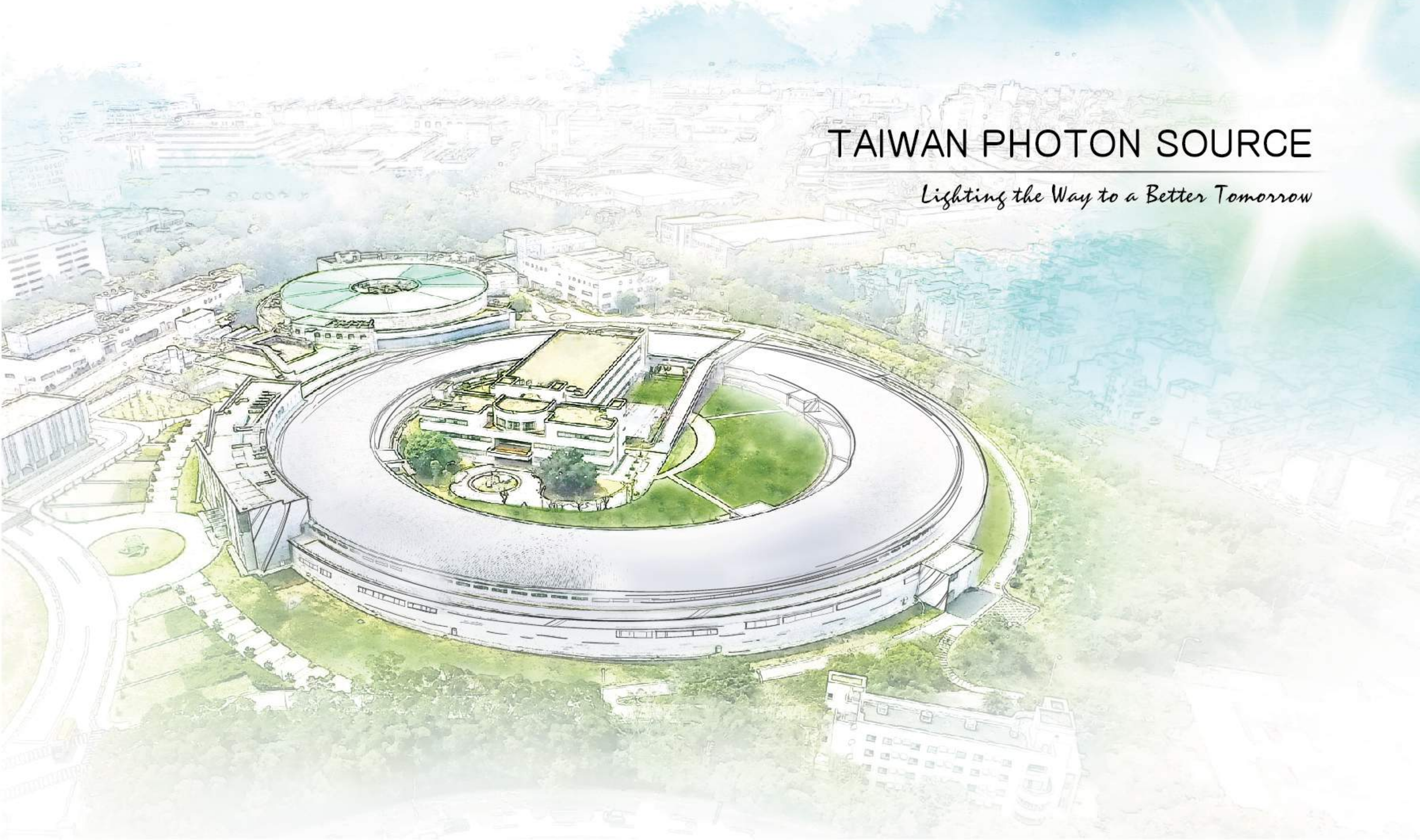
國家同步輻射研究中心
National Synchrotron Radiation Research Center

TAIWAN PHOTON SOURCE

Lighting the Way to a Better Tomorrow



Taiwan’s technology ascends to the global stage

A synchrotron light source is among the most advanced large-scale research facilities available to allow the pursuit of basic and applied science and technology research. The campus of the National Synchrotron Radiation Research Center (NSRRC) includes two such light sources, the Taiwan Light Source and the Taiwan Photon Source. The recently commissioned Taiwan Photon Source is the largest state-of-the-art research facility ever designed, constructed and operated by local management, scientists and engineers in Taiwan. It is a high-precision synchrotron that produces high-brightness synchrotron light from a 3 GeV electron beam. Today, the Taiwan Photon Source is among the most advanced and brightest light sources in the world to provide brilliant synchrotron light to scientific and industrial experimenters coming from all over the world.

In order to deliver the extremely high-brightness X-rays required by users to conduct advanced scientific research, the NSRRC submitted a feasibility study for the construction of a synchrotron accelerator, the Taiwan Photon Source, in 2005. The construction plan was approved by the Executive Yuan in 2007 and ground breaking occurred in Feb 2010. First light was produced by the end of 2014 after overcoming many challenges. Phase I beamlines and experimental stations were inaugurated in 2016, providing industrial and academic users in Taiwan with cutting-edge experimental technology. The Taiwan Photon Source offers new opportunities of scientific studies in the fields of nanotechnology, pharmaceutical, biotechnology, green energy, basic sciences, and supports industrial product developments and process optimization.

The construction of the Taiwan Photon Source has integrated advanced accelerator technology with high precision mechanics and electronics, automatic system control, high-precision measurement and quality control procedures while pushing all to their ultimate capabilities. Fortunately, during the course of construction, many domestic vendors were willing to meet the challenges and collaborate intensely with NSRRC staff to elevate their technological level, which helps both to facilitate the creation of the Taiwan Photon Source as well as further Taiwan industry. We are glad to see that the Taiwan Photon Source Construction Project has thus contributed to the advancement of domestic technology. With the successful commissioning of the Taiwan Photon Source, it is expected that more technologic miracles will prevail.

We salute those who have dedicated their time and effort in the realization of the Taiwan Photon Source. The Taiwan Photon Source will continue to enable NSRRC to make its mark on the contribution to local and international scientific development.

Shangjr Gwo, Director

The world's major third-generation synchrotron light source facilities

Milestones for the Taiwan Photon Source

2023
Completion of Taiwan Photon Source Phase-III beamline construction (planned)

2020
Completion of Taiwan Photon Source Phase-II beamline construction (planned)

2016.09
Dedication ceremony of the Taiwan Photon Source Phase I beamlines

2015.01
Inauguration ceremony of the Taiwan Photon Source

2014.12.31
The first light of the Taiwan Photon Source

2013.04
Completion of the civil construction for the Taiwan Photon Source

2010.02
Groundbreaking ceremony of the Taiwan Photon Source

2007.08
Approval of the "Taiwan Photon Source Accelerator Construction Plan" by the Executive Yuan

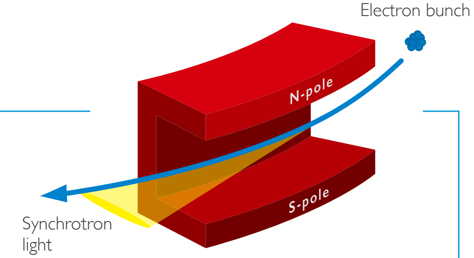
2005.07
Submission of the "Feasibility Study Report to the National Science Council on the Construction of the "Taiwan Photon Source"

What is synchrotron light?

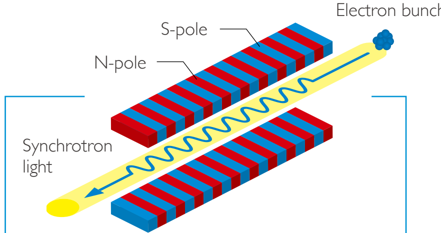
Ever since the discovery of X-rays by Wilhelm Roentgen in 1895 electromagnetic waves have become an indispensable means to investigate atomic and molecular structures of materials. Synchrotron light is emitted every time a charged particle like an electron becomes deflected by a magnetic field. The electromagnetic spectrum of synchrotron light consists of micro-waves, infrared (IR), visible and ultraviolet (UV) light, X-rays and gamma rays. Light with different wave-lengths play different roles in the daily life of human-beings. Only "visible light" can be observed by humans.

Synchrotron light was first observed 1054 by a Chinese Astronomer during the Crab Nebula supernova and again, after almost 1000 years, in a cyclotron at a General Electric laboratory in 1947. Its main features are very high brightness, narrow photon beam collimation and a wide spectrum of wavelengths ranging from tens of micrometers to well below a hundredth of a nanometer allowing us to observe the world beyond what could be seen with visible light.

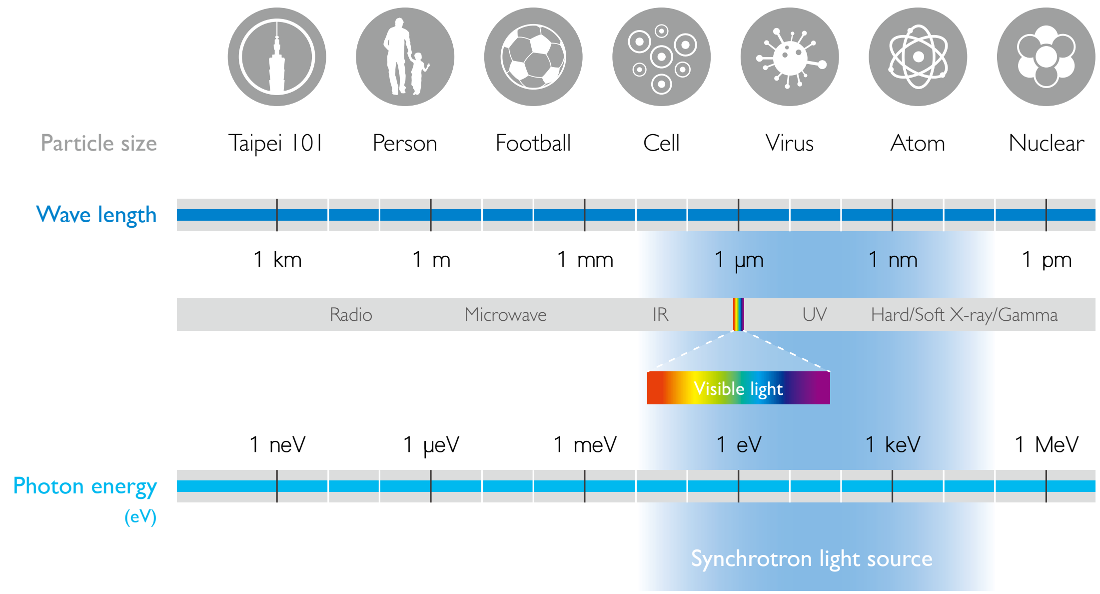
Using "synchrotron light", the observer can explore the internal atomic structure and interaction between electrons inside of materials. It is an essential experimental tool used in state-of-the-art basic and applied science, biomedical technologies and industries in the 21st Century. Synchrotron light is widely applied in the studies of materials, biology, medicine, physics, chemistry, chemical engineering, geology, archeology, environment protection, energy, electronics, micro-machinery, nanometer-devices and more.



Electrons, orbiting close to the speed of light in a storage ring, pass a dipole magnet and while being deflected emit tangentially to their path very bright synchrotron light. The X-ray beams produced by the Taiwan Photon Source is a trillion times brighter than that generated by a conventional X-ray generator, and thousands of times brighter than the smaller Taiwan Light Source.



An insertion device is a device consisting of a series of magnets producing alternate fields and causing the electron beam to follow wiggling trajectories as it passes through the device while emitting light that interferes constructively with itself to form a quasi-monochromatic photon beam of high brightness.



Synchrotron structure of Taiwan Photon Source

1 Linear accelerator

Electrons are generated from a 90 keV electron gun and pass through the linear accelerator to be accelerated to 150 MeV before traveling through a transport line to the booster ring.

2 Booster ring

The Electron beam enters a booster ring of 498.6 m in circumference to orbit nearly at the speed of light. Every time the electrons pass though the radio frequency(RF) cavity, they experience a kick thus increasing their energy. The magnetic-field strength of the magnets increases simultaneously with the energy to keep the electrons moving along the design path inside the vacuum chamber. While orbiting the booster synchrotron some 100,000 times within 0.2 sec, the electrons are accelerated to 3 GeV. And then ejected for injection into the storage ring.

3 Storage ring

The 3 GeV electrons are injected into the storage ring repeatedly, until the electron current reaches 500 mA. Every time the orbiting electron bunch passes the super-conducting RF cavity, its energy lost from emitting photons will be replaced. With short top-up injection every few minutes an almost constant photon beam intensity can be maintained for the experimenters.

4 Dipole bending magnets and insertion devices

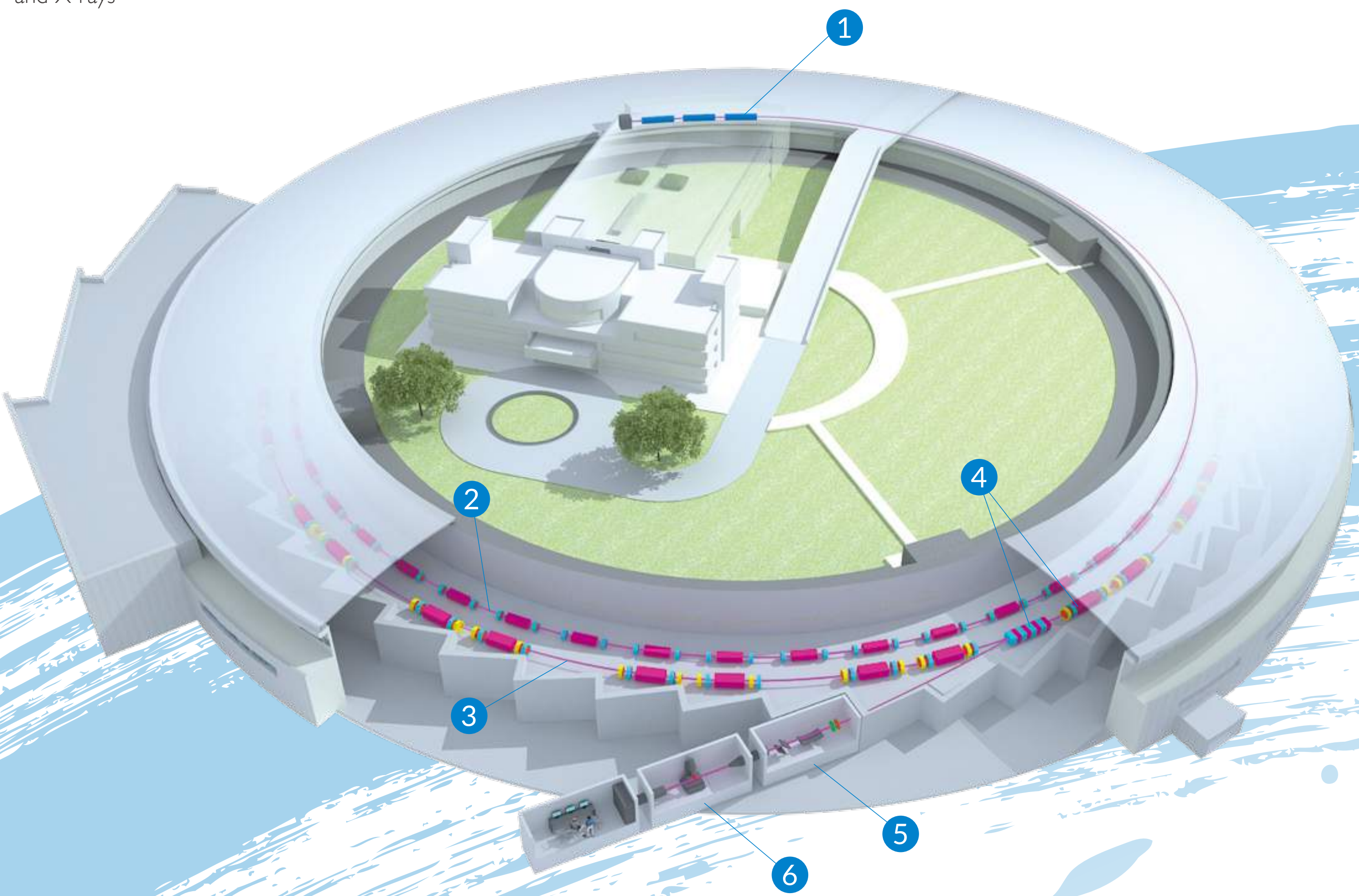
Electrons orbiting in the storage ring, are bend many times while passing through dipole magnets or insertion devices, emitting radiation of extreme brightness in a spectral range from microwaves to and X-rays

5 Beamline

Radiation generated from the dipole magnets or insertion devices are focused and pass through a spectrometer to select photons of the desired by the experimenter in the experimental station.

6 Experimental station

The users investigate the sample's physical & chemical properties by using specific experimental equipment and detectors installed at the beamline.



Synchrotron illustration diagram

Building the Taiwan Photon Source to advance technologies and vision of local industries

Civil & Electrical Mechanics

The NSRRC supervised its vendors, Falcon Machine Tools Co. and Chenfull International Co., to machine high-precision magnet support structures to a precision of 15 microns and their positioning to 100 microns. This process has advanced the technical capability of eliminating mechanical stresses and enhanced vendor's competitiveness on bidding of processing large-scale high precision machines.

Electromagnets

NSRRC staff designed the high-precision (<10 micron) magnets and facilitated the technology transfer to its vendors, including Gongin Precision Industrial Co., Unelectra International Co and Hueijer Co., etc., during the production process. As a result, these vendors have been trained and meet technical production standards for accelerator magnet production.

Radio Frequency

The design of the radio frequency (RF) super-conducting cavities is based on technology created at KEK (Japan's High-energy Synchrotron Research Institute) and manufactured successfully in close collaboration of the NSRRC with MHI and KEK. NSRRC staff has built the electronic control system independently and completed the integration tests in house.

Injector

NSRRC staff designed and produced high-precision pulse-systems for injection providing stable injection conditions, and completed the installation, integration and tests of the accelerator injection system. In addition, NSRRC staff has designed and manufactured the electron source in a joint effort with Yuan Chang Machinery Co., Wave Power Inc. and other laboratories.

Power supply

Chroma ATE Inc. and ITRI applied their technical capability in collaboration with the technical experience of NSRRC staff to develop high-precision power supplies with signal to noise tolerances below 1 part in a million (ppm). The standard of these products meets all demanding synchrotron light source power supply specification and subsequently introduced Chroma into the list of qualified global synchrotron manufacturers.

Insertion device

The elliptically polarizing undulators are designed by NSRRC staff and are manufactured & assembled by ITRI and Cheng Jun Photoelectrics. Moreover, the NSRRC was instrumental in guiding the Kung Chyou Machinery Co. and Huijer Co. to produce superconducting wiggler magnets. Due to their exceptional performance, orders from foreign synchrotron light facilities could be secured.

Racks & positioning

The NSRRC supervised its vendors, Falcon Machine Tools Co. and Chenfull International Co., to machine high-precision magnet support structures to a precision of 15 microns and their positioning to 100 microns This process has advanced the technical capability of eliminating mechanical stresses and enhanced vendor's competitiveness on bidding of processing large-scale high precision machines.

Beamline and radiation-shielding hutch

Designed by the NSRRC staffs, the radiation-shielding lead walls, vibration-resisting columns/beams and precise temperature control for the beamlines and experimental stations were contracted to the Li Kan Metals Co., Xinzhuangzi Machinery Co., Becquerel & Sievert Co. and Anson E&M Co. for construction. It has elevated vendor's construction capability in radiation related special construction tasks.

Beam diagnosis and control

By applying ADLINK industrial computers as the main control platform, the completion of TPS's control system promoted ADLINK products to be adopted by the European Synchrotron Light Source. The network switch equipment and various high-precision RF coaxial cables and connectors provided by Ringline Technologies Co. and Jebo Enterprise Co. have increased the precision level through the course of the Taiwan Photon Source construction.

Ultra-vacuum chamber

The NSRRC collaborated with Sengxin Precision Industrial Co., Xingguan Industrial Co. and Wave Power Inc. on the alcohol-free precise machining technology to produce the ultra-high vacuum chambers and to develop vacuum chamber degaussing as well as building high-precision electron beam position detectors. The vendors thus have elevated their skills to the standard of ultra-high vacuum devices & system production.

Cryogenic equipment

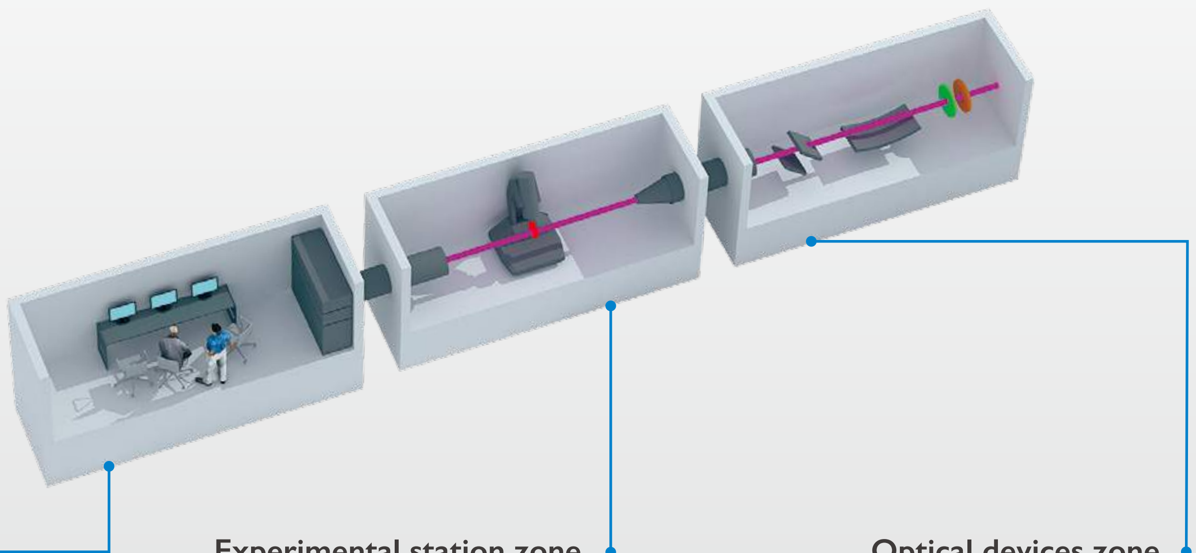
The Taiwan Photon Source cryogenic facility is the largest liquid-helium system in S. Eastern Asia. The NSRRC offered technical know-how on the equipment, and the Pinhui Engineering Co. and Gihon Enterprise Co. built the helium, liquid nitrogen and liquid helium pipelines and transmission pipelines with built-in multiple piping. The experience has elevated vendors' installation and testing capability of cryogenic equipment.

Front end

The NSRRC and Feiyie Machinery Co. with Laser Stations Inc. and Wave Power co-developed oxygen-free copper and stainless steel high-heat-load absorbers and photon-beam-position detectors. By designing the fixtures and welding paths, low-leakage vacuum detectors were built using laser welding technology.

Introduction to beamline design and technology

The function of a photon beamline is to transport an X-ray beam emitted by an electron beam while passing through bending magnets and insertion devices through filters, optical focusing devices and precise energy selection to the experimental stations. Since synchrotron light-based experiments cover a broad spectrum of applications, a variety of requirements on the X-ray beam characteristics exist, such as energy range, photon flux and X-ray polarization properties. Therefore, the design quality of a photon beamline relies heavily on tolerances of optical elements, X-ray mirror surface quality, grating elements, twin-crystal monochromators and micro focus-lens to cope with and optimize different experimental requirements. The such prepared photon beam is guided to the experimental station to interact with the samples to be studied. By measuring photon beam density, scattering angle, photon energy, or signals from excited or dissociated atoms or molecules, users can gain in-depth knowledge of the atomic and molecular structures, such as protein structures, chemical material compositions, electronic and magnetic structure, etc.



Data analysis zone

Researchers can use data-analysis software provided at the experimental stations to monitor the experiment and perform preliminary sample analysis or store the data on memory devices to bring back to the home laboratory for further analysis.

Experimental station zone

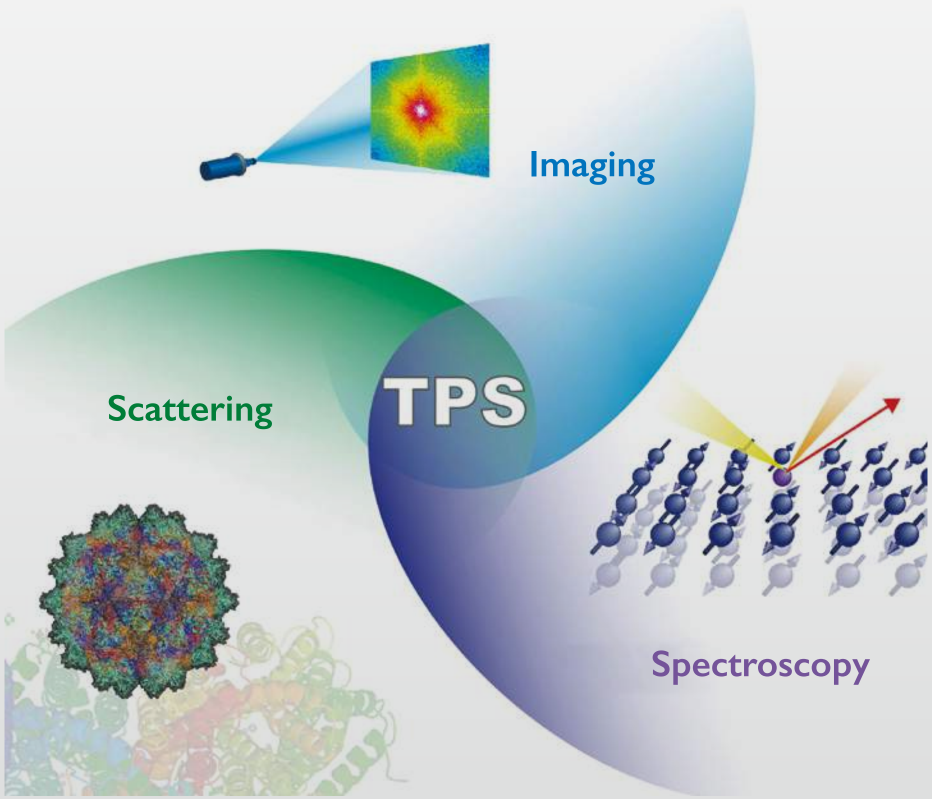
For different study topics and beamline features, different and specialized high precision equipment and sample preparation facilities are installed.

Optical devices zone

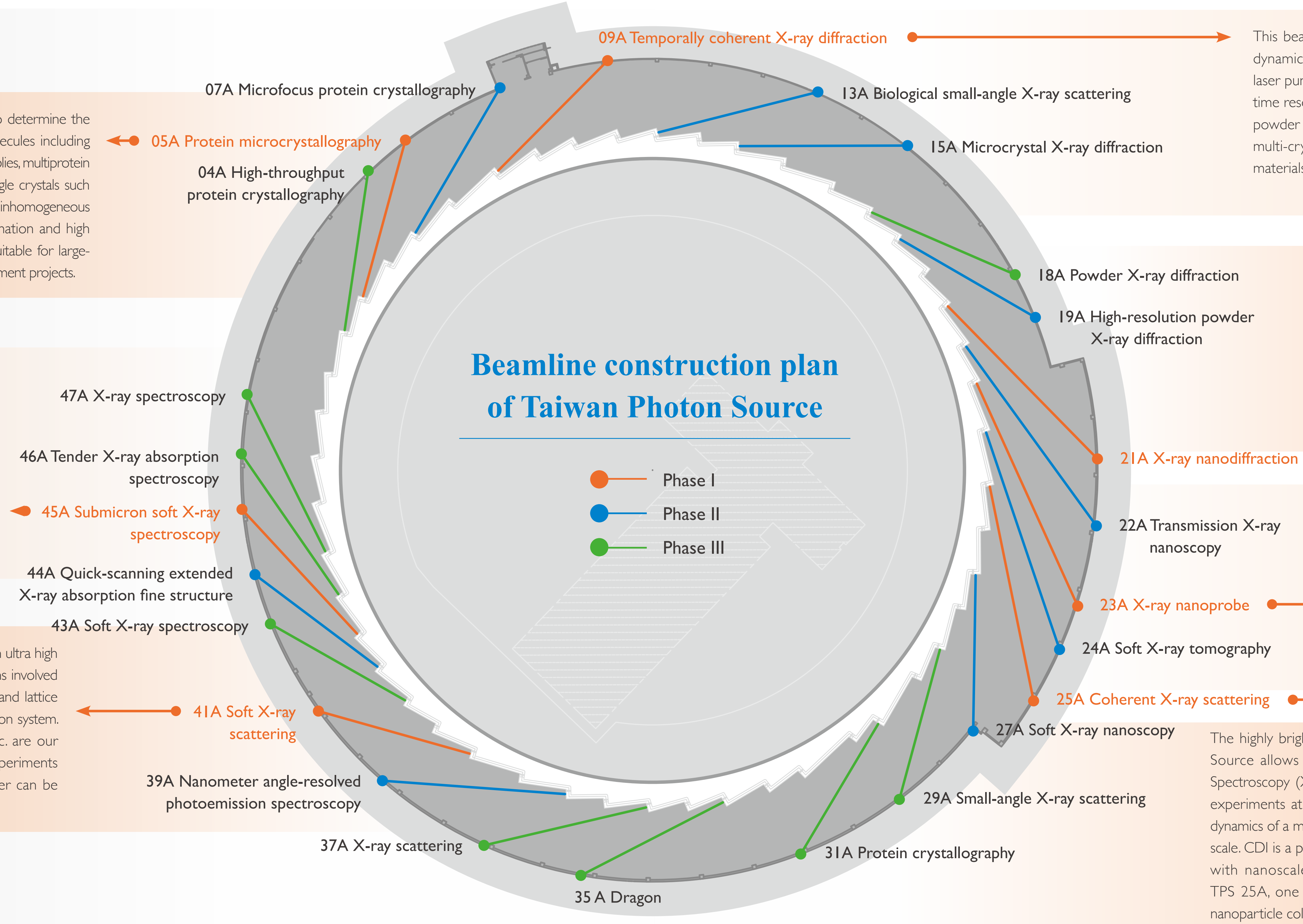
Different optical elements, such as slits, focusing elements, spectrometer and micro focus-lenses are used, to focus and direct the synchrotron light to the sample position at the experimental station.

Features of Taiwan Photon Source scientific study and building plan of beamlines

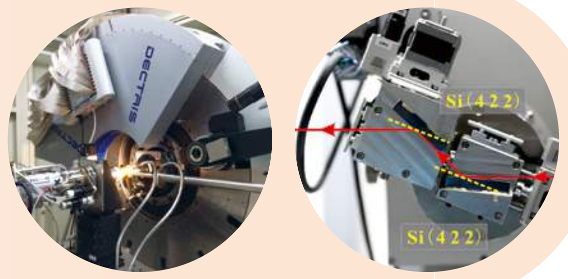
The Taiwan Photon Source utilizes different features of the light source to optimize experimental facilities for different functions. Based on the technique used in scientific experiments, the technologies can roughly be categorized into three types: imaging techniques, scattering, and spectroscopic techniques. Given the complexity and specificity off each beam line and experimental station for diverse functions, it cannot be done within a short time. Given the budget and personnel being approved according to the planned schedule, the light source facilities are constructed in three different phases. Phase I is scheduled to be completed at the end of 2016 to build seven beamlines with four of them made available to experimenters in Sept. 2016 while the remaining will be opened in 2017. Further information for the Phase I beamlines is shown in the picture below. There are 18 beamlines in Phase II & III to be completed in 2020 and 2023, respectively. During the process, beamlines from the Taiwan Light Source are transferred to the Taiwan Photon Source while undergoing significant functional upgrades. With the brilliant synchrotron light source and advanced experimental instruments, the NSRRC becomes a state-of-the-art scientific research center that allows forefront research and development in biomedical, materials, environmental, energy, semiconductor and other fields.



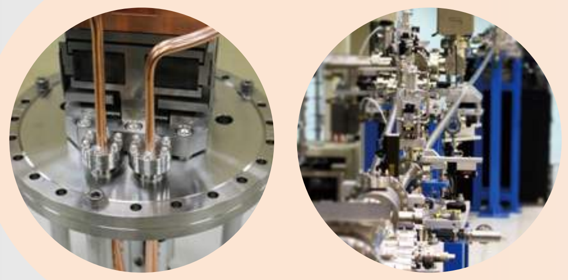
	Imaging technique	Scattering	Spectroscopy technique
05A Protein microcrystallography		●	
09A Temporally coherent X-ray diffraction		●	●
21A X-ray nanodiffraction		●	●
23A X-ray nanoprobe	●	●	●
25A Coherent X-ray scattering	●	●	●
41A Soft X-ray scattering	●	●	●
45A Submicron soft X-ray spectroscopy			●
44A Quick-scanning extended X-ray absorption fine structure	●		●
24A Soft X-ray tomography	●		
13A Biological small-angle X-ray scattering	●	●	
39A Nanometer angle-resolved photoemission spectroscopy			●
19A High-resolution powder X-ray diffraction		●	
07A Microfocus protein crystallography		●	
15A Microcrystal X-ray diffraction		●	
27A Soft X-ray nanoscopy	●		
22A Transmission X-ray nanoscopy	●		
43A Soft X-ray spectroscopy			●
47A X-ray spectroscopy			●
18A Powder X-ray diffraction		●	
29A Small-angle X-ray scattering		●	
37A X-ray scattering		●	
31A Protein crystallography		●	
46A Tender X-ray absorption spectroscopy			●
35A Dragon		●	●
04A High-throughput protein crystallography		●	



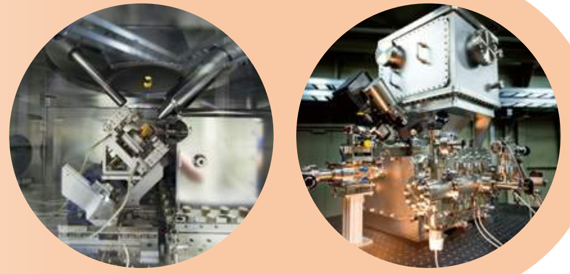
This station for protein crystallography allows to determine the 3D molecular structure of biological macromolecules including membrane proteins, large macromolecular assemblies, multiprotein complexes and viruses from their challenging single crystals such as large unit cell, high mosaicity, weakly diffracting, inhomogeneous and micro crystals. The unique beamline automation and high throughput data collection capability are very suitable for large-scale structure-based drug discovery and development projects.



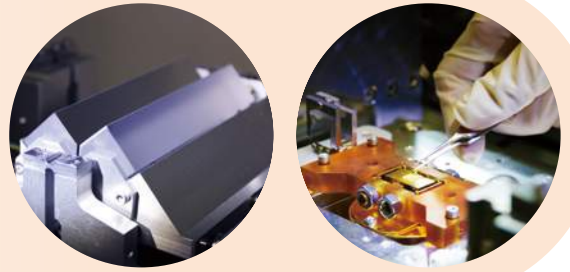
This beamline provides X-ray scattering techniques for dynamic studies on the picosecond scale; it combines laser pump and synchrotron X-ray probe techniques for time resolved experiments. It also proves high resolution powder diffraction capability with a linear detector and multi-crystal analyzer detection for phase transition of materials under non- ambient conditions.



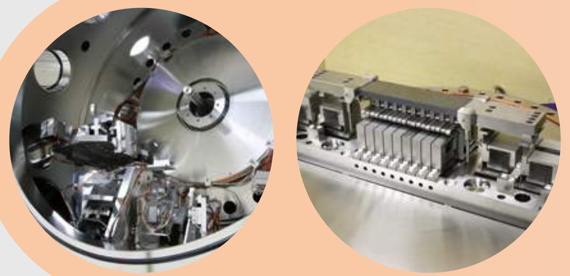
Users at this beamline will benefit from the high flux and small photon beam spot on the sample to perform angle-resolved X-ray photoemission, X-ray emission, and X-ray magnetic circular dichroism as well as linear dichroism experiments. Moreover, the unprecedented high-energy resolution would help users extract more detailed information concerning the band structures of the materials under study, especially strongly-correlated systems with *3d*, *4d* and *5d* transition metal elements.



80-nanometer-focused high-intensity X-ray beam; Based on the 3D Laue diffraction technology it is possible to perform a complete material structure analysis with nanometer precision. It is a very powerful tool especially to investigate material defects.



The X-ray Nanoprobe (XNP) beamline and associated facility provide multimodal X-ray probes for resolving atomic, chemical and electronic structures of modern advanced materials with 40 nanometer spatial resolution in 3D tomographic and nondestructive manners.

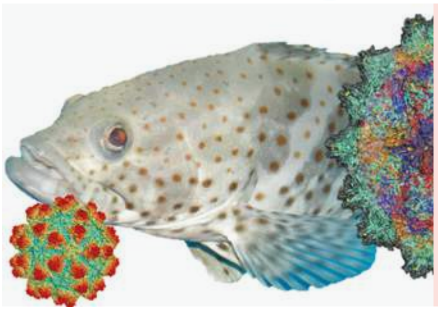


This beamline combines soft x-ray scattering with ultra high energy resolution to study low-energy excitations involved with the interplay between charge, spin orbital and lattice degrees of freedom in strongly correlated electron system. Excitations of phonons, magnons, orbitons etc. are our primary topics. Coherent diffraction image experiments with spatial resolution down to 10 nanometer can be performed at this beamline as well.

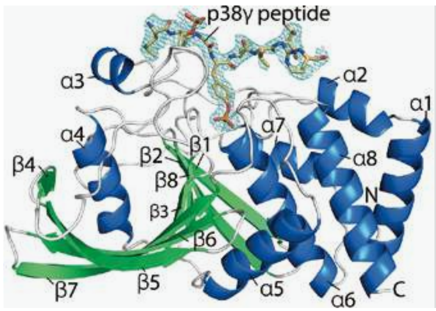
The highly bright and coherent X-rays of the Taiwan Photon Source allows users to perform X-ray Photon Correlation Spectroscopy (XPCS) and Coherent Diffraction Imaging (CDI) experiments at TPS 25A. XPCS is the possibility to study the dynamics of a multitude of collective processes with microsecond scale. CDI is a phase retrieval technique to solve static structures with nanoscale resolution. Combined core techniques at TPS 25A, one can reveal static structures and dynamics of nanoparticle colloid, solution, thin film and bulk materials.

Prospective study at the Taiwan Photon Source—sample

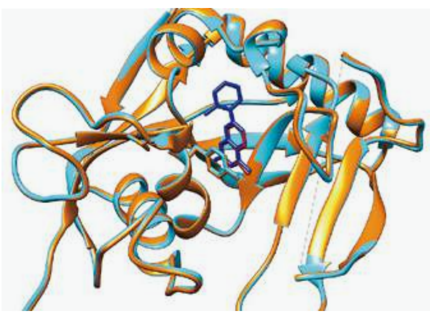
Biologic technology and pharmaceutical industry



Unravel the structure of a necrotic virus on grouper fish with in-depth understanding of the virus composition and the mechanism that infects fish cells. Propose measures of fighting against the virus infection and maintain the reputation: "Taiwan–the grouper breeding kingdom".



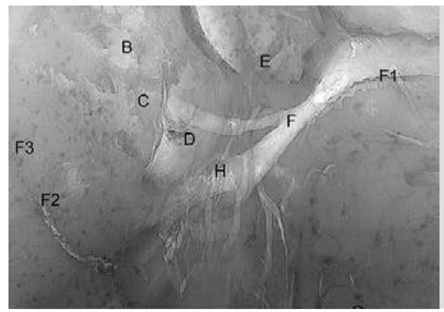
Decode the protein complex and molecular structure associated with the cell signal transmission process of colorectal cancer. Based on the research outcome, the targeted drugs are designed to enhance the effectiveness of cancer treatment against the rising incidence of colorectal cancer.



During the process of structure-based drug design, X-ray crystal diffraction techniques are used to analyze the lead compound and the 3D structure of molecular marker compound in order to understand the interaction between the drug and molecular markers. This technique can significantly reduce the cost and development time of new drugs.

Biomedical imaging

Alzheimer's disease is caused by abnormal protein accumulation in the brain cells resulting in entangled nerve fibers and thus affecting the neuronal conduction functions. Synchrotron light imaging technique can analyze the 3D neuronal fiber structure within the brain cells caused by protein accumulation helping to unveil the mystery of Alzheimer's disease.



X-ray radiation biomedical imaging techniques provide nanoscale spatial resolution and 3D tomographic images for chemical analysis to deduce the pathological information that helps early detection and treatment of cancers and diseases.

Use of infrared micro-spectroscopy allowed the inspection of a dinosaur embryo fossil specimen, which is nearly two hundred million years old. Scientists discovered that it contains extremely rare, well-preserved collagen-like organic substances. From the ultra-high resolution images, the researchers are able to infer the dinosaur egg hatching and embryonic growth status.

Environment- friendly energy (Green Energy)

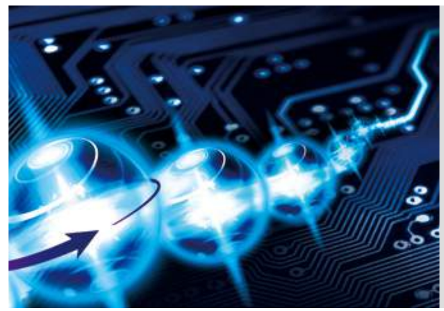
Green energy developments delivers a two-fold win-win solution in an energy crisis or to environmental protection. Develop new materials for generation, storage and saving of energy and key technologies for high-efficiency electric catalysts. Experimental techniques based on light from the TPS are powerful tools for Green Energy R&D.

Synchrotron-based technologies help develop high-performance lithium batteries and supercapacitors and to overcome technical bottlenecks of electrical vehicles, resulting in significant pollutant emission reduction in Taiwan.

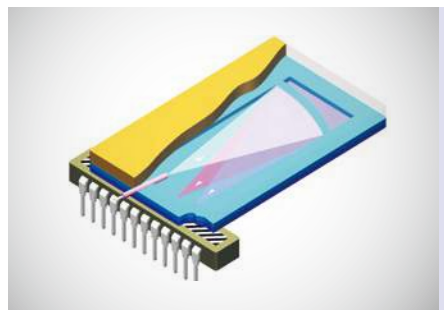
Develop high-performance petro-chemical catalysts using various experimental X-ray techniques to increase the conversion efficiency of chemicals, reduce pollution emission and increase industrial production values.

Nanometer technology application

Industry for specific high- production-value chemical materials continuously develop high-performance functional organic materials. Synchrotron radiation helps express the features of form, stacking structure and electron configuration of these soft materials.



Develop new magnetic semiconductor materials; study related magnetic features, self-spinning injection and electron polarizing ratio in order to manipulate the degrees of freedom on electron self-spinning. Help new industries develop self-spinning electronic devices of low power-consumption and non-volatility characteristics.



Synchrotron radiation X-rays can be used as a light-source for micro-machining to produce high-precision and high-aspect-ratio nanometer -scale functional structures by means of lithographic techniques. It can be widely applied in mechanical, fluid, optical, microwave and other nanometer-system applications.

Diverse industrial applications

TSMC

Apply synchrotron light-based photoelectron spectroscopy, X-ray absorption, diffraction and other technologies to analyze the composition, the electronic structure and the crystal structure of thin-film materials on a chip. Improve key manufacturing processes todevelop the world's most advanced nanometer-wafer.

ScinoPharm Taiwan, Formosa Laboratories and Mycenax Biotech Inc.

Use synchrotron X-ray diffraction and circular dichroism spectroscopy to analyze protein crystals and molecular structure, as well as crystal forms of small molecule drugs. Help to develop technologies for drug and production processes.

Cheng Shin Rubber Ind., Co.

Identify polymer microstructure using synchrotron small-angle X-ray scattering technology; help improve its rubber raw materials qualities, industrial fibers and processes to develop a new generation of high-performance energy-savings tires.

Far Eastern New Century Co.

Use synchrotron X-ray small-angle scattering techniques to analyze the microstructure of polymer and effectively improve its plastic raw material qualities and fabrication processes, in order to develop high value-added industrial artificial fibers.

Advanced Lithium Electrochemistry Co.

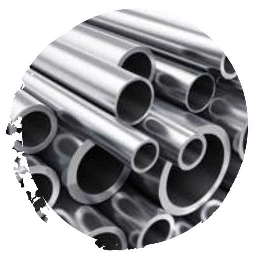
Analyze crystal structure, phase change and chemical configuration with synchrotron X-ray diffraction and absorption spectroscopy. Help develop new electrode materials for lithium batteries, obtain key international patents, and successfully expand in the global market.

Light Core Chip Co.

Using synchrotron-based nanofabrication technology. Key diffraction optical components with ultrahigh aspect-ratio microstructures can be manufactured to produce micro-spectrometers. Newly developed products can be widely used in applications of food safety, biomedical testing and Internet of Things.

CPC Corp., ITRI-Chemical Eng. Inst., and Dairen Chemical Corp.

Identify the crystal structure and chemical configuration using synchrotron X-ray diffraction and absorption spectroscopy; help develop and improve new catalyst materials; reduce environmental burdens; increase the production output of the petrochemical process.



CSC R&D Center

Use synchrotron X-ray diffraction and absorption spectroscopy to observe, in-situ, changes of material properties in steel during the process of thermal treatment, stretching and oxidation. Develop next generation ultra-high-strength steel as well as high-efficiency electromagnetic steel.

Chinan Biomedical Technology Inc. and Aurora (USA)

Help develop key accelerator and high-precision magnet technology for advanced medical instruments required in protontherapy and NMR, etc.

Taiwan Photon Source spawns integration of state-of-the-art technologies in Taiwan

Civil & E.M

CTCI Smart Eng. Co.
Gaiwen Construction Co.
Gaolong Construction Co.
JJPan and Partners, Architects
KEDGE CONSTRUCTION Co.
Shihon ConstructionCo.

Accelerator systems

Yuan Chang Machinery Co.

Low-temp system

Anson E&M Co.
Jim-Mandy Industrial Co.
Pinhui Engineering Co.
Tate Engineering Co.

Power source system

Chroma ATE Inc.
ITRI-Center for Measurement Standards

Magnets

Cheng Jun Photoelectrics
Fuhui Construction Co.
Gongin Precision Industrial Co.
Huijer Co.
ITRI-Mechanical & Mechatronics Systems Research Lab.
Kung Chyou Machinery Co.
Leicong Industrial Co.
Unelectra International Co.
Yi Chang Technology Co.

High-precision machines

Chenfull International Co.
Daju Machinery Co.
Falcon Machine Tools
Ginweida Co.
Holo-Pack Technology Co.
Lienke Co.
Mingyi Machinery Co.
Seven-Star International Co.
Xinzhuangzi Machinery Co.

Control/Instrument

ADLINK
ICP DAS
Jyebao Co.
Ringline Co.
Radistar Co.
Tatung System Technologies Co.

Vacuum system

Anson E&M Co.
Dingyeishen Machinery Co.
Feiyie Machinery Co.
Fukei Industrial Co.
Hung Kang Steel Tube Co.
Huiming Enterprise Co.
Licheng Precision Co.
Laser-Station, Inc.
Lung Ming Enterprise Co.
Pemo Precision Co.
Quinde Industrial Co.
Roncheng Vacuum
Sengxin Precision Industrial Co.
Shentin Industrial Co.
Tailien Aluminum
VINNO Technologies Co.
Wave Power
Xingguan Industrial Co.

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