High Magnetic Field Laboratory

Steady High Magnetic Field Facility (SHMFF, Hefei)

2023 Annual Report

High Magnetic Field Laboratory, CAS

2024.03

CONTENTS

Overview

High Magnetic Field Facilities (HMFF) Project was approved on January 25th, 2007, which was jointly applied by Chinese Academy of Sciences and Ministry of Education. The HMFF Project includes two parts: Steady High Magnetic Field Facility (SHMFF), constructed by Hefei Institutes of Physical Science, CAS; Pulsed High Magnetic Field Facility (PHMFF), constructed by Huazhong University of Science and Technology.

SHMFF started its construction on May 19th, 2008. Partial magnets of SHMFF have been open to users since October 28th, 2010. SHMFF passed national acceptance and was fully put into operation on September 27th, 2017.

SHMFF consists of a world-record 45.22T hybrid magnet, five water-cooled magnets (38.5T/Φ32, 25T/Φ50, 20T/Φ200, 27.5T/Φ32 and 35T/Φ50), four superconducting magnets (10T/Φ100/Φ100, 20T/SMA, 20T/NMR and 9.4T/MRI) and series of experimental systems (transport, magnetic, magneto-optical, extremely low temperature, ultrahigh pressure, STM-AFM-MFM combo, etc.).

SHMFF gives priority to original fundamental research, applied research with important application prospects and high-tech development to improve technical innovation in China, encourages users to undertake national and ministerial major research projects, and welcomes industrial users. Users have been playing a leading role in its operation and opening, which are conductive to feature scientific objectives, prioritize key research fields, and promote important scientific outcomes.

By the end of 2023, SHMFF has provided 606,988 hours of operation time and executed 3551 approved user projects. Users from 197 organizations across the world have carried out research here, and have made series of important research achievements in materials, chemistry, biology science and other disciplines. The users have published nearly 2500 peer-reviewed journal articles, including dozens in Nature, Science, Cell and other top journals.

In 2023, SHMFF completed the operation task, and provided 51888 hours of operation time. 314 users' projects from 76 organizations carried out research projects and published 267 articles in peer-reviewed journals.

SHMFF focuses on three missions:

1. Advance magnet-related technology, stimulate invention and creation in high magnetic fields.

2. Perform the frontier research of physics, chemistry, biology and material under high magnetic fields.

3. Promote economic development such as pharmaceuticals, medical treatment etc.

Research progress and results

Research highlights

- **Discovery of the strange-metal state in FeSe superconductor**

Understanding the behavior of strange metal has been an important path towards unraveling the microscopic mechanism of high-temperature superconductivity. However, the strange-metal state is veiled by superconductivity at low temperatures, and in order to study their behaviors strong magnetic fields are desired to suppress superconductivity. A research team led by Prof. Jin Kui from the Institute of Physics, CAS performed transport measurement in the water-cooled magnet of SHMFF and obtained experimental evidence for the strange-metal state in FeSe films when superconductivity was suppressed by the strong magnetic field, resistivity showed a linear dependence on temperature down to the lowest measurement temperature. In addition, the slope of the linear-in-temperature resistivity of the strange-metal state showed a parabolic dependence on the superconducting temperature. David Abergel, editor-in-chief of Nature Physics commented “This paper is exciting because finding a quantitative relationship between the strange metal and superconductivity indicates that the mechanism for these might be universal to other superconductors, such as the cuprates.” This work was published in ***Nature Physics***.

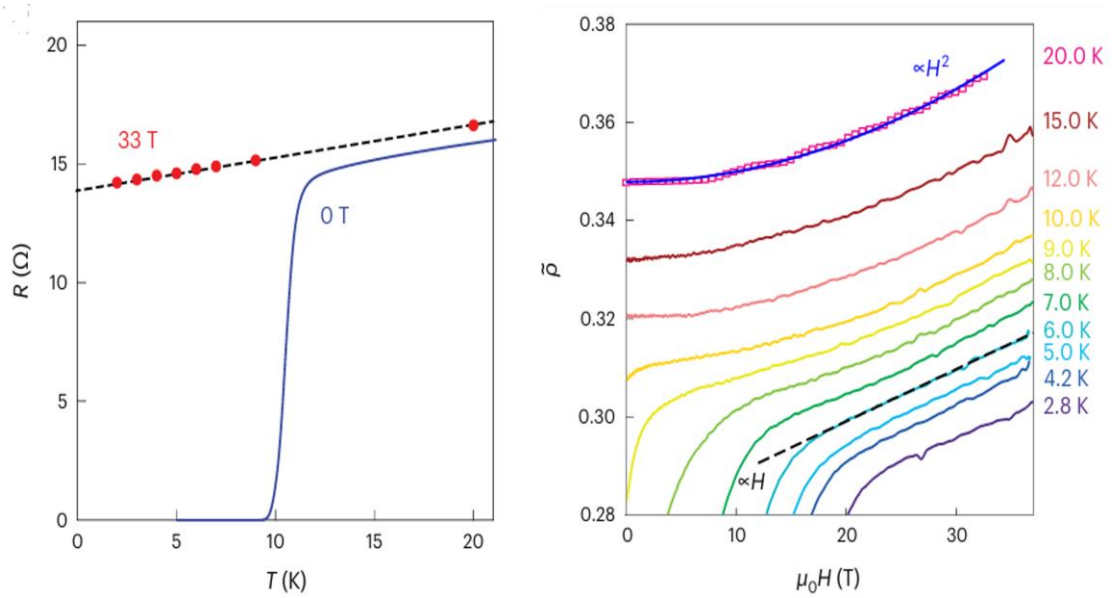


Fig.1. Left: Temperature dependence of the resistance of a FeSe film under zero and 33 T magnetic field. Right: Field dependence of resistivity of a FeSe film at different temperatures.

- **The structure-property relationship in 2D amorphous materials revealed for the first time**

Exploring and characterizing disorder in amorphous structures remains the most challenging scientific problem in materials science and condensed matter physics. Prof. Liu Lei from Peking University together with Prof. Wang Zhaosheng from High Magnetic Field Laboratory, Chinese Academy of Sciences (CHMFL) and other co-authors, obtained two-dimensional amorphous carbons with different structural disorders through the precise control of the molecular source. Then they drew out the phase diagram of "microstructure-macroscopic conductivity" through structural characterization and electrical measurements including temperature dependent Hall measurements at SHMFF, realizing the establishment of the first structure-property relationship in the field of amorphous material physics. This work has made a major breakthrough in understanding the structure-property relationship of amorphous materials, and provides new ideas for the application of two-dimensional amorphous materials. The results were published in ***Nature***.

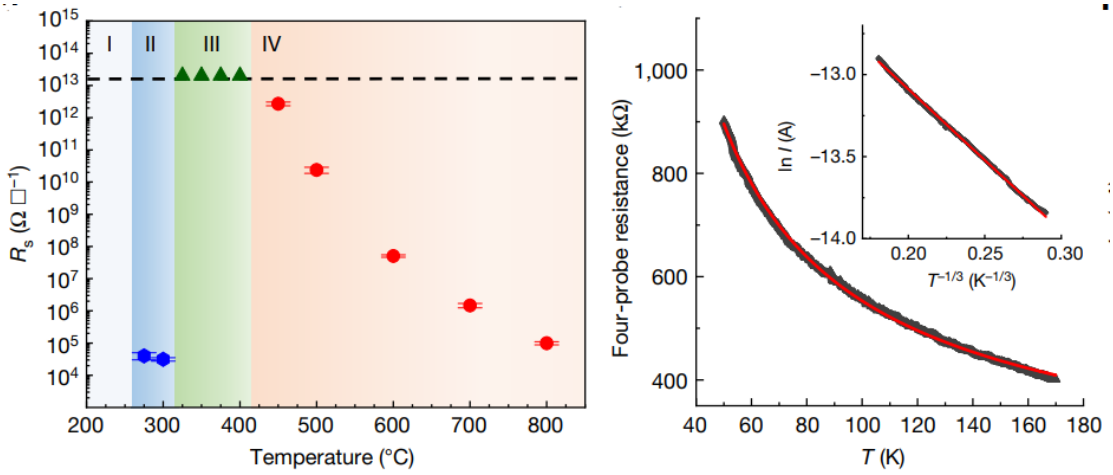


Fig.2. Electrical characterizations of AMC

- **The first spontaneous reassembly of G-quadruplex via novel Hoogsteen strand displacement reaction of DNA**

DNA G-quadruplexes (GQs) could be adopted by guanine-rich sequences which are widely distributed in the human genome. As well-folded GQs are highly stable and mostly resistant to Strand Displacement Reaction (SDR) with other guanine-rich strands, spontaneous reassembly of three-stranded GQs was extremely rare. With the assist of SHMFF's superconducting magnet SM3 and accessary NMR facilities, a research team led by Professor Zhang Na from CHMFL revealed the first non-classical Hoogsteen-pairing based SDR spontaneously proceeded in GQs and demonstrated an NMR solution structure of the final SDR product, a novel heteromeric three-stranded GQ reassembly with a unique binding mode of two G-rich probes vs one GQ target. Relative to traditional antisense probes, the new type of short G-rich probe has a superior binding efficiency and especially exhibits an appealing selectivity on differently folded GQ targets. These findings provide a new theoretical supplement in the field of DNA GQ-based nanomaterials, break the traditional perspective of Hoogsteen SDR inertness in GQs, and offer new insights into the design of novel G-rich probes to target GQs. This work has been published in ***the Journal of the American Chemical Society***.

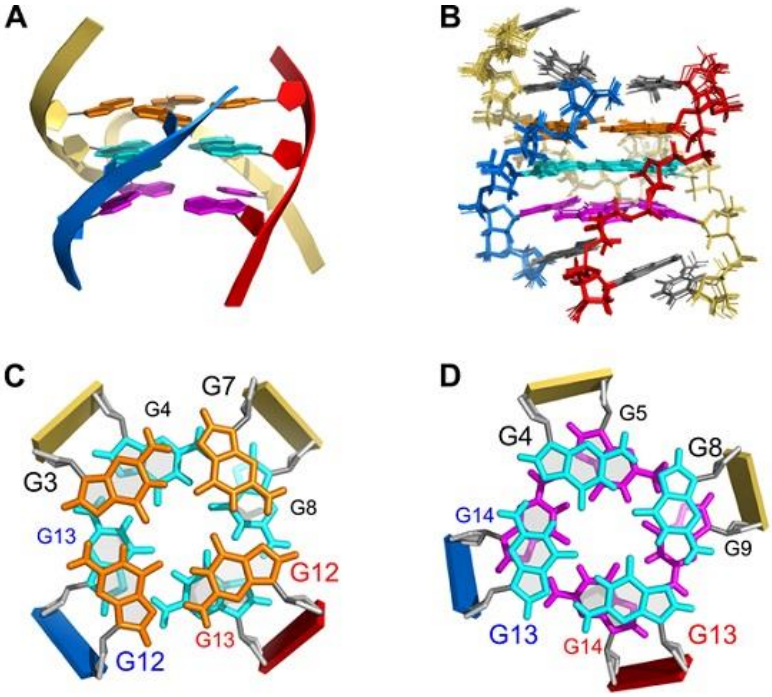


Fig.3. NMR solution structure of the heteromeric tri-GQ of Tub10/2P1

- **Development of the first Tesla class iron-based superconducting coil in the world**

Iron-based superconducting materials are new superconducting materials discovered in the field of superconductor after cupric oxide superconducting materials, and have been widely concerned and studied in recent years. The team of Chen Wenge from CHMFL has designed and optimized the iron-based superconducting coil based on the 100-meter iron-based superconducting tape provided by Ma Yanwei from the Institute of Electrical Engineering, CAS. The coil with an outer diameter of 120 mm and an inner diameter of 35 mm was developed by exploring heat-treatment, transition layer protection, superconducting joint and coil reinforcement. The insert coil generated a 1.03 T central magnetic field (The highest field previously reported was 0.26 T @ 10 T.) under a 20 T background field of a 200 mm diameter water-cooled magnet. It is the first Tesla class iron-based superconducting high field insert coil. This work has

realized the first practical application of iron-based superconducting materials in high field. The result was published as a Letter in ***Superconductor Science and Technology***, a leading journal in the field of superconductivity. Professor Tsuyoshi Tamegai from the University of Tokyo, Japanese authority in the field of iron-based superconducting materials, commented in a viewpoint published in the journal "Iron-based superconductors have joined the practical high-field magnet family."

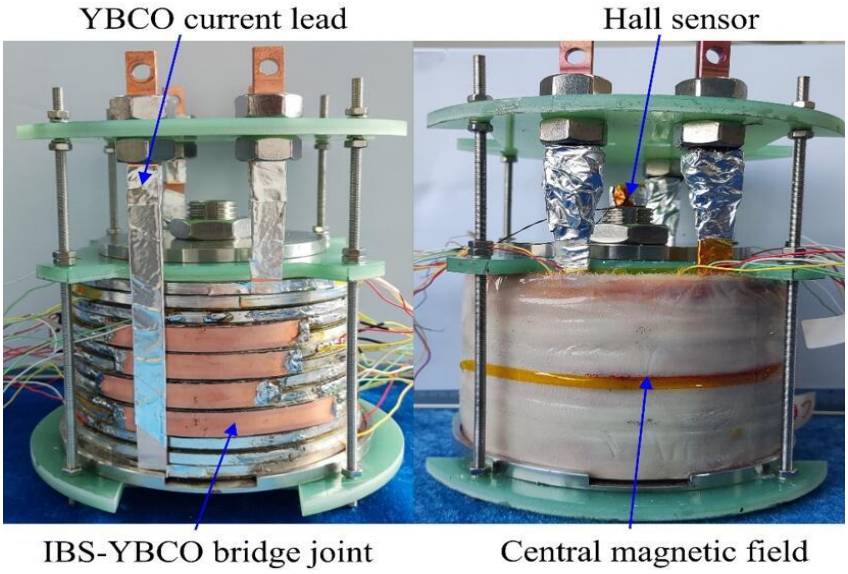


Fig.4. Iron-based superconducting high field insert coil

In 2023, SHMFF also produced a number of important achievements in the fields of quantum control, new low-power electronic devices, thermoelectric/metal/catalytic materials, and biomedicine.

Publications & Awards

Kuang Guangli from CHMFL won "The 2022 Major Science and Technology Achievement Award of Anhui Province" for his contribution in the development of SHMFF.

Number of Publications and patents related to SHMFF in 2023

SCI/EI	Number of awards received at/above the provincial or ministerial level	Authorized patents	Pending patents	Software copyrights	Nature Index Journal publications
254	1	31	80	6	82

Operation

In 2023, SHMFF served users from 76 universities and institutes, covering 314 projects. Planned running time is 49206 hrs, and actual running time is 51888 hrs.

	HW/WM	SM3+NMR	SM4+MRI
Planned time(hrs)	**1950**	**8208**	**2530**
Actual time(hrs)	**2386**	**8210**	**2616**

	Planned time（hrs）	Actual time(hrs)
SM1	2850	3037
SM2	6552	7104
PPMS	6600	6984
Cryostat	880	824
MPMS	7440	7632
ESR	1200	1375
Raman	880	949
FTIR	800	805
XRD	1120	1137
Extreme Low Temperature Transport System	2100	2472
Ultra-pressure Physical Measurement System	1000	1021
STM-MFM-AFM Combo	4096	4336
Condensed Nuclear Magnetic Resonance	1000	1000

Scientific & technical personnel and talent training

CHMFL has a total of 203 employees including 60 professors, 59 associate professors, and 84 other staff. CHMFL also has 31 postdocs and 365 graduate students.

Total number of facility staff	Classified by positions			Classified by professional titles			Students			In-house post-doctor
	Operation & maintenance staff	Researchers	Others	People with senior professional title	People with medium professional title	Others	graduated Ph.D	Graduates master	Post-graduate in progress	
203	120	77	6	119	73	11	35	44	365	31

Cooperation and exchange

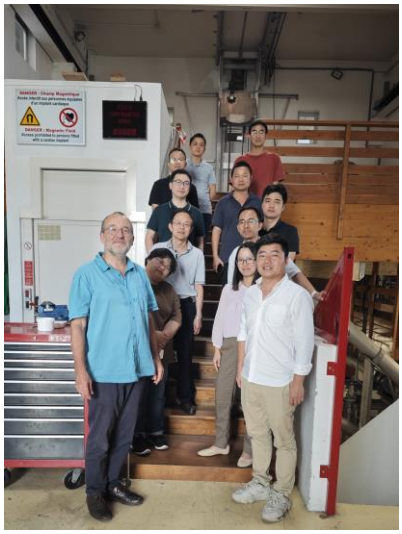
International cooperation and exchanges were carried out in 2023. Scholars and experts were invited to visit SHMFF and gave academic presentations. The numbers of forums in recent five years are as follows:

Year	2023	2022	2021	2020	2019	2018
No. of presentations	24	12	9	7	17	23

From September 10th to 15th, the 28th International Conference on Magnet Technology, MT 28 was successfully held in Aix-en-Provence, France. A team of twelve researchers from the department of Magnetic Science and Technology of CHMFL attended the conference. The team introduced the breakthroughs of magnet technology from different perspectives, focusing on the 45.22 T hybrid magnet. The team also visited LNCMI after the conference.

By attending the conference and visiting LNCMI, researchers from CHMFL learned the latest progress of international magnet technology, broadened their research ideas, and may promote the high-quality development of magnet science and technology at CHMFL in the future.

The 28th International Conference on Magnet Technology



Visiting LNCMI

Chronicle of events

- May.11st -12th "SHMFF Users' Workshop on Condensed matter NMR and electron magnetic resonance" was held.
- May. 27th The meeting of the SHMFF User Committee was held.
- Oct. 30th "Magnetobiology Symposium 2023" was held.
- Nov. 18th The meeting of the SHMFF Science & Technology Committee was held.
- Nov. 22th "Conference of Anhui Provincial Key Laboratory of High Field Magnetic Resonance Imaging" was held.
- Nov. 25th "2023 Workshop on Magneto-Optics" was held.