Year	2019	2020	2021	2022
Construction of hutch and utilities				
Design, assembly and installation of optics, vacuum components				
Design, assembly and installation of CUT18				
Installation of DCM				
Installation of mirrors (FM, VFM, HFM)				
Commissioning of beamline				
Commissioning of ES2, open to users				
Commissioning of ES1, open to users				
Commissioning of ES2 at TPS 09A2, open to users				

Fig. 4: Construction schedule of **TPS 15A**.

TPS 15A is currently under construction; the schedule appears in **Fig. 4**. The construction of a radiation safety hutch was completed at the end of 2019. In 2020, the main construction will focus on the beamline optical components and utilities. The entire beamline is expected to be commissioned at the beginning of 2022. (Reported by Lai-Chin Wu)

Soft X-ray Nano-Spectroscopy for Advanced Material Sciences

Symmetry is one of the most general and fundamental concepts in physics, yet sometimes what novelty needs is to break it. Take two-dimensional (2D) materials as an example, their reduced size and broken symmetry have led to many exotic properties. To unravel the electronic origins of these emergent properties, however, conventional spectroscopy along with microscopy is better, allowing the location and dimension of the specimen can be taken into account.

Beamline **TPS 27A** hosts two soft X-ray microscopy stations; a scanning transmission X-ray microscopy (STXM) station at the A1 branch and a photoelectron related imaging and nano-spectroscopy (PRINS) station at the A2 branch. The photon source powering **TPS 27A** is a four-meter long elliptically polarized undulator (EPU) with a

(a) (b)

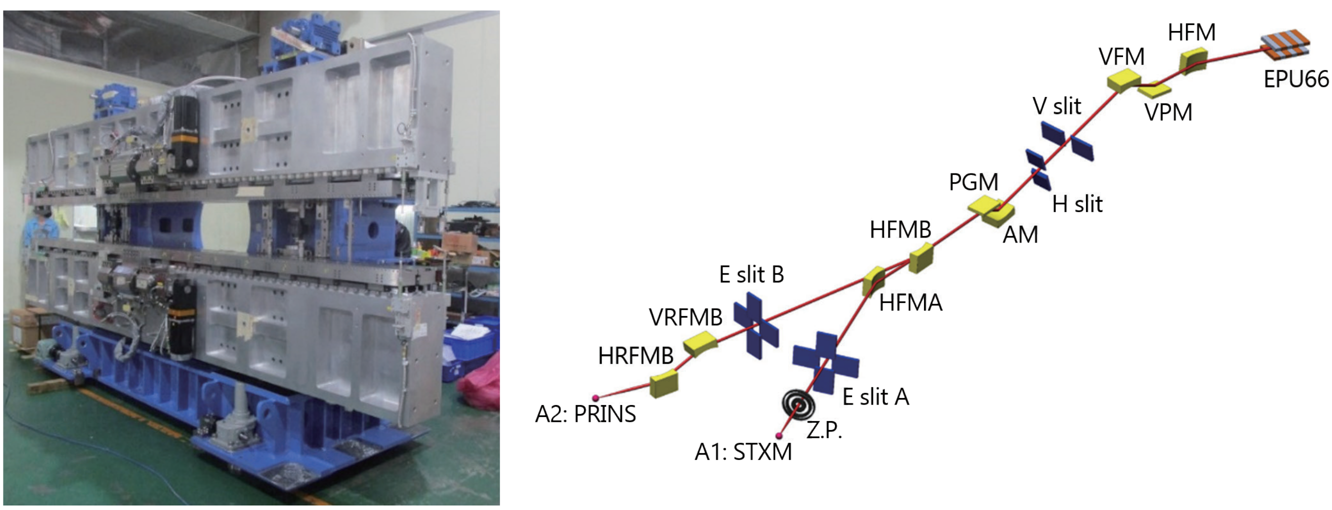

Fig. 1: (a) Mechanical frame of EPU 66. (b) Optical layout of **TPS 27A** soft X-ray nano-spectroscopy beamline.

magnetic period of 66 mm. **Figure 1(a)** shows the mechanical frame of EPU delivered to NSRRC recently. After going through an in-house designed active-mirror plane grating monochromator (AM-PGM), the photons reach A1/A2 branch at an estimated flux of 3 x 10^{12} ph/s before the zone plate (for STXM) and 1 x 10^{12} ph/s at the focal point of Kirkpatrick-Baez mirror (for PRINS), respectively. **Figure 1(b)** is the optical layout of **TPS 27A**.

STXM located at **TPS 27A1** is an in-house designed, with the constructed microscope developed jointly by Way-Faung Pong at Tamkang University (TKU) and NSRRC scientists. The microscope is assembled inside a chamber made of 304 stainless steel for UHV compatibility. All of the components, including the stepping/piezo motors, mechanical supports, and adaptors, are carefully chosen for their UHV compatible as well. The initial test has shown that the microscope can easily reach a pressure of 5 x 10^{-7} Torr without baking. For experiments that need no UHV, the chamber will be filled with He gas to ensure the photon and thermal stability during measurements. The key components inside the STXM chamber are shown in **Fig. 2(a)** which includes the vacuum window, zone plate (ZP) optics, stepping/piezo motors, sample stage, photomultiplier, and laser interferometers. During the raster scan, the sample position is feedback controlled by the laser interferometers monitoring the displacements between ZP and sample in V and H directions. In addition, due to the nature of multitasking during image acquisition, we have a field-programmable gate array (FPGA) board to control the timing, data counting, triggering and shutter voltage in the STXM. **Figure 2(b)** is the first X-ray image taken by the STXM during its commission in November 2019 at **TLS 08B1**. The test sample is a Cu 1000 mesh with a hole and the bar measuring 19 x 19 mm^2 and a width of 6 mm, respectively.

The PRINS station hosted at **TPS 27A2** is a microscope based on photoelectron related imaging and spectroscopy techniques. With an imaging type electron column integrated with a hemispherical electron energy analyzer and an imaging spin filter, the microscope is able to conduct full-field imaging by collecting photoelectron in either real-space or momentum-space with spin contrast. The concept of the working principle and chamber geometry of the PRINS station is shown in **Fig. 3**. Spin-resolved images are recorded by introducing a spin polarizing mirror into the electron optical path after the energy analyzer. Spin contrast is obtained due to the spin-dependent reflectivity of low energy electrons at the non-magnetic surface of the scattering target, which is an Au passivated Ir(100) surface. Taking advantage of the EPU photon source, *i.e.* the energy and polarization of the X-ray are both tunable, the PRINS microscope has multiple capabilities, such as (1) XAS or X-ray magnetic circular dichroism (XMCD)-based real-space imaging to obtain element-resolved mapping or spin-texture information, (2) XPS-based real- and *k*-space imaging to obtain spatially-resolved chemical state mapping and band-structure imaging, (3) spin-resolved band structure measurement when the imaging spin filter is introduced, and (4) micro-area spectroscopy (XAS and XPS) and angle-resolved photoelectron spectroscopy (ARPES) extracted from a series of images measured at different kinetic energies of the electrons. The microscope including a liquid helium-cooled sample

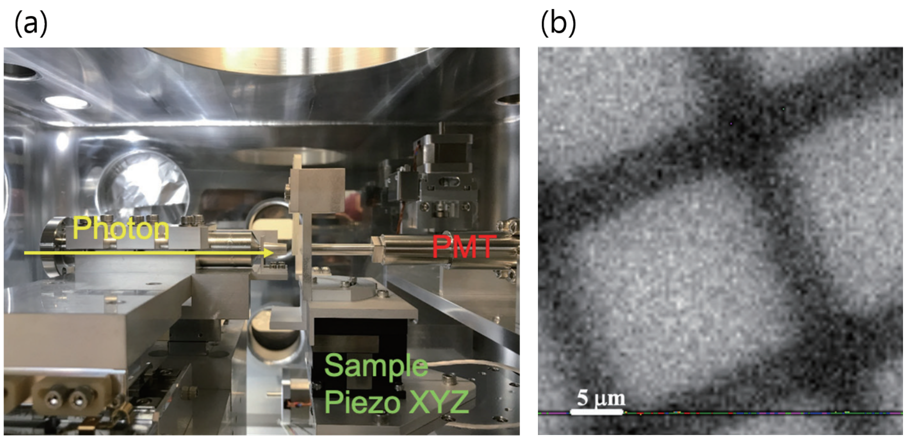

Fig. 2: (a) Major components inside the STXM. (b) First STXM image recorded at **TLS 08B1**.

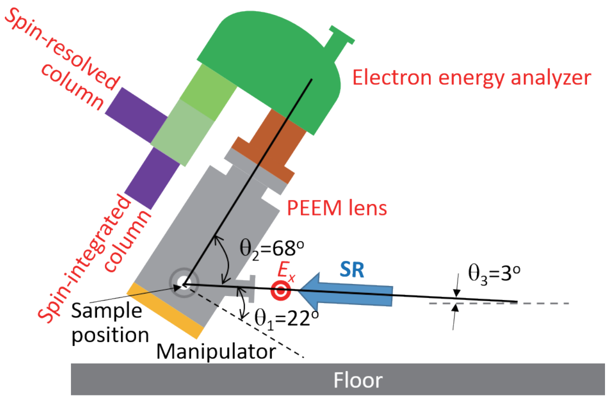

Fig. 3: Working principle of the photoelectron related imaging and nano-spectroscopy (PRINS) station.

manipulator, imaging spin filter system, two UV light sources (mercury and helium), and the main UHV-chamber. The microscope is expected to arrive at NSRRC in December 2020.

In summary, **TPS 27A** is scheduled to start its commission in September 2020 after the completion of the beamline optics and EPU 66 installation. Both microscopy stations are to routinely record the images at a few 10's nm spatial resolution and the soft X-ray spectrum from a sub-micrometer area. With STXM's flexibility in sample manipulation and PRINS's diversity in image contrast, the **TPS 27A** soft X-ray nano-spectroscopy beamline will be a new platform bringing innovation and breakthrough to the material sciences. (Reported by Hung-Wei Shiu, Tzu-Hung Chuang, and Der-Hsin Wei)

nanoARPES Beamline

Angle-resolved photoemission spectra (ARPES) have emerged as a cardinal experimental tool to elucidate the emergence of many interesting physical properties in advanced materials, because of their unique capability to probe directly their momentum-resolved electronic structures. It allows the researchers not only to map the band dispersion and Fermi surface topology but also to understand comprehensively complicated phenomena dependent on momentum and energy in advanced materials. A central challenge in condensed-matter physics is to investigate the many-body systems in which strong interactions lead to novel ordered ground states. Examples include complex oxides, graphene-based materials, transition-metal dichalcogenides (TMD), topological insulators (TI), unconventional superconductors *etc*. These materials typically contain, however, domains or structural patterns or chemical inhomogeneities due to spontaneous phase separation or dopant or defect segregation or sample-surface mosaicity. The sizes of most such new crystals and thin films are generally smaller than several tens of micrometres. For even a crystal of millimeter size, its homogeneity is still a crucial issue. The small size of a beam spot might provide a chance to probe the electronic structure of these samples that consist of small domains. This proposal calls for the construction of a high-resolution and high-flux nanofocusing ARPES beamline.

Table 2: Parameters of VLS gratings

Energy range (eV)	20–200	50–650
N_0 (l mm^{-1})	600	1200
2θ (°)	155	160

The designs of a focusing optical system at nanoARPES beamline **TPS 39A** based on Kirkpatrick-Baez (KB) mirrors and zone-plate techniques, and of a new end station with a scanner stage, aim to enable high-resolution ARPES on a micrometre and nanometre scale. At **TPS 39A,** an elliptically polarized undulator (EPU) of period length 168 mm serves as a photon source. The operational photon energy is from 20 to 650 eV, which covers most of the VUV and soft X-ray photon energy range. The source parameters of EPU168 are listed in **Table 1**. **Figure 1** shows the optical layout of **TPS 39A**. The total length of the nanoARPES beamline is about 45 m from the center of the undulator to the hallway. An active- mirror plane-grating monochromator (AM-PGM) of a novel type developed at NSRRC is applied to increase the energy-resolving power across all photon energies. The idea originates from setting a bendable optic in front of a grating to expand the footprint of the incident beam on the grating. An increased coverage of the ruling number of the grating can increase the energy-resolving power. Also, a design of a bendable mirror can cor-

Table 1: Specifications of EPU168

Mode	Magnetic field (T)	K	E1st	Partial power within 4.4 sigma (kW)	Partial power on B1 chamber Miss steering 2 mm/0.2 mrad (W)
Horizontal linear	$B_y \leq 0.516$	$K_y \leq 8.1$	≥ 15	0.568	~0
Circular	$B_y = B_x \leq 0.223$	$K_y = K_x \leq 3.5$	≥ 39	~0	40/16
Vertical linear	$B_x \leq 0.223$	$K_x \leq 3.5$	≥ 72	0.237	3.6/2