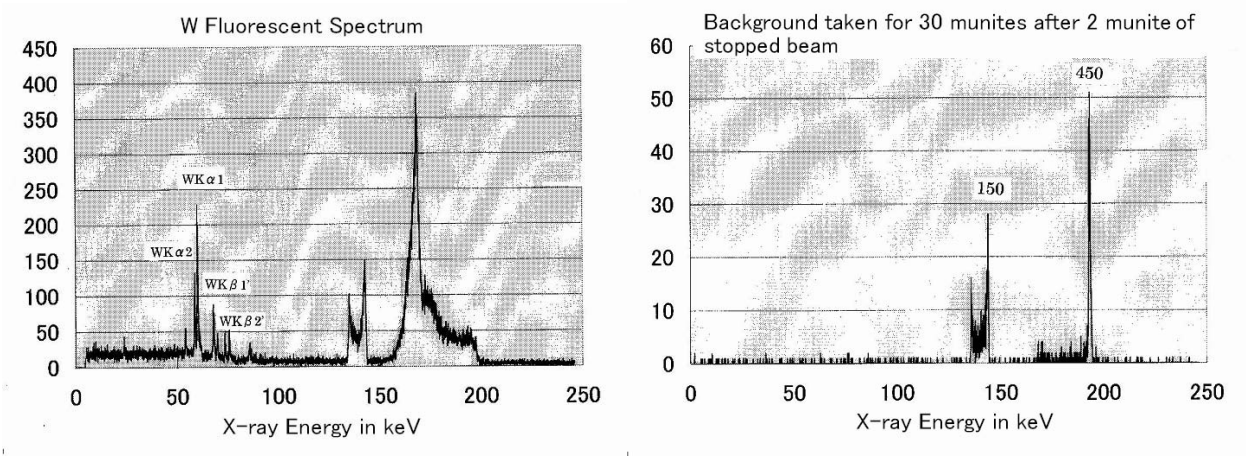

FIGURE 5: MIRRORCLE provides x-ray fluorescent analysis of heavy elements, while it is possible with more than 5 GeV SR sources.

X-Ray Fluorescent Analysis

X-ray fluorescent analysis of heavy elements [7] has been carried out by MIRRORCLE, while it was possible only by synchrotrons of more than 5GeV electron energy. The data shown in Fig. 6 was taken by MIRRORCLE-20. We found the extremely low level background. X-ray fluorescent analysis is planed to study the role and effect of heavy metal components in the environment as well as in human body.

CONCLUSION

Synchrotron Light Life Science program is in progress. The unique portable synchrotrons already provide powerful X-ray and IR/FIR beams. The IR/FIR beam line will be completed by the end of this year. The X-ray crystallography and X-ray fluorescent beam lines will be ready by the end of this fiscal year. International Symposium on Portable Synchrotron Light Sources and Advanced Applications is scheduled in January 13, and 14, 2004 to focus on the activity of portable synchrotrons, X-ray laser and compact LINAC based X-ray sources [8].

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