

Current Status of TPS 39A NanoARPES Beamline

The investigation of emergent quantum materials provides a foundation to develop new technology. The novel phenomena from these materials including electrical, optical and magnetic properties provide opportunities for the development of quantum computing, energy storage, catalysis, etc. In the early stage of material discovery, the insight of electronic structure can give clues to shorten the period of development. To probe the band structure of novel materials, angle-resolved photoemission spectroscopy (ARPES) has emerged as a cardinal experimental tool to elucidate the emergence of many interesting physical properties in advanced materials, due to its unique capability to probe directly their momentum-resolved electronic structures. It allows researchers not only to map out the band dispersion and Fermi surface topology but also to understand comprehensively momentum- and energy-dependent complicated phenomena in advanced materials. A central challenge in condensed-matter physics is to investigate further the many-body systems in which strong interactions lead to novel ordered ground states. Examples include high- T_c superconductors, complex oxides, graphene-based materials, 2D materials, transition-metal dichalcogenides, topological insulators, unconventional superconductors, heavy Fermion materials, Dirac semimetal and Weyl semimetals, etc.

A plan of a novel nanoARPES beamline was approved in 2017. Two separate branches with different beam-focusing methods were planned to meet the research requests and to expand the scope of emergent quantum materials. A

micro-focusing μ ARPES branch (**TPS 39A1**) supported by Taiwan Consortium of Emergent Crystalline Materials and the NSRRC was constructed first; another construction plan of a nano-focusing ARPES beamline (**TPS 39A2**) was also begun in 2019. The design of focusing optical systems at **TPS 39A** nanoARPES beamline was based on Kirkpatrick-Baez (K-B) mirrors and zone-plate techniques; a new endstation with a scanner stage aimed to enable a high-resolution ARPES at the micrometer and nanometer scale. The monochromator type is the active mirror-plane grating monochromator (AM-PGM), which was developed by the NSRRC. The novel AM-PGM design can deliver high energy resolution, high photon flux and a wider photon energy range. After the monochromator, the K-B mirrors focusing method was used at **TPS 39A1** μ ARPES branch to achieve the design goal of a minimum spot size about 10 μm ; the zone plate focusing method was used at **TPS 39A2** nanoARPES branch to focus the beam spot size down to 100 nm.

An elliptically polarized undulator (EPU) of period length 168 mm was used as a photon source. The operating photon energy is from 20 to 650 eV to cover most VUV and soft X-ray photon energy range. The insertion device of EPU168 was installed in November 2020. Owing to a pandemic of COVID-19, shipment of several beamline optics was delayed to the NSRRC, but most construction work was still on track. The beamline optics in a hutch before the monochromator were installed completely. The active mirror-plane grating monochromator is still under

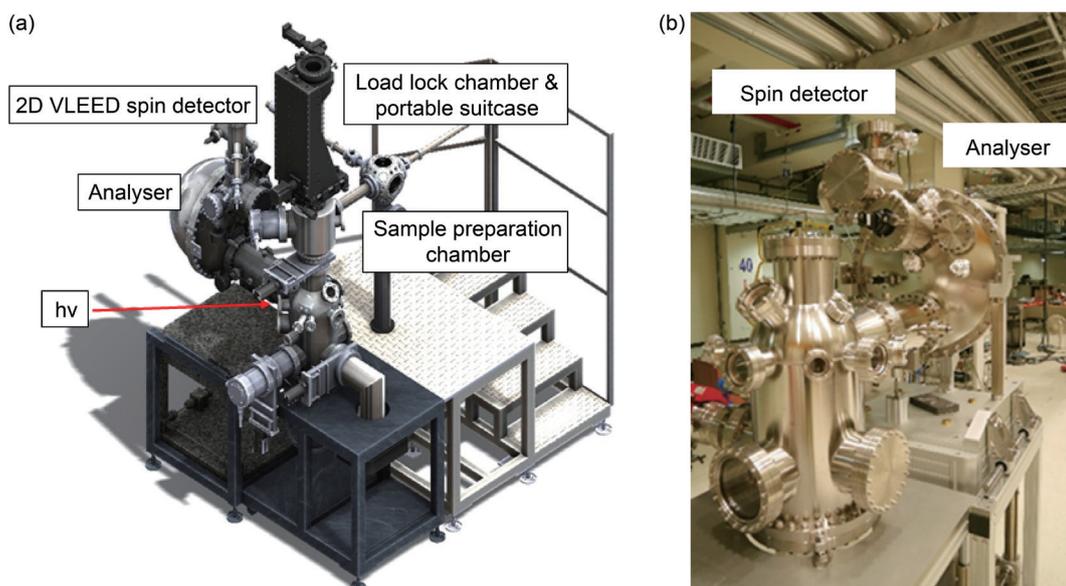


Fig. 1: (a) Design of reshaped endstation TPS 39A1 μ ARPES. (b) Assembled endstation TPS 39A1 μ ARPES.

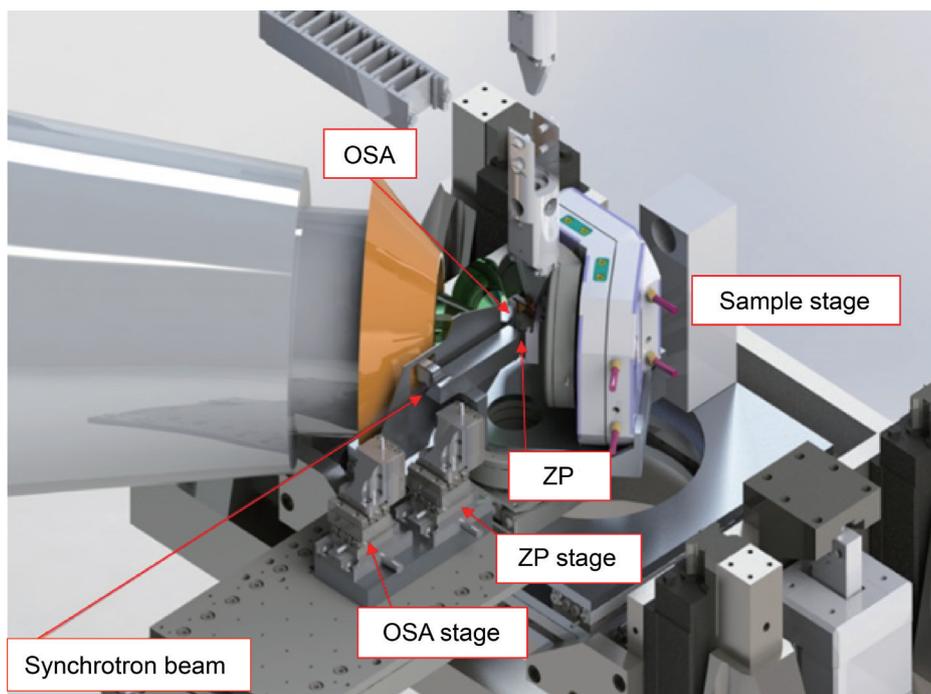


Fig. 2: Design of zone plate, OSA and sample stages in nanoARPES branch.

test and will be installed on site in March 2022. In addition, a safety interlock system was set up in December 2021. All beamline optics will be installed in April 2022 for a further commissioning stage.

The construction work of **TPS 39A1** μ ARPES branch was led by Den-Sung Lin (National Tsing Hua University) and NSRRC teams. The endstation was assembled in early 2018 and test began at the end of 2018. Because the μ ARPES endstation was constructed earlier than the beamline construction and there was a serious delay of shipment of beamline optics, a reshaped work of the μ ARPES endstation was carried out to optimize the experimental efficiency. The major concepts of reshaped μ ARPES endstation should obey safety guidelines, but also maintain high efficiency in taking data. The design of the reshaped endstation was completed in April 2021. **Figure 1(a)** displays the design of the reshaped μ ARPES endstation, located at port 39 of the TPS. A 2D-VLEED spin detector was equipped with the endstation for spin-resolved ARPES. A Scienta DA30L energy analyser with deflection mode and a six-axis low-temperature manipulator developed by the NSRRC can satisfy effectively the request of Fermi-surface mapping. A large area platform with a solid guard rail can avoid

possible accident effectively during experiments. The reshaped μ ARPES endstation was assembled in November 2021, as shown in **Fig. 1(b)**. The overall system will be installed on site after completing beamline construction in April 2022. The commissioning work will be conducted after May 2022. The endstation will be partially opened to users at the end of 2022. This novel endstation can allow users to conduct spin-resolved ARPES and conventional ARPES in the near future.

For the **TPS 39A2** nanoARPES branch, the design of all scanning stages including zone plate, order-sorting aperture (OSA) and sample stage was finished in July 2020. **Figure 2** exhibits the final design of the whole system. All stages were delivered and assembly began in June 2021. The integration of motors and analyser will be completed in April 2022. The mu-metal chamber was shipped to NSRRC in December 2021. The functional test of zone plate stages will be done in June 2022. The assembly of the entire system including chamber, analyser and all stages will be done in August 2022.