counting detector—EIGER 2X CdTe 1M. This setting allows the measurement of the full diffraction sphere up to very high resolution and avoids X-ray polarisation related issues.

The second endstation has additional X-ray optics that reduces the X-ray focussing down to 10 microns at sample position and can be further reduced by pinholes down to 2 microns. It is equipped with an ultra-precise horizontal kappa goniometer and a large-area photon counting detector—EIGER 2X CdTe 9M. This design allows to keep data completeness very high for fast and precise measurements.

The beamline is equipped with a wide variety of devices for the control of samples environment, allowing advanced analysis of materials properties under various conditions. Measurements can be performed at very low temperatures (down to 4 K), high temperatures (up to 400 K), and at high pressure (up to 20 GPa or higher, depending on the diamond culet size). Additionally, photo-excited state measurements can be achieved thanks to a solid-state laser (static excitation) or a femto-second laser (**15A2** only) for time-resolved ultra-fast measurements. The combination of measurements under controlled temperature, pressure, and photo excitation can also be done on demand.

The large combination of instrument capabilities and sample environments allow for a wide variety of possibilities for the investigation of structural properties of materials.

TPS 15A1 received its first X-ray in 2023; subsequently, after a period of tests and calibrations, it was possible to obtain the first crystal structure just before the end of 2023. The diffraction spots looks sharp (**Fig. 2(a)**); the reciprocal space is well ordered (**Fig. 2(b)**); and the crystal structure quality is very good (**Fig. 2(c)**).

The data collection strategy still requires further optimization to reach full completeness as well as appropriate redundancy. The installation of low-temperature devices will further improve the quality as well. Further development of **15A1** will include the installation of a fully automated goniometer head to reduce the crystal centering time. Tests will be performed to use it in combination with a deep learning algorithm to fully automate the crystal centering process. Additionally, a robotic arm will be installed to fully automate the crystal mounting/unmounting process, with the aim to have **15A1** fully automated. Data processing performance tests will also be performed and automated to the best of possibilities. **TPS 15A2** is still under construction and should start the commissioning process by mid-2024. (Reported by Arnaud Grosjean and Lai-Chin Wu)

Reference

1. L.-C. Wu, J.-J. Lee, S.-H. Chang, M.-H. Lee, B.-Y. Liao, AIP Conf. Proc. **2054**, 060029 (2019).

Advancements in the NanoARPES Beamline for Investigating Emergent Quantum Materials

The exploration of emergent quantum materials serves as a critical foundation for technological innovation. This article examines the significance of investigating electronic structures in these materials, presenting opportunities for advancements in electrical, optical, and magnetic properties, with implications for quantum computing, energy storage, catalysis, and more. Additionally, the role of angle-resolved photoemission spectroscopy (ARPES) is highlighted as a crucial tool for probing the band structure of novel materials. In the initial stages of material discovery, insights into electronic structures provide valuable clues to expedite development. ARPES, with its unique capability to directly probe momentum-resolved electronic structures, facilitates the mapping of band dispersion and Fermi surface topology. Moreover, it enables a comprehensive understanding of momentum- and energy-dependent phenomena in advanced materials. A central challenge in condensed-matter physics lies in investigating many-body systems where strong interactions lead to novel ordered ground states. Examples encompass a diverse range of materials, including high-Tc superconductors, complex oxides, graphene-based materials, 2D materials, transition-metal dichalcogenides, topological insulators, unconventional superconductors, heavy Fermion materials, Dirac semimetals, and Weyl semimetals.

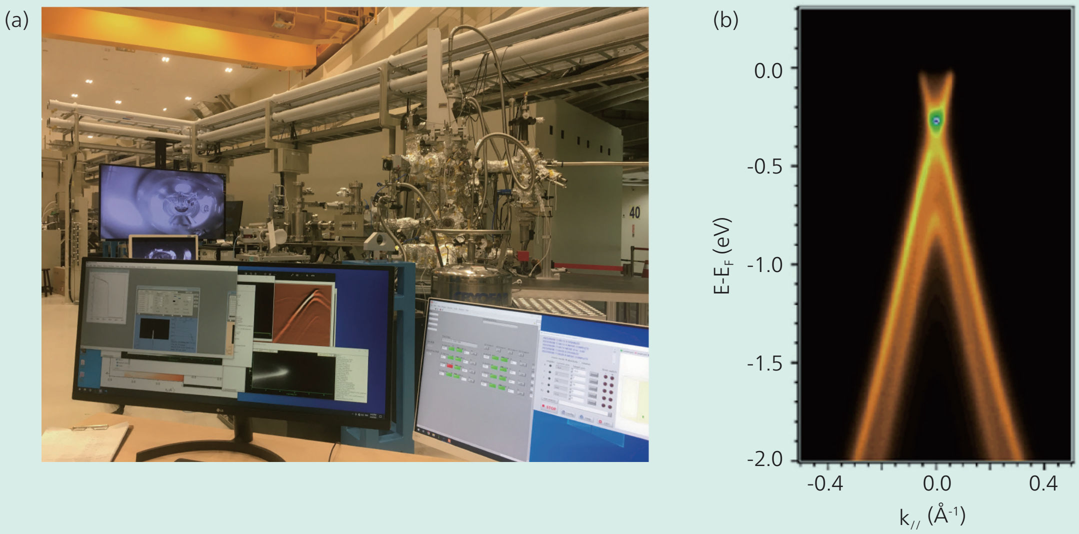
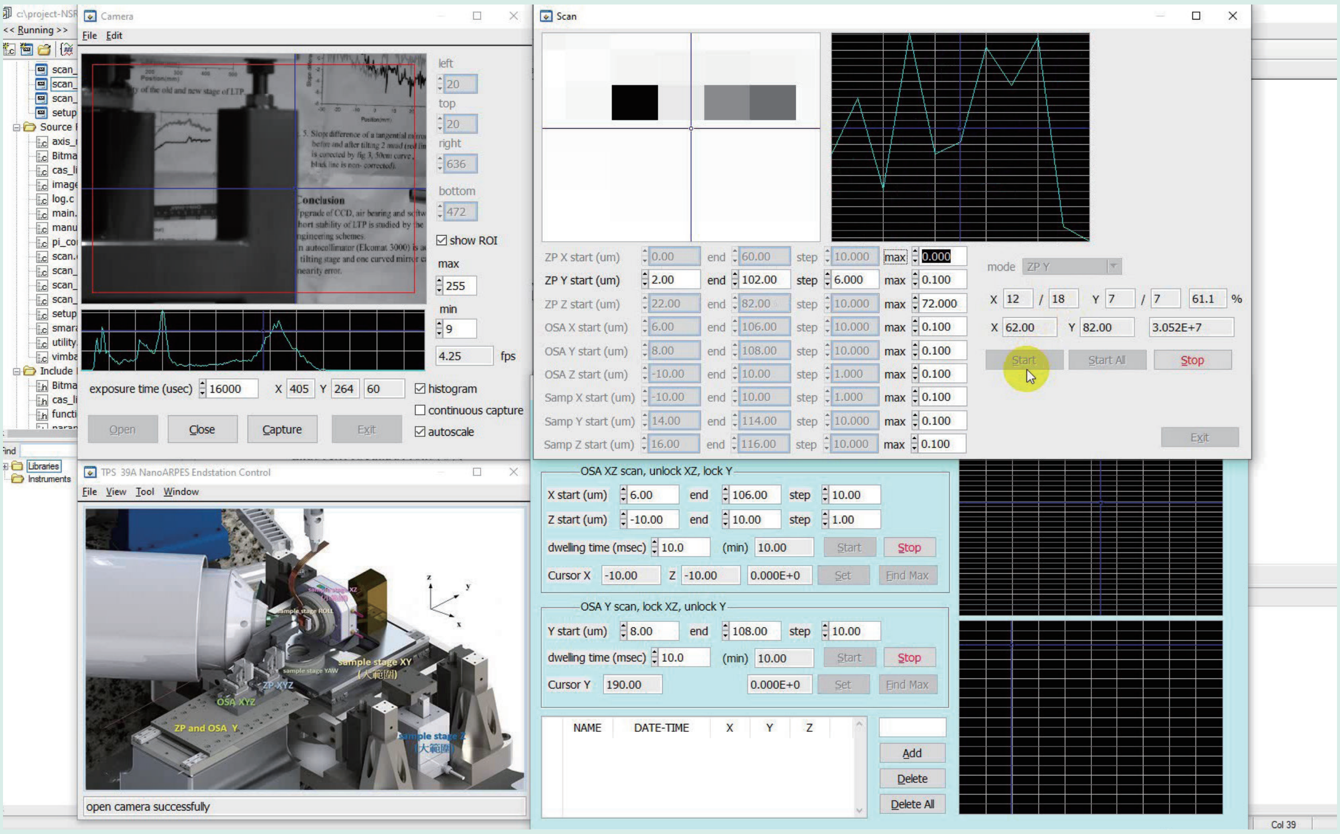


Fig. 1: (a) The endstation of **TPS 39A1** μARPES. (b) The band structure of bilayer graphene prepared on Si-terminated SiC substrate recorded at the **TPS 39A1** μARPES branch.



left 20
top 20
right 636
bottom 472
☑ show ROI
max 255
min 9
4.25 fps
exposure time (usec) 16000 X 405 Y 264 60
☑ histogram
☐ continuous capture
☑ autoscale

open camera successfully

ZP X start (um)	0.00	end	60.00	step	10.000	max	0.000
ZP Y start (um)	2.00	end	102.00	step	6.000	max	0.100
ZP Z start (um)	22.00	end	82.00	step	10.000	max	72.000
OSA X start (um)	6.00	end	106.00	step	10.000	max	0.100
OSA Y start (um)	8.00	end	108.00	step	10.000	max	0.100
OSA Z start (um)	-10.00	end	10.00	step	1.000	max	0.100
Samp X start (um)	-10.00	end	10.00	step	1.000	max	0.100
Samp Y start (um)	14.00	end	114.00	step	10.000	max	0.100
Samp Z start (um)	16.00	end	116.00	step	10.000	max	0.100

mode ZP Y
X 12 / 18 Y 7 / 7 61.1 %
X 62.00 Y 82.00 3.052E+7

OSA XZ scan, unlock XZ, lock Y
X start (um) 6.00 end 106.00 step 10.00
Z start (um) -10.00 end 10.00 step 1.00
dwelling time (msec) 10.0 (min) 10.00
Cursor X -10.00 Z -10.00 0.000E+0

OSA Y scan, lock XZ, unlock Y
Y start (um) 8.00 end 108.00 step 10.00
dwelling time (msec) 10.0 (min) 10.00
Cursor Y 190.00 0.000E+0

NAME	DATE-TIME	X	Y	Z

Fig. 2: The operation interface of the entire system at **TPS 39A2** nanoARPES branch.

In 2017, the approval of a novel nanoARPES beamline marked a significant step forward. Two branches, each employing different beam-focusing methods, were conceptualized to cater to research needs and broaden the scope of emergent quantum materials. The micro-focusing μARPES branch (**TPS 39A1**) was constructed first, supported by the Taiwan Consortium of Emergent Crystalline Materials and the NSRRC. Simultaneously, plans for a nano-focusing ARPES beamline (**TPS 39A2**) were initiated in 2019. The design of the **TPS 39A** nanoARPES beamline's focusing optical systems relied on Kirkpatrick–Baez (KB) mirrors and zone-plate techniques. A new endstation with a scanner stage aimed to enable high-resolution ARPES at the micrometer and nanometer scale. The monochromator type, an active mirror–plane grating monochromator (AM–PGM), was developed by the NSRRC to ensure high energy resolution, photon flux, and a broader photon energy range. Distinct focusing methods were employed for the two branches, achieving spot sizes of 10 μm for **TPS 39A1** and 100 nm for **TPS 39A2**.

Led by Den-Sung Lin from National Tsing Hua University and NSRRC teams, the construction of the **TPS 39A1** μARPES branch was completed in early 2018. Due to delays in beamline optics shipment, restructured work on the μARPES endstation was conducted in 2021 to optimize experimental efficiency. The first synchrotron beam was achieved for beamline commissioning by the end of 2022. An elliptically polarized undulator of a 168 mm period served as the photon source, covering the vacuum ultraviolet and soft X-ray photon energy range. Despite COVID-19-related delays in beamline optics shipment, construction work remained on track. The AM–PGM underwent testing and was installed on-site in March 2022. A safety interlock system was established in December 2021, and all beamline optics were installed in April 2022 for the commissioning stage. Leveraging the advantages of bendable optics developed by the NSRRC, the incident synchrotron beam size can be precisely focused down to 20 μm with fully opened slits. This capability enables us to achieve ultrahigh energy resolution for individual photon energy. A comprehensive table detailing photon energy versus undulator gap was established during the commissioning stage. We extend an invitation to potential users to actively participate in ARPES experiments and encourage them to provide valuable feedback for optimizing the performance of the endstation. **Figure 1** displays the excellent resolution band structure of bilayer graphene obtained at the **TPS 39A1** μARPES branch. With these advancements, this novel endstation is poised to facilitate users in conducting both spin-resolved ARPES and conventional ARPES in the near future.

For the **TPS 39A2** nanoARPES branch, the design of scanning stages, including zone plate, order-sorting aperture, and sample stage, was completed in July 2020. **Figure 2** illustrates the operation interface of the entire system. Assembly commenced in June 2021, with motor and analyzer integration scheduled for April 2022. The μ-metal chamber was shipped to the NSRRC in December 2021, and functional tests of the zone plate stages are planned for June 2022. Full system assembly, including chamber, analyzer, and all stages, is anticipated to be conducted in April 2024, with commissioning expected to begin before the middle of 2024.

The advancements in nanoARPES beamline facilities presented in this article underscore the ongoing commitment to unraveling the mysteries of emergent quantum materials. These developments hold significant promise for the future of condensed-matter physics and materials science, offering researchers and potential users the tools to conduct cutting-edge experiments, including spin-resolved ARPES and conventional ARPES, in the near future. (Reported by Cheng-Maw Cheng)