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Division of Condensed Matter Physics
Association of Asia Pacific Physical Societies

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Division of Condensed Matter Physics
Association of Asia-Pacific Physical Societies

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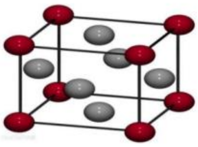

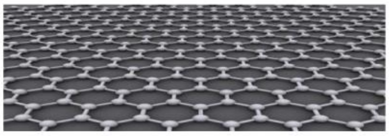

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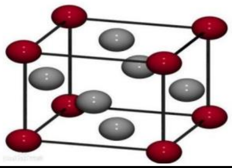
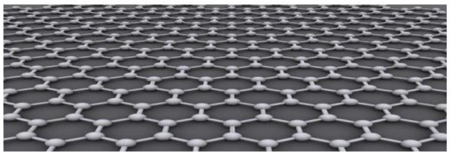




Chair message

Let us meet in AC2MP

The condensed matter division organizes annual meetings. In 2021, it was held in an online format and, in 2022, it was held in Sendai, Japan in onsite-online hybrid format. This year, the AC2MP2023-Asia-Pacific Conference in Condensed Matter Physics has been held in Hualien, Taiwan from 26 to 29 November entirely as on-site format. It is very impressive to think of how the division has struggled to overcome the difficulty of the covid-19 pandemic.

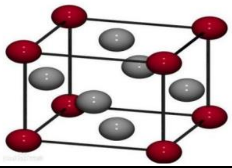
The program of the conference is available on the website: https://ac2mp2023hualien.ps-taiwan.org and you can see the distinguished speakers including 3 plenary speakers. You may enjoy the broadcasting of the conference talks. Moreover, participants have enjoyed coming back to the traditional style of in-person conference attendance including excursions and dinners.

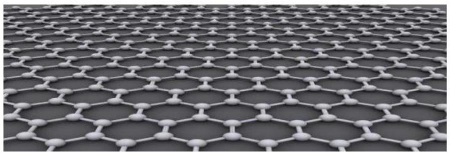
The year 2023 is the year that the international academic exchange shows full recovery and many of you have participated in different conferences and enjoyed the conversation with old and new friends. Despite your busy schedule, I strongly recommend you join us in the annual meeting, AC2MP. As you may know, more than half of condensed matter physicists are working in the Asia-Pacific area and it is the most developing center of science. There are lots of new results created day by day.

I believe that the AC2MP will be the 1st choice for newcomers of this fields such as students and postdoc fellows to participate in the international exchanges and collaborations. The experience to hear the excellent lectures and to talk with established researchers and talented young researchers from different areas and different disciplines would strongly stimulate your ideas. It will be the flash point for new concepts and will be the starting point for new international collaborations. I still remember my first short talk in a neutron scattering conference in Oxford when I was in my late 20s. Not only the exchange and discussion on science but chats in pubs were also so important to meet with new friends and collaborators. It created the important treasure continuing to the present data in my research life. At that time, I had to travel a long distance to join the international conference. Now, you can reach the AC2MP in only a few hours travel. Please use this chance to join the international research community. We are planning to hold AC2MP2024 in India and AC2MP2025 in China.

To stimulate the participations of young researchers, the DCMP is planning to launch the division award for young scientists. Our plan is that the annual meeting of the DCMP will be the place for the presentation for the finalist of the award applicants or the opportunities for presentations for awardees. It makes another reason to come to AC2MP. Finally, I would like to ask readers to join the DCMP, if you are not a member. Also please recommend DCMP for your colleagues – it is free to join! Let us meet in AC2MP every year.

Professor Hiroyuki Nojiri (Chair)
Institute for Material Research, Tohoku University





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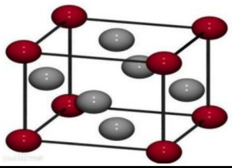
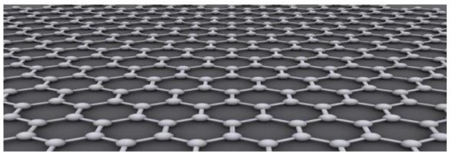




Large facilities/institute/organization reports

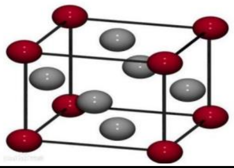
Report 1:

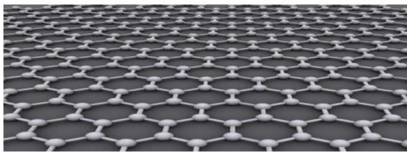
National Synchrotron Radiation Research Center (NSRRC), Hsinchu, Taiwan

Jung-An Liu and Stella Su

Overview

Situated within the Hsinchu Science Park in Taiwan, the National Synchrotron Radiation Research Center (NSRRC) aims to produce intense, reliable and high-quality X-rays—a capability beyond the scope of conventional laboratories. This remarkable feature attracts users from the global academic and technological communities to engage with the NSRRC. Operating as a prominent international facility for thirty years, the NSRRC caters to a diverse user base, both domestically and internationally. Its dynamic applications have facilitated significant progress in physics, chemistry, biology, soft matter, materials science, energy, environmental sciences, as well as earth and planetary sciences.





Today, the NSRRC accommodates two synchrotron storage rings, namely the Taiwan Light Source (TLS) and the Taiwan Photon Source (TPS), offering users access to 36 beamlines. Additionally, it operates two beamlines at SPring-8 in Japan, and a neutron instrument at ANSTO in Australia. In its entirety, the NSRRC stands as the largest user facility in Taiwan, providing quantum beams for scientific research and fostering industrial innovations.

Taiwan Beamlines at SPring-8, Japan

As a successful example of international collaboration between Taiwan and Japan, the Taiwan Beamlines Project at SPring-8 initiated the construction of two hard X-ray beamlines in 1998. The first beamline, SP 12B1, welcomed users in 2001, initially concentrating on materials science spectroscopy and later broadening its scope to include protein crystallography in 2002. The second beamline, SP 12U1, specializing in inelastic X-ray scattering, became accessible to users in 2003. In 2013, it expanded its capabilities to include hard X-ray photoemission spectroscopy (HAXPES). As it seamlessly entered its second decade, the Taiwan Beamlines Project at SPring-8 underwent its inaugural 10-year review in 2010, commending the project's successful task execution and paving the way for its subsequent phase. The project's noteworthy contributions to photon science at SPring-8 undoubtedly played a pivotal role in shaping the conception of the TPS.

Neutron Instrument at ANSTO, Australia

In addition to collaborations in synchrotron facilities, Taiwan and Australia established a partnership in 2005 to develop a cold neutron triple-axis spectrometer named SIKA at the Australian Nuclear Science and Technology Organisation (ANSTO). Located at ANSTO's Open Pool Australian Light (OPAL) water reactor, SIKA operates at 20 MW and was constructed by Taiwan’s National Central University. Upon the completion of construction, the NSRRC was entrusted with the responsibility of operating SIKA and promoting neutron science in Taiwan. In 2013, the NSRRC assumed full responsibility for SIKA’s commissioning, formally inaugurating its office at ANSTO.

From TLS to TPS

Construction on the TLS began in 1986, and it achieved its first electron beam storage, becoming operational for users in 1993. In response to rapidly evolving international scientific landscape and the demand for intense X-rays to support complex experiments, a mission emerged to ensure that Taiwan's scientific community and high-tech industry stay at the forefront innovation. This led to the transformation of the synchrotron-based light source with the addition of the TPS to the TLS.

Following a thorough evaluation with substantial input from our user community, the decision to launch the TPS project was formally endorsed during a board meeting held in July 2004. This ambitious endeavor aimed to establish an advanced, low-emittance synchrotron light source on the NSRRC campus. The TPS features a circular design spanning 518 meters and boasts an electron beam with an impressive energy level of 3 GeV. Civil construction on the TPS began in February 2010 and concluded by the end of 2013, as illustrated in **Figure 1**.

Figure 1: An aerial view of the NSRRC site

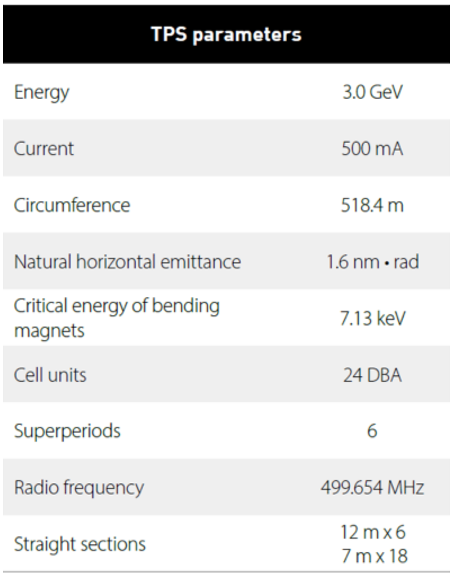
The First Synchrotron Light

On December 31, 2014, a significant milestone was reached as the TPS storage ring generated its first synchrotron light at the designed energy level of 3 GeV, as depicted in **Figure 2**. This achievement set a worldwide benchmark for the fastest commissioning of a modern accelerator light source. It underscores the exceptional quality of the accelerator system design, the rigorous standards upheld within the subsystems, and the excellent craftsmanship of its components.

Figure 2: The first synchrotron light from TPS

TPS Parameters

The enhancements in brilliance achieved with the TPS compared to those of the TLS are nothing short of remarkable, boasting an improvement of 3 to 4 orders of magnitude. The TPS ring parameters are listed in **Table 1** and details about its brilliance and flux can be found in **Figure**



TPS parameters	
Energy	3.0 GeV
Current	500 mA
Circumference	518.4 m
Natural horizontal emittance	1.6 nm • rad
Critical energy of bending magnets	7.13 keV
Cell units	24 DBA
Superperiods	6
Radio frequency	499.654 MHz
Straight sections	12 m x 6 7 m x 18

Table 1: The TPS ring parameters

3.

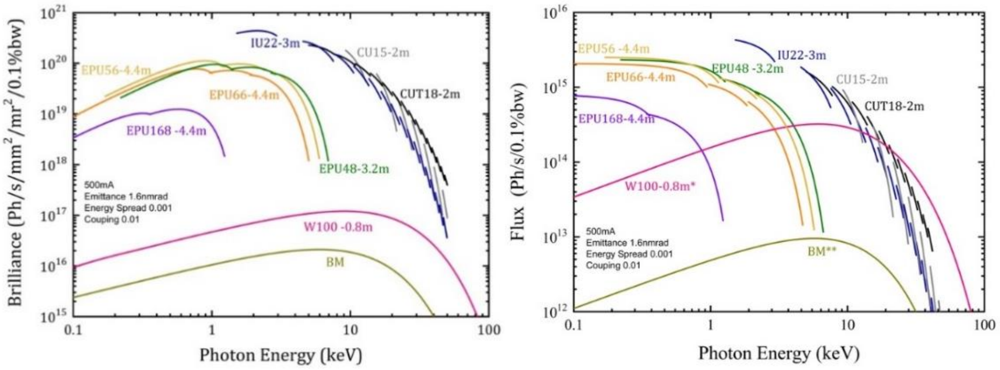


Figure 3: The TPS brilliance and flux

Three Phases of TPS Beamline Construction

Due to the sophisticated and specialized features of each beamline and endstation designed for diverse functions, the construction of these beamlines is organized into three distinct phases, aligning with approved budgets and personnel allocation outlined in the predetermined schedule.

The Phase-I beamlines were designed to pioneer frontier synchrotron radiation techniques, pushing the boundaries of scientific exploration beyond what was achievable with the TLS. These techniques include protein micro-crystallography, coherent X-ray diffraction/scattering, X-ray nanofocusing beamlines, and soft X-ray scattering and spectroscopy. All seven of these beamlines are now fully operational and open to users.

To maximize the unique features and unlock the complete potential of the TPS, NSRRC presented a proposal in 2016 to develop nine Phase-II beamlines. These beamlines incorporate advanced techniques such as X-ray imaging, nanoscopy, high-resolution diffraction and high energy-resolution spectroscopy to drive innovative science at TPS. The Phase-II beamlines also prioritize powerful techniques for studies in biomedical imaging, green energy and nano-devices. The plan includes six undulator-driven beamlines and three bending magnet-based beamlines, with a primary focus on conducting groundbreaking scientific research and enabling a smooth transition from TLS to TPS. Most of these Phase-II beamlines are currently available to users or soon be operational. The floor map of TPS is shown in **Figure 4**.

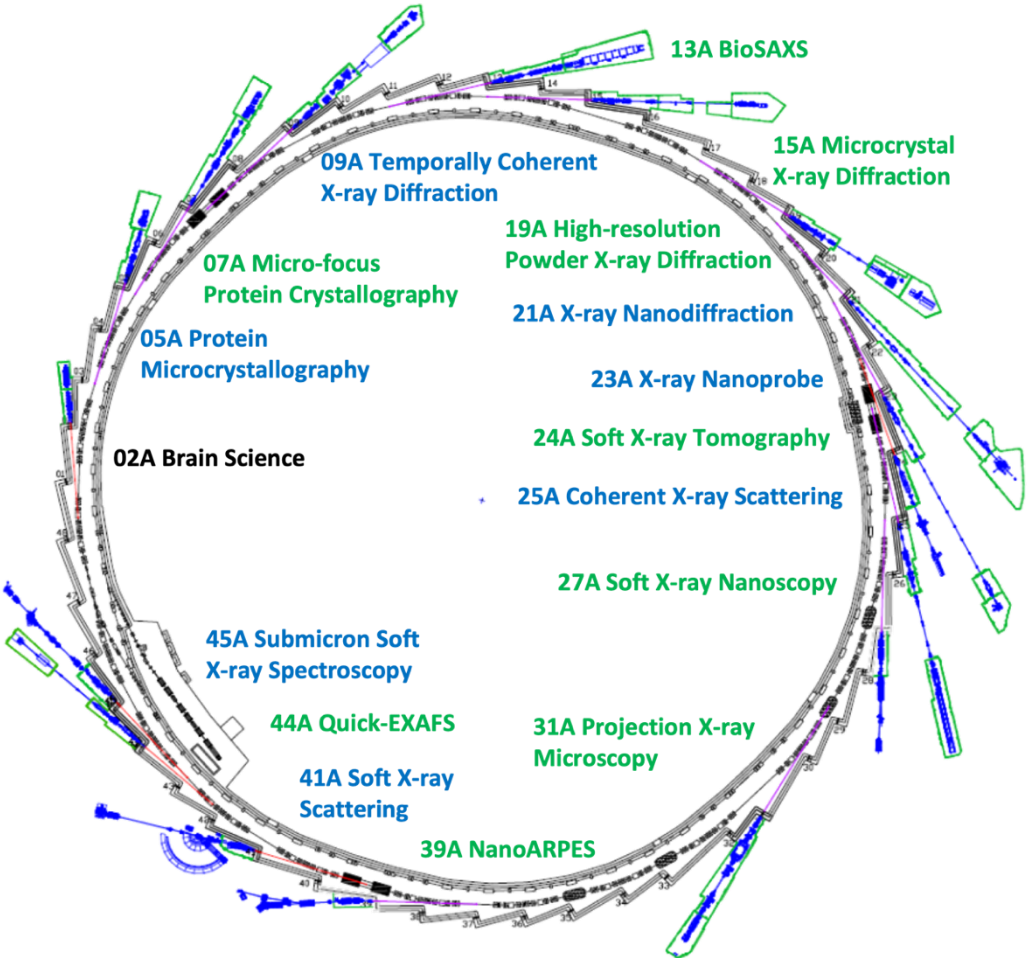
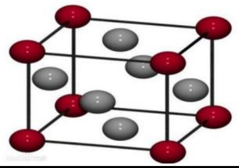
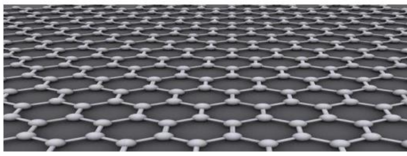


Figure 4: Current floor map of TPS beamline distribution

The initiation of the TPS Phase-III beamline project was officially announced in 2021, with planned activities extending through 2026. The construction of Phase-III beamline includes nice beamlines, featuring five insertion devices and four bending magnets. Among these nine beamlines, three are designated as soft X-ray beamlines, one as a tender beamline and the remaining five as hard X-ray beamlines. The primary objective of the phase-III beamline project is to transition the existing TLS beamlines to the TPS, ensuring continued user support and incorporating innovative technological advancements.

The TPS leverages various aspects of its light source to optimize the functionality of its experimental facilities, catering to a diverse range of scientific techniques. The beamlines of all three phases and their corresponding experimental techniques are summarized in **Table 2**.



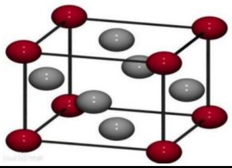


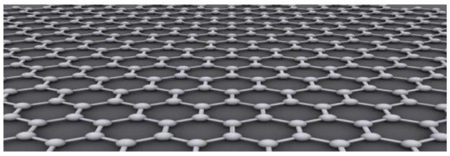
Phase	Beamline	Energy Range	Source		Experimental technique												
			Insertion devices	Bending magnet	Imaging					Scattering/ Diffraction		Spectroscopy					
					Coherent	Full-field	Scanning	Transmission	Non-Transmission	Diffraction	Scattering	XAS	XEOL	RIXS	PES	XRF	ARPES
I	05A Protein Microcrystallography	5.7 - 20 keV	IU22 x 1	-						•							
	09A Temporally Coherent X-ray Diffraction	5.6 - 25 keV	IU22 x 1	-						•	•						
	21A X-ray Nanodiffraction	6 - 28 keV	Tapered IU22 x 1	-			•	•	•	•	•	•	•			•	
	23A X-ray Nanoprobe	4 - 16 keV	IU22 x 1	-	•	•	•	•	•	•		•	•			•	
	25A Coherent X-ray Scattering	5.5 - 20 keV	IU22 x 1	-	•					•	•						
	41A Soft X-ray Scattering	400 - 1,200 eV	EPU48 x 2	-	•		•	•	•	•	•	•		•			
	45A Submicron Soft X-ray Spectroscopy	280- 1,500 eV	EPU46 x 1	-								•	•	•	•		•
II	07A Micro-focus Protein Crystallography	5.7 - 20 keV	IU22 x 1	-						•							
	13A Biological Small-angle X-ray Scattering	4 - 23 keV	IU24 x 1	-						•	•						
	15A Micro-crystal X-ray Diffraction	9 - 35 keV	Tapered CU18 x 1	-						•	•						•
	19A High-resolution Powder X-ray Diffraction	10 - 40 keV	CU15 x 1	-						•							
	24A Soft X-ray Tomography	260- 2,600 eV	-	•		•		•				•					
	27A Soft X-ray Nanoscopy	90 - 3,000 eV	EPU66 x 1	-	•	•	•	•	•			•			•	•	
	31A Projection X-ray Microscopy	5 - 50 keV	W100 x 1	-		•						•					
	39A Nanometer Angle-resolved Photoemission Spectroscopy	20 - 650 eV	EPU168 x 1	-			•		•						•		•
	44A Quick-scanning X-ray Absorption Spectroscopy	4.5 - 34 keV	-	•			•					•				•	
PRT	02A Brain Imaging	4 - 25 keV	-	•		•											
III	20A Two-dimensional X-ray Diffraction	10 - 30 keV	-	•						•							
	35A Soft X-ray Absorption Spectroscopy	0.1 - 3 keV	EPU66	-								•				•	
	33A TBA	0.1 - 3 keV	EPU66 x 2	-								•					
	32A Tender X-ray Absorption Spectroscopy	1.7 - 11 keV	-	•								•			•	•	
	38A X-ray Absorption Spectroscopy	4.5 - 34 keV	-	•								•					
	43A Ambient Pressure/UHV X-ray Photoelectron Spectroscopy	0.2 - 3 keV	EPU56x 1	-								•			•		
	47A High-energy Resolution X-ray Spectroscopy	3.2 - 20 keV	Tapered IUT24 x 1	-								•			•		

Table 2: The experimental techniques corresponding to the three phases of beamlines

Vision

NSRRC remains devoted to its pursuit of becoming a world-class research facility and nurturing the growth of new generations of talented scientists. The collective efforts and unwavering commitment of NSRRC members consistently lead to ongoing enhancements, resulting in high-quality synchrotron light sources, advanced experimental facilities, and opportunities for cutting-edge multidisciplinary scientific research. This commitment is geared towards elevating the standard of academic research and making valuable contributions to scientific advancements in Taiwan.





Report 2:

NanoTerasu-Next Generation Synchrotron Radiation Facility

H. Nojiri, IMR, Tohoku University

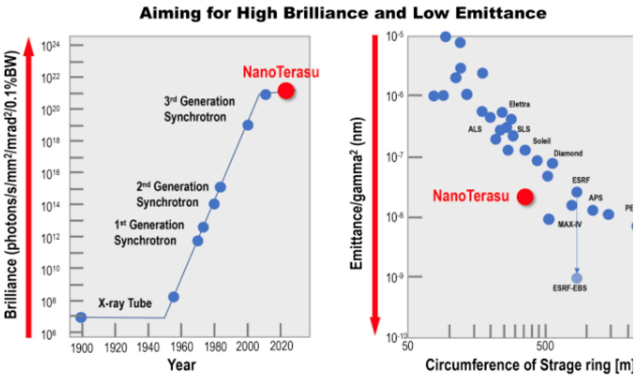
1. Introduction

NanoTerasu is the new next generation synchrotron radiation facility which will be open in 2024 in the campus close to Tohoku University, Sendai, Japan. The nickname "NanoTerasu" expresses the feature of the synchrotron radiation facility. It is explained as “the powerful light illuminates and observes the "nano universe" within materials”, which is the subject of research and observation at the new facilities. Another reason is the concept of "the wish that the research results produced by this facility will bring abundant fruits to the world's academia and industry, just like the goddess "Amaterasu," enlightens the world in Japanese mythology.” In Japan, there is SPring8 synchrotron radiation facility located in the west side of Japan. It covers the hard X-ray region based on the 8Gev synchrotron. NanoTerasu is the new center in the east part of Japan dedicated as a soft X-ray region.

Photo of NanoTerasu (from the website)

2. Performance

One of the features of the NanoTerasu is its compact design. All components, accelerator, light source, and X-ray optics are developed to achieve the excellent performance with its compact size. The higher brilliance and low emittance allows us to investigate nanoscale objects clearly. The expected brilliance will be about 10^{21} photons/s/mm^2/mrad^2/0.1%BW or better. The emittance will be well below 10^{-7} gamma^2(nm). This emittance is better than Diamond in the UK and is similar to ESRF in France. As such, NanoTerasu will be the one of the top class synchrotron radiation facilities in the world.



Performance of NanoTerasu(from the website)

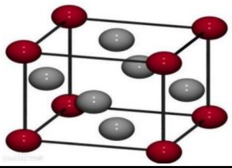
3. Beamlines

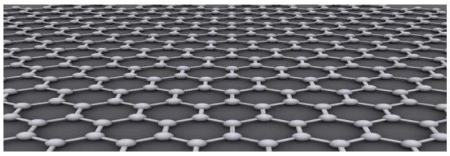
NanoTerasu has the capacity for 28 beamlines. In the 1st stage of the construction, there will be 3 beamlines founded by the government and 7 beamlines founded by the coalition of the partners including Photon Science Innovation Center, Tohoku University, Miyagi Prefecture, Sendai City, Tohoku Economic Federation.

The beam lines are listed below.

BL-02U: Ultra-high resolution resonant inelastic Scattering

BL-06U: Soft X-ray nano photoelectron-Spectroscopy





BL-13U: Soft X-ray nano absorption-spectroscopy

Coalition beam lines

- BL-07U: Soft X-ray electronic structure analysis
- BL-08U: Soft X-ray in operando spectroscopy
- BL-08W: X-ray atomic and electronic structure analysis
- BL-09U: X-ray spectroscopy
- BL-09W: X-ray hierarchical structural analysis
- BL-10U: Coherent X-ray imaging
- BL-14U: Soft X-ray magnetic imaging

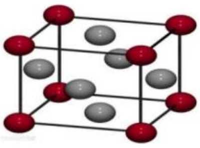
4. Integration of Science

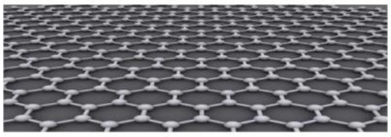
NanoTerasu is targeting a wide range of subjects from the hard materials to the objects for life sciences including live systems. One of the important concepts is the data-driven deductive approach using artificial intelligence, such as machine learning to extract the essential parameters. The combination with computer simulation and the material data base will be also pushed for high throughput research. Such approaches enables researchers and engineers from different fields to work together for advanced research and development to solve important issues with multiple approaches. NanoTerasu will create a research environment for the integration of science.

5. Access and location

It is located within 2 hours from Tokyo by the combination of a bullet train and a subway. It is only 5 km from Sendai Station and 9 min. by subway. From, Sendai Airport, it is within 40 min. The user application for national beam line will be started in early next year and the one can also work together with the members of Tohoku University to access the coalition beam lines. The application scheme for this part will be announced also in early 2024.

For more details, please visit the website https://nanoterasu.jp/nanoterasu_online_poster4/index-eng.html





Selected Contributions on condensed Matter Physics in the Asian Pacific Areas

Report 1:

Title: Absence of near ambient superconductivity in $LuH_{2\pm x}N_y$

Subtitle: *Nitrogen-doped Lutetium hydride $LuH_{2\pm x}N_y$ synthesized using a high-pressure and high-temperature synthesis technique did not show near-ambient superconductivity at pressures below 40.1 GPa.*

By Qing Li
Department of Physics, Nanjing University, Nanjing, 210093, China

Recently, near-ambient superconductivity has been claimed in a nitrogen-doped lutetium hydride (*1*), which sheds light on the long-held dream of room-temperature superconductivity. In their report, a color change from blue to pink to red with increasing pressure was observed, and the superconducting state appeared only in the pink color phase. If the results could be replicated by other groups, it would be a major scientific breakthrough. In this article, by using a high-pressure and high-temperature synthesis technique, we have obtained nitrogen-doped lutetium hydride ($LuH_{2\pm x}N_y$) with dark-blue color, which has a structure with the space group of $Fm\bar{3}m$ as evidenced by X-ray diffraction. Raman spectroscopy and energy-dispersive X-ray spectroscopy measurements confirmed the presence of hydrogen and nitrogen in our samples. On applying pressures up to 41 GPa, we observed a gradual color change from dark blue to violet to pink-red. However, based on comprehensive high-pressure resistance and magnetization measurements, we conclude the absence of superconductivity down to 2 K in $LuH_{2\pm x}N_y$ at pressures below 40.1 GPa (*2*).

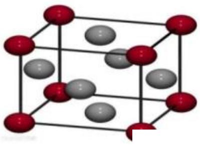
1. The pursuit of room temperature superconductivity

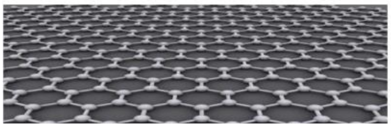
Materials known as superconductors can transmit electrical energy essentially with no losses. They have a wide range of applications, such as magnetic resonance imaging (MRI) in hospitals. However, the applications of superconductivity have been hampered, largely because the superconducting state can only exist at very low temperatures. Therefore, the search for high-T_c superconductors at ambient conditions has been a perpetual dream for both experimental and theoretical scientists since the discovery of superconductivity in 1911 (*3*).

Metallic hydrogen and hydrogen-rich materials provide interesting platforms for searching for room-temperature superconductivity since it was proposed theoretically (*4*). According to the prediction, under certain circumstances, elements that have low atomic masses can contribute to high critical temperatures and the hydrogen-rich compounds could become superconducting more easily due to the chemical compression induced by the other elements (*5*). Experiments have shown that several polyhydride compounds can transition into a superconducting state at temperatures above 200 Kelvin, such as H_3S, LaH_{10}, CaH_6, but the pressures required are still very high (*6-9*).

Recently, Dasenbrock-Gammon *et al.* reported the possible evidence for near-ambient superconductivity by replacing some of the hydrogen in a lutetium hydride compound with nitrogen (*1*). Interestingly, the sample underwent a striking visual transformation from blue to pink to red with increasing pressure, and the superconducting state appeared only in the pink-color phase. In previous experiments, superconductivity with much lower transition temperature was reported in lutetium hydrides at high pressures (*10,11*). Thus, it is interesting to study whether room-temperature superconductivity really exists in this compound at such a low pressure.

2. Synthesis and crystal structure of nitrogen-doped lutetium hydride





At the beginning of the experiment, we found that the sample preparation temperature provided in the original paper was too low, so we quickly determined our own synthesis scheme based on the high-pressure and high-temperature synthesis technique and the hydrogenation strategy that we developed.

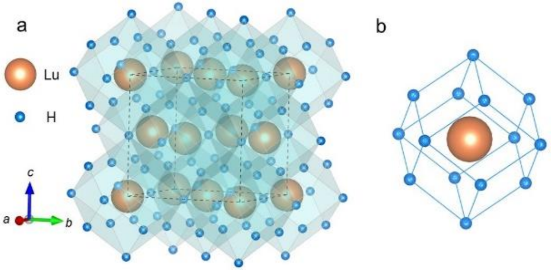


Fig. 1. **a,** Schematic crystal structure of nitrogen-doped lutetium hydride. Lu and H atoms are shown by orange, blue spheres, respectively. **b.** Lu atom are surrounded by 14 coordination hydrogen atoms to form a H_{14} cage.

have explored for a long time, and successfully prepared the nitrogen-doped lutetium hydride samples with dark-blue color. Using X-ray diffraction analysis, we found that almost all the diffraction peaks corresponded well with the results of Dasenbrock-Gammon *et al.* reported, and the material is found to satisfy a face-centered cubic structure (space group $Fm\bar{3}m$) as shown in Fig. 1. Similar to the other metal-superhydrides with an atomic hydrogen sublattice (*6-9*), each Lu atom is surrounded by 14 coordination hydrogen atoms to form H_{14} cages. Raman spectra data of our samples also show good consistency with the previous report (*1*). Note that, due to the difficulty to identify the light elements, the actual occupation ratio of hydrogen and the position of nitrogen in nitrogen - doped lutetium hydride remains elusive. Thus, we define the chemical formula of our samples as $LuH_{2\pm x}N_y$. (*2*)

3. Pressure induced color change and absence of superconductivity in $LuH_{2\pm x}N_y$

One of the most notable phenomena reported in nitrogen-doped lutetium hydride is the color change from dark blue to pink to red with increasing pressure. The near-ambient superconductivity was suggested to occur in the state with a pink color (*1*). To confirm this, we use a diamond anvil cell (DAC) apparatus to generate *in-situ* high-pressure environment to investigate the behavior of the title material under different pressures. Fig. 2 shows the optical microscope images of $LuH_{2\pm x}N_y$ at three selected pressures. the color gradually changes from dark blue to violet, and then to pink-red. Except for the higher pressures required for the color change, the observations are quite similar to the results by Dasenbrock-Gammon *et al.* (*1*) The color change in our samples may be explained by the shift of the plasma edge of a metal with a proper charge-carrier density; the latter can be easily tuned by pressure in systems containing shallow bands (*12*).

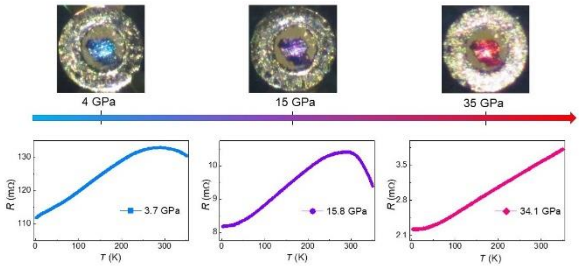


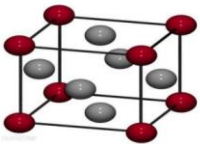
Fig. 2. Pressure-induced color change and evolution of temperature-dependent resistance of $LuH_{2\pm x}N_y$ at different pressures.

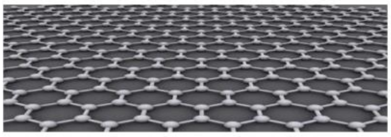
The lower panel of Fig. 2 displays the temperature dependent electrical resistance of $LuH_{2\pm x}N_y$ from 2 to 350 K at corresponding pressures. Except for a resistance hump around 300 K in the low-pressure region, the general electrical behavior of our samples is metallic for all the states at all pressures. To check whether there is a diamagnetic signal of the possible superconductivity in our as-grown samples, we also measured the temperature-dependent d.c. magnetization curves of $LuH_{2\pm x}N_y$ at different pressures. The net magnetic moments after removing the related background is positive and very weak with a roughly flat feature in the temperature region from 100 to 320 K. And the isothermal magnetization curves also exhibit a roughly linear behavior with a positive correlation. Our high-pressure resistance and magnetization measurements both show that there is no trace of near-ambient superconductivity in $LuH_{2\pm x}N_y$.

4. Outlook

In summary, we have successfully synthesized nitrogen-doped lutetium hydride $LuH_{2\pm x}N_y$ with a dark-blue color. The XRD and Raman spectroscopy confirmed that our samples have a structure similar to the samples that reported previously (*1*). We also observed a color change from dark blue to violet to pink-red on applying pressures. However, the comprehensive high-pressure resistance and magnetization measurements proved that no near-ambient superconductivity exists in $LuH_{2\pm x}N_y$. After the reports of our work (*2*), the absence of near-ambient superconductivity in nitrogen-doped lutetium hydrides is supported by recent experimental and theoretical calculations (*13-17*).

Although the room-temperature superconductivity in $LuH_{2\pm x}N_y$ is proved to be absent, the strategy of exploring high-temperature superconductivity in hydrogen-rich materials is worth continuing. Usually, materials containing hydrogen tend to generate high-temperature superconductivity since hydrogen is the lightest chemical element, which means it has





the highest vibration frequency. The high frequency should increase the critical temperature of a phonon-mediated superconductor. In this sense, C, B, N-based light elements-rich compounds are also available. We hope that room-temperature superconductivity at ambient pressure can be realized in the near future.

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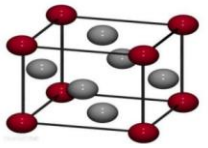
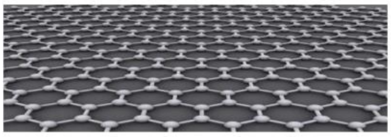




Report 2:

Title: A new high-T_c superconductor

Subtitle: *Superconductivity was discovered at 80 K in a Ruddlesden-Popper double-layered nickelate, $La_3Ni_2O_7$ under pressures of 14.0-43.5 GPa.*

By Meng Wang
School of Physics, Sun Yat-sen University, Guangzhou, 510275, China

Cuprates are the only unconventional family that shows high-T_c superconductivity above the boiling point of nitrogen at 77 K. Very recently, our group discovered the Ruddlesden-Popper double-layered nickelate, $La_3Ni_2O_7$, which superconducts at 80 K under 14.0-43.5 GPa pressure (1). The oxidization state of $Ni^{2.5+}$ in $La_3Ni_2O_7$ is far away from $Ni^{+1.2}$ in $Nd_{0.8}Sr_{0.2}NiO_2$, where superconductivity at 9~15 K was observed (2). The magnetic properties of $La_3Ni_2O_7$ may be fundamentally different from that of cuprates and iron-based superconductors (3). The double-layered nickelate $La_3Ni_2O_7$ represents a new family of high-T_c superconductors which is ideal for exploring the mechanism of unconventional superconductivity.

1. Exploration of superconductivity in nickelates

The La-Ni-O materials were first synthesized in the 1950s. Since the discovery of high-T_c superconductivity in copper oxide materials, extensive efforts have been investigated in nickelates. Ni^+ has the same spin configuration as Cu^{2+}. It was expected that the nickelates with Ni^+ may show superconductivity. In 2019, Hwang's group at Standford University reported the discovery of superconductivity in film samples of $Nd_{0.8}Sr_{0.2}NiO_2$ with the transition temperature T_c 9~15 K (2). The superconductivity was soon after observed on film samples of nickelates with the same valent state of $Ni^{1.2+}$, including $La_6Ni_5O_{12}$ (4). Under pressure, the T_c can be increased over 30 K in $Pr_{0.82}Sr_{0.18}NiO_2$ (5). While no report for observation of superconductivity on bulk samples of the hole-doped nickelate 112 system.

2. Discovery of high-T_c superconductivity in $La_3Ni_2O_7$

To realize superconductivity in bulk samples of nickelates, our group systematically grew the Ruddlesden-Popper (RP) nickelates, including La_2NiO_4, $La_3Ni_2O_7$, $La_4Ni_3O_{10}$, and $LaNiO_3$ single crystals with a high-pressure floating zone technique. After that, we obtained the reduced RP phases of nickelates $La_3Ni_2O_6$, $La_4Ni_3O_8$, and $LaNiO_2$ single crystals by employing a topochemical method using CaH_2 to remove the apical oxygen of the NiO_6 octahedra (3). We focused on the paramagnetic metal $La_3Ni_2O_7$, with the double NiO_6 octahedra layers. A simple electron counting gives a $Ni^{2.5+}$, i.e., $3d^{7.5}$ state for both Ni cations. Our electronic transport measurements reveal a superconducting transition up to 80 K under 14.0-43.5 GPa pressure (1). The superconductivity on the samples grown by our group was soon after confirmed independently by J. G. Cheng's group and H. Q. Yuan's group (6, 7). Our discovery has established a new high-T_c superconductor and inspired significant experimental and theoretical investigations.

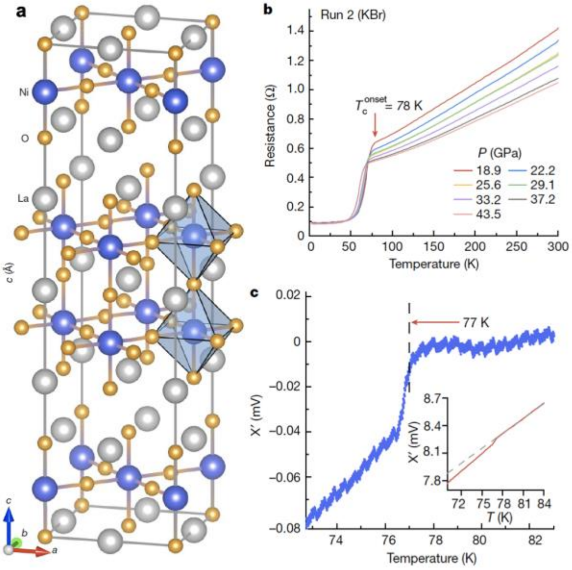
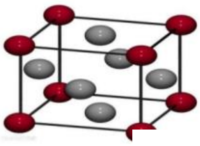
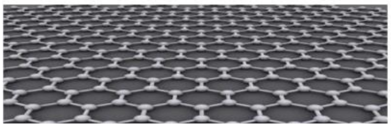


Fig. 1. (a) Structure of $La_3Ni_2O_7$. (b) Resistance of $La_3Ni_2O_7$ under pressure and (c) diamagnetic response measurements at 25.2 GPa.





3. Cracking the mysteries under pressure

It is challenging to elucidate the properties of a superconductor under pressure. We characterized the structure, resistivity, magnetization, and heat capacity at ambient pressure. $La_3Ni_2O_7$ shows metallic and paramagnetic behavior, distinct from the antiferromagnetic parent compounds of the other unconventional superconductors (3). In the superconducting state under pressure, the samples show strange metal behavior in the normal state with a linear resistance up to 300 K (1). The high transition temperature and strange metal behavior reveal unconventional superconductivity in $La_3Ni_2O_7$ under pressure. We combined density function theory in our analysis.

3.1 The crystal structure under pressure

The crystal structure was refined from the synchrotron X-ray diffraction (XRD). An anomaly was identified in the evolution of the peak positions under 10-20 GPa pressure. It is known X-ray is not sensitive to oxygen. The first principles method was employed to calculate the enthalpies of the *Amam* and *Fmmm* space groups. The results reveal that the enthalpy of *Fmmm* is indeed lower than that of the *Amam* at high pressures. The XRD patterns above 20 GPa can be fitted by the *Fmmm* space group. Thus, we conclude the Ni-O-Ni angle between two adjacent octahedra changes from 168° in the ambient pressure *Amam* space group to 180° in the high-pressure *Fmmm* space group.

3.2 σ-bonding bands metallization

The electronic structure was calculated by the density functional theory. At ambient pressure, the $3\,d_{x^2-y^2}$ bands cross the Fermi level, while the bonding $3d_{z^2}$ band locates 50 meV below the Fermi level at the Γ point. The electronic states of oxygen hybridize with that of nickel. At 29.5 GPa, the $3d_{z^2}$ bands lift upward crossing the Fermi level, and a small hole Fermi pocket emerges around the center of the Brillouin zone, corresponding to the metallization of the lower σ bond and the emergence of superconductivity. The $3d_{z^2}$ bands are close to half-filling with hole doping, where the strong electronic correlation originates; the $3d_{x^2-y^2}$ bands are quarter-filling, thus the electronic correlations are weak.

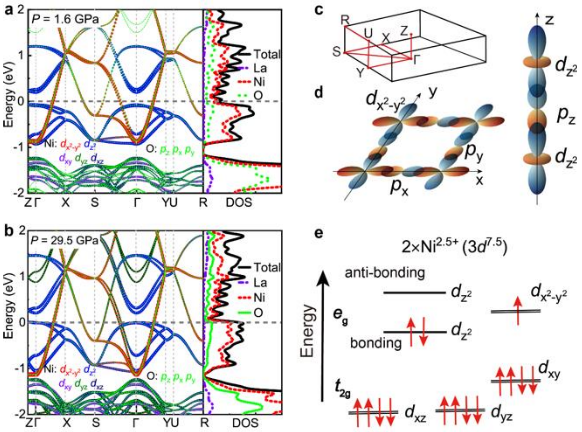


Fig. 2. (a) Calculated electronic band structures at 1.6 GPa and (b) 29.5 GPa. (c) Three-dimensional orthorhombic Brillouin zone. (d) Schematics of the intralayer and interlayer σ bonding states. (e) Electronic configuration of the two $Ni^{2.5+}$ in the bilayers of NiO_6 octahedra.

4. Outlook

The electronic correlations revealed by infrared measurements in $La_3Ni_2O_7$ are comparable with that of cuprates (8). The band structures from angle-resolved photoemission measurements are consistent with the calculations. Furthermore, orbital dependent correlations are also revealed (9). The emergence of superconductivity under pressure is very sensitive to the content of oxygen. It seems fully occupied oxygens are benefit for superconductivity. However, the synthesis of such samples requires high-pressure oxygen. Y. P. Qi's group has recently successfully grown polycrystalline samples with T_c up to 86 K under pressure (10). It is possible to realize higher T_c superconductivity and at ambient pressure.

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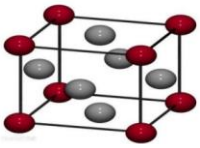
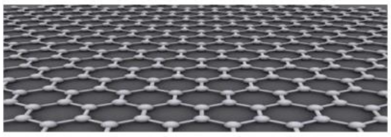




Report 3:

Title: Pair density wave in iron-based superconductor

Subtitle: *The primary pair density wave state with spatially modulated Cooper-pair density has been discovered in the monolayer Fe(Te,Se) film grown on $SrTiO_3$ substrate, a two-dimensional iron-based high-T_c superconductor.*

By Jian Wang
International Center for Quantum Materials, School of Physics, Peking University, Beijing, 100871, China

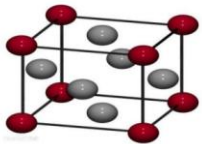
The pair density wave (PDW) is an extraordinary superconducting state where Cooper pairs carry nonzero momentum (*1,2*). Theoretically, the PDW order is hypothesized to play a fundamental role in high-temperature (high-T_c) cuprate superconductors, wherein experimental evidence of the PDW state has been reported (*3-6*). However, the PDW order has not been experimentally observed in iron-based superconductors, another high-T_c superconductor family. By using scanning tunneling microscopy/spectroscopy, we report for the first time the primary PDW state at the innate domain walls of the monolayer iron-based high-T_c Fe(Te,Se) films grown on $SrTiO_3$(001) substrates (*7*), which provides a low-dimensional platform to study the interplay between the correlated electronic states and unconventional Cooper pairing in high-T_c superconductors.

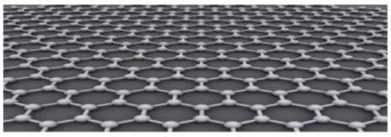
1. Spatially modulated Cooper-pair density in superconductors

As a macroscopic quantum state of matter, superconductivity has attracted tremendous attention in the field of scientific research and industry over the past century. According to the BCS (Bardeen-Cooper-Schrieffer) microscopic theory, superconductivity arises from the condensation of coherent Cooper pairs, and each Cooper pair is formed by two electrons with opposite spins and momenta (*8*). Theoretically, when time-reversal symmetry is broken, Cooper pairs may acquire a finite momentum and exhibit a spatially modulated superconducting order parameter, which is known as the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state (*9,10*). Although the FFLO state was theoretically proposed in 1964, it has proven challenging to observe the FFLO state due to the stringent requirement for materials (*11*). To date, direct evidence of the FFLO state, such as the modulation of the superconducting order parameter in real space, have not been detected experimentally.

To understand the observed two-dimensional (2D) superconducting properties in cuprates, some theoretical works predicted that the finite-momentum Cooper pairs can exist in strong-coupling systems without breaking time-reversal symmetry and show the spatial modulation of Cooper-pair density (*12,13*). This extraordinary superconducting state, referred to as the pair density wave (PDW), has sparked numerous theoretical investigations due to the potential connection between the PDW and unconventional superconductivity (*14-16*). Among various theoretical hypotheses, the most intriguing one is that the PDW is another principal state along with *d*-wave superconductivity in the phase diagram of cuprates (*1*), which provides new insights into the complex intertwined orders of the cuprates showing high-temperature superconductivity. Moreover, according to some theoretical proposals, the enigmatic pseudogap phase of cuprates can be attributed to the PDW state (*16*), further indicating the potential importance of PDW. However, previous evidences of the PDW state in high-temperature (high-T_c) superconductors were only observed in some cuprates (*3-6*). The existence of PDW state in iron-based superconductors, another high-T_c superconductor family, has never been experimentally detected. Furthermore, early theoretical studies of cuprates proposed the PDW is a low-dimensional stripe order in 2D systems (*13*), but no compelling experimental evidences of the PDW in 2D systems were reported.

2. Pair density wave state in a monolayer iron-based superconductor





By using molecular-beam epitaxy (MBE) technique, we successfully grew large-area and high-quality one-unit-cell-thick Fe(Te,Se) films on $SrTiO_3$(001) substrates (1-UC Fe(Te,Se)/STO), which show superconducting gap as large as 18 meV, much higher than that (~1.8 meV) in bulk Fe(Te,Se), a promising topological superconductor candidate (*17,18*). Previously, we have observed zero-energy excitations at both ends of 1D atomic line defects in 1-UC Fe(Te,Se)/STO, which are found to be consistent with the Majorana zero modes interpretation (*19*). In the current work, another atomic structure in 1-UC Fe(Te,Se)/STO, the innate domain wall (Fig. 1a) where the atomic lattice is compressed along Fe-Fe direction across the domain wall, was investigated by in situ low-temperature (4.3 K) scanning tunneling microscopy/spectroscopy (STM/STS). Within the domain wall area, clear spatial modulation of the local density of stats (LDOS) is detected (Fig. 1c-d). Further bias voltage dependent measurements show that the period of the LDOS modulation is independent of the energy, demonstrating an origin of electronic order. Furthermore, the electronic ordering-induced LDOS modulations mainly exist in the energies within the superconducting gap, indicating that the charge order is potentially related to the superconductivity of 1-UC Fe(Te,Se)/STO.

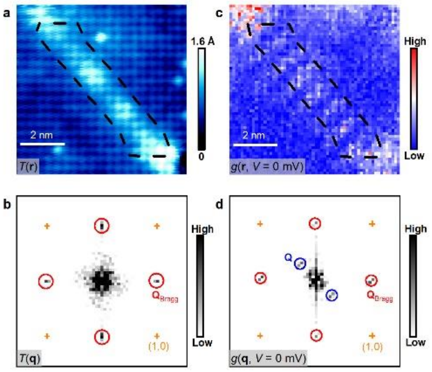


Fig. 1. Innate domain wall on the 1-UC Fe(Te,Se) film and sptial modulation of the local density of stats at the domian wall.

By performing further STS measurements, spatial modulations of the superconducting coherence peak height (Fig. 2a-b) and gap energy (Fig. 2c-d) are detected at the domain wall. Previous studies have reported the strong correlation between these two physical quantities and superconducting order parameter. Therefore, the spatial modulation of the superconducting order parameter is directly observed in real space, which provides compelling evidence of the existence of PDW order in the 2D iron-based high-temperature superconductor. Note that no spatial modulation can be detected in the topography of the 1-UC Fe(Te,Se) films and the LDOS modulations at the domain wall mainly exist in the energies within the superconducting gap, indicating that the primary CDW state is absent and the PDW state is a primary state.

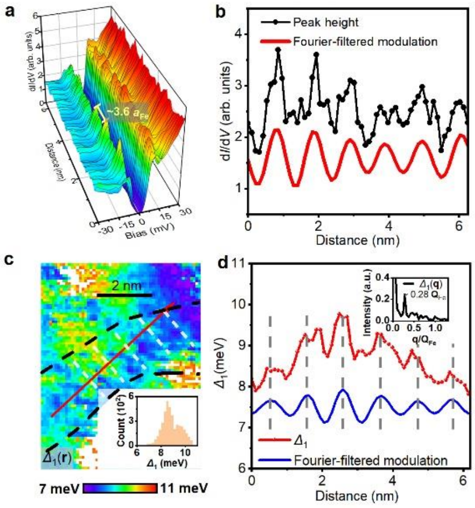
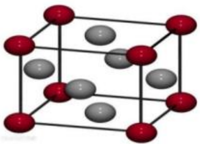
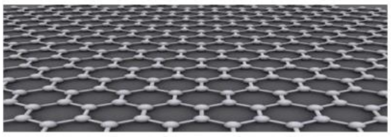


Fig. 2. Spatial modulation of the superconducting coherence peak height and gap energy at the domain wall, providing compelling evidence of the existence of PDW order in the 2D iron-based high-temperature superconductor.

Apart from the PDW state, a charge density wave (CDW) state with a period of about $1.8a_{Fe}$ (half of the period of PDW) is also detected at the domain wall. Fig. 3e and 3f show the phase map of the PDW (period ~ $3.6a_{Fe}$) and CDW state (period ~ $1.8a_{Fe}$) at the domain wall, in which vortices with 2π phase winding in the CDW phase (black dots in Fig. 3f) and π-phase shifts in the PDW phase (arrows in Fig. 3e) can be identified. It is clear that the π-phase shifts in the PDW phase are observed near the vortices of the CDW, which is consistent with the theoretical scenario of a primary PDW and PDW-induced secondary CDW (Fig. 3a-d), further confirming that the PDW state observed at the domain wall of 1-UC Fe(Te,Se)/STO is a primary state.





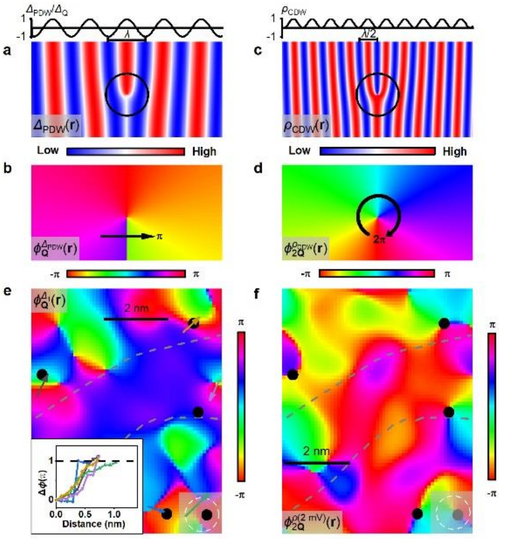


Fig. 3. Correspondence between primary PDW π-phase shift and secondary CDW topological defect.

To explain the mechanism of the primary PDW state at the domain wall, we proposed a novel triplet equal-spin pairing model. At the domain wall, the broken inversion and mirror symmetry introduce the Rashba and Dresselhaus spin-orbit couplings (SOC). Due to the large SOC, electrons with equal spin can pair across the Fermi points of the SOC splitting bands, leading to a primary PDW state with finite-momentum Cooper pairs. Theoretical calculations based on the equal-spin pairing model show the spatial modulation of the LDOS and the superconducting gap, which are consistent with our experimental results and reveal the possible existence of topological spin-triplet superconducting order parameters.

3. Outlook

This work is the first observation of the primary PDW state in iron-based superconductors, which provides a new material platform to study the PDW state and its interplay with the topological electronic states and unconventional high-T_c superconductivity.

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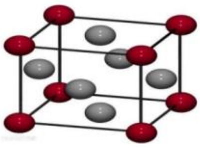
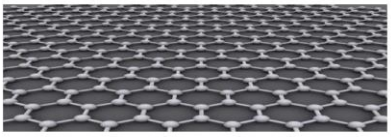




Recent Academic Exchanges and Activities in the Asian Pacific Areas

Report 1:
The International Conference on Strongly Correlated Electron Systems 2023

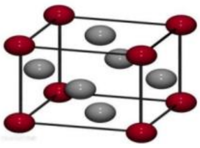
Profs. Je-Geun Park and Jaejun Yu, chairs of SCES

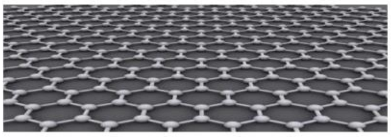
On behalf of the SCES2023 Organizing Committee

Group Photo of SCES2023

The International Conference on Strongly Correlated Electron Systems 2023 (SCES2023) was held on 2 – 7 July in Incheon, South Korea. SCES has traditionally been the major scientific meeting since the first SCES in 1992, where the latest developments and discoveries have been reported in strongly correlated electron systems. This year, it has attracted 864 participants from 30 countries. There were 711 presentations, including 12 plenary talks, 83 invited talks, 187 contributed talks, and 429 poster presentations.

The meeting started on 2nd July with a public lecture





on “Quantum computer and quantum materials: present and future” by Dr. Hanhee Paik (IBM Quantum). It was followed by a reception with beverages and various Korean foods. The following day, Prof. Je-Geun Park, chair of the SCES2023 organizing committee, gave the opening address, followed by a congratulatory speech by Prof. Se-Jung Oh of Seoul National University.

There were three plenary talks daily: two in the morning and one in the afternoon, except for Thursday. The topics of the 12 plenary talks covered the most exciting developments in the fields: in the order of presentation, Profs. S-W Cheong, A. Black-Schaffer, B. A. Bernevig, M. Berciu, S. Hayden, Y-W. Son, G. Zwicknagl, Q. Si, P. Kim, S. Nakatsuji, A. Georges, and R. Valenti. We also held a best poster prize ceremony as the first event for the morning session. By doing so, we celebrated science done by some of our enthusiastic young generations.

There were two special sessions to celebrate this year’s SCES: one on Monday and the other on Tuesday. The Monday session was dedicated to the 30 years of SCES and Kondo physics, and each of the five invited speakers (Prof. T. Yanagisawa, Dr. J. Thompson, Prof. G. Zwicknagl, Prof. Y. Onuki, Prof. F. Steglich) covered the broad history of SCES and remembered the scientific contributions by the late Prof. J. Kondo. The Tuesday session was on a more futuristic theme of “Quantum Materials: the future direction,” where three speakers (Profs. A. MacDonald, P. Canfield, and R. Valenti) each presented their personal views on the future.

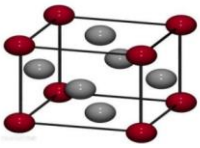
On Wednesday, the conference went festive, with the conference banquet preceded by a cocktail reception. During the two and a half hours, the participants enjoyed the food and the Korean traditional music. The closing ceremony was conducted on the final day with the summary talks: Experiment by Prof. A. de Visser and Theory by Prof. H-Y. Kee. The program committee chairs (Profs. K. Kim and T. Park) reported the statistics of the scientific program. The final closing address was delivered by Prof. Jaejun Yu, co-chair of SCES2023.

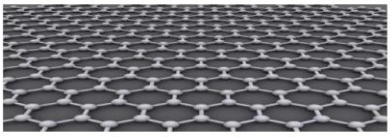
Report 2:
Annual Conference of Condensed Matter Physics 2023 (CCMP2023) was successfully held in Liyang, Jiangsu province, China

The annual Conference of Condensed Matter Physics 2023 (CCMP2023) was successfully held at Yangtze River Delta Physics Research Center from August 7th to 11th in Liyang city, China. This year’s CCMP was co-hosted by Institute of Physics, Chinese Academy of Sciences, Shanghai Jiao Tong University, Fudan University, Zhejiang University, Nanjing University and Kavli Institute for Theoretical Sciences, University of Chinese Academy of Sciences and was co-organized by Chinese Physical Society.

CCMP evolved from the annual conference series "International Conference on Condensed Matter Theory and Computational Materials," which began in 2002. In 2015, the Organizing Committee decided to expand the conference's scope and scale to reflect the latest developments in condensed matter physics by adding new sessions that cover a broader range of topics. Consequently, the conference was renamed as the Conference of Condensed Matter Physics (CCMP). The conference's objectives are to update the rapid progress in condensed matter physics, promote academic exchanges, facilitate interdisciplinary research, and enhance the global recognition of Chinese contributions to condensed matter physics and related fields.

CCMP2023 focused on the frontier issues of condensed matter physics, and set up four parallel sessions, including (i) Unconventional superconductivity and strongly correlated systems；(ii) AI and computational condensed matter physics; (iii) Quantum computation; and (iv) Low-dimensional





systems and topological physics. This grand event of condensed matter physics attracted more than 800 scholars from more than 160 research institutions from 18 countries to gather in Liyang. The leading experts shared their insights and generated significant interest among the audience.

The five-day conference was conducted with 150 invited talks and 190 poster presentations attracting huge crowds in every session. Delegates from diverse backgrounds eagerly participated in the discussions and actively shared their ideas, exploring the latest advancements and future horizons in this field of research.

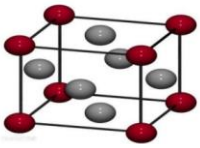
CCMP2023 provided an excellent platform for scholars and researchers from diverse fields to share their knowledge and perspectives. In the future, with joint efforts of the organizing committee, CCMP will attract the attention and participation of more international attendees.

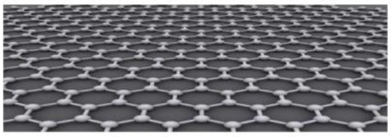
Report 3:
The 17th National Conference on Superconductivity of China (NCSC 2023)

The 17th National Conference on Superconductivity of China was successfully held from October 20th to 24th at Xi'an International Conference Center in China, sponsored by Northwest Nonferrous Metals Research Institute. This conference is routinely held in every two years. Over 1000 representatives from more than 170 universities, research institutes, and enterprises participated in the conference. Twenty-four companies participated in the exhibition during the conference. The scale of the conference sets a new record.

The National Conference on Superconductivity of China is the largest series of academic conferences in China for the research of superconductivity. Its purpose is to exchange the latest research achievements in China about research of superconductivity, including physics and technology, explore new ideas and methods in the field of superconducting technology research, provide opportunities for academic mutual understanding and exchange, and promote the further development of superconducting physics, materials and application research and technology.

The theme of the conference covers various aspects, including microscopic mechanism of superconductivity, vortex dynamics, Josephson Effect, exploration of new superconductors, practical superconducting materials, superconducting magnet technology, electric power applications of superconductivity, superconducting electronic device, cryogenic refrigeration technology, superconducting tests and standards, etc. The conference included 11 plenary lectures, 266 parallel talks and 301 poster presentations. Twenty-





five graduate students also won the outstanding poster awards.

Participants discussed the latest progress in China about the superconductivity research, superconducting materials, and applications in the past two years, and clarified the trends and future goals of superconductor technology. It is believed that the discussions and outcomes of the conference will provide strong support for the future development of superconductivity in China.

Report 4:
The 1st China National Conference on Vortex Matter in Superconductors

The research on Superconducting Vortex is of great significance to superconducting physics and high power applications of superconductors. In order to promote domestic development in the field of Superconducting Vortex, Professor Hai-Hu Wen from Nanjing University and Professor Zhixiang Shi from Southeast University initiated the Conference on Vortex Matter in Superconductors.

The First National Conference on Vortex Matter in Superconductors was successfully held from August 2nd to 6th, 2023, in Kunming city, Yunnan province, China. The conference, which was hosted by Nanjing University and co-organized by Yunnan University, included 30 invited talks and attracted 60 participants. The topics of the conference included (i) Vortex dynamics and vortex phase diagram; (ii) Vortex image and vortex structure; (iii) Vortex pinning and related application;(iv) Superconductivity mechanism related to vortex physics.

The conference aimed to promote the exchange of ideas and research findings and to foster collaboration among researchers in the field. The conference was also an opportunity for young researchers to showcase their work and to network with established researchers. Five young researchers were awarded prizes for their poster presentations. The organizing committee hopes that the conference will encourage further collaboration and research on vortex matter in superconductors in the future.

Group Photo of the 1st China National Conference on Vortex Matter in Superconductors

Report 5:
The 9th Chinese Heavy-fermion Forum

The 9th Chinese Heavy-fermion Forum was successfully held in Wuhan on Nov. 11-12, 2023. This forum was hosted by the Wuhan National High Magnetic Field Center (WHMFC) in Huazhong University of Science and Technology (HUST), China. The conference was co-organized by Prof. Guangming Zhang (Tsinghua Univ.), Prof. Huiqiu Yuan (Zhejiang Univ.), Prof. Yifeng Yang (IOP-CAS), and Prof. Yongkang Luo (HUST). More than 120 experts, scholars and students attended the conference.

The opening ceremony of the forum was hosted by Prof. Guangming Zhang. Prof. Liang Li, Director of the WHMFC, delivered a speech on behalf of the organizer, introducing to the attendees the development history of the WHMFC, the main achievement in recent years, and the facility optimization and improvement project plan during the "14th Five-Year Plan" period. He also expressed the vision of hoping that more domestic and foreign users can utilize the facilities to conduct research on correlated quantum materials such as heavy fermions.

This forum is the first formal gathering held after the end of the COVID-19 pandemic. The topics discussed are more diverse compared to previous editions. In addition to heavy fermions, it also included Ni-based superconductivity, frustrated quantum magnetism and other hotspots in the strongly correlated system in recent years. The forum set up 8 specialized academic sessions, with 34 invited talks from Tsinghua Univ., Peking Univ., Nanjing Univ., Zhejiang Univ., USTC, Lanzhou Univ., Sun Yat sen Univ., IOP-CAS, and HUST. During the conference, a poster exhibition session was arranged, featuring 39 exhibits, which facilitated mutual learning and exchange among young faculty, postdoctoral researchers, and graduate students.

The closing ceremony of the forum was hosted by Prof. Huiqiu Yuan, who summarized the frontier progress in heavy-fermion physics and related interdisciplinary fields. He also discussed the future development trends in these areas and presented awards to the 8 outstanding poster winners.

The two-day Heavy-fermion Forum provided a platform for academic exchange and intellectual collision among domestic experts, scholars, and students. It fostered a vibrant research atmosphere.

Group Photo of the 9th Chinese Heavy-fermion Forum