High Magnetic Field Laboratory of the Chinese Academy of Science

Steady High Magnetic Field Facility (SHMFF, Hefei)

2021 Annual Report

High Magnetic Field Laboratory, CAS

2022.02

中國科學院強磁場科學中心
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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), which was constructed by Hefei Institutes of Physical Science, CAS; Pulsed High Magnetic Field Facility (PHMFF), which was 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 formally put into operation on September 27th, 2017.

SHMFF consists of a 40T level 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 six experimental systems (transport, magnetic, magneto-optical, extremely low temperature, ultrahigh pressure and STM-AFM-MFM combo).

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 industry users to use. 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 2021, SHMFF has provided 504362 hours of operation time and executed 2960 approved user' projects. Users from 171 organizations across the world have carried out research here, and formed a group of advanced SHMFF users, who have made a series of important research achievements in materials, chemistry, biology science and other subjects. The users have published about 2000 peer-reviewed journal articles, including dozens in Nature, Science, Cell and other top journals.

In 2021, SHMFF has smoothly completed the operation task, and provided 51407 hours of operation time. 300 users' projects from 64 organizations carried out research projects and published 224 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

Publications & patents

In 2021, the users of SHMFF published 224 articles in peer-reviewed journals, including 212 in SCI. In addition, they obtained 24 authorized patents, 37 pending patents.

Publications and patents related to SHMFF in 2021

SCI	EI and others	Authorized patents	Pending patents	Software copyrights	Nature Index Journal publications
212	12	24	37	7	77

Grant Application

In 2021, 99 new research projects were approved for funding in total, including 1 by National Key R & D Programs of China, 18 by NSFC, 10 by CAS and 6 by Anhui Province.

Research Highlights

- **New "Flavors" of Rashba physics in 2D electronic systems of black arsenic**

The emergence of novel two-dimensional materials opens enormous opportunities in manipulating electron spins in a fast and efficient manner by the spin-orbit coupling effect. In heavy 2D systems, the orbital motion of conduction electrons in the periodic crystal field is strongly attracted by the positively charged nucleus, producing a relativistic coupling between the electron spin and the direction of orbital motion in the case of inversion symmetry breaking.

Recently, the research team led by Prof. Zheng Yi at the Zhejiang University Department of Physics made a major breakthrough. The team demonstrated that synergetic effects between spin-orbit coupling (SOC) and the Stark effect can be activated continuously and reversibly by an external electrostatic gate in centrosymmetric few-layer black arsenic (BAs). Using such an orchestrating effect, they discovered spin-valley-flavored Rashba band formation and unconventional quantum Hall states (QHSs) in the two-dimensional hole gases of BAs for the first time. Furthermore, the existence of unconventional QHSs was confirmed by the electrical transport measurement system of SHMFF. The study was published in *Nature*. (Fig.1)

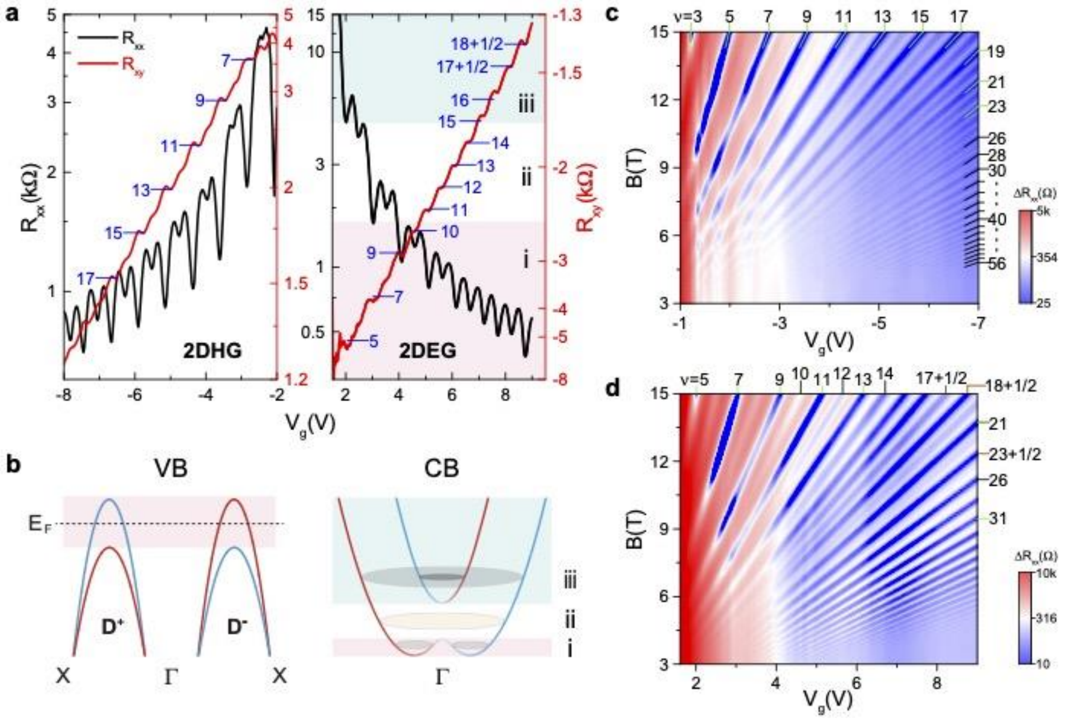

Fig.1 Quantum Hall signatures of gate-tunable Rashba valley formation in BAs 2DHG and 2DEG with particle–hole asymmetry

- **Realizations of skyrmion bundles and current - controlled topological manipulations**

Topological charge *Q*, which determines dynamics and topological magneto-transport properties, is a fundamental parameter of spin textures. However, among the topological magnetic zoo, their topological charges are mostly one. With the help of SHMFF, a research group led by Prof. Du Haifeng, Prof. Tian Mingliang, and Dr. Tang Jin from CHMFL reported, for the first time, that they clarified a type of magnetic quasiparticles with arbitrary topological charges, and then further realized current driven dynamic motion of skyrmion bundles and skyrmion-bubble transformations. Observation of skyrmion bundles and current-induced topological manipulations in this study expands the charge of topological magnetic members from one to arbitrary integer values and sheds the diversity in topological magnetic zoo. Related studies were published in *Nature Nanotechnology* and *Advanced Materials*. (Fig.2)

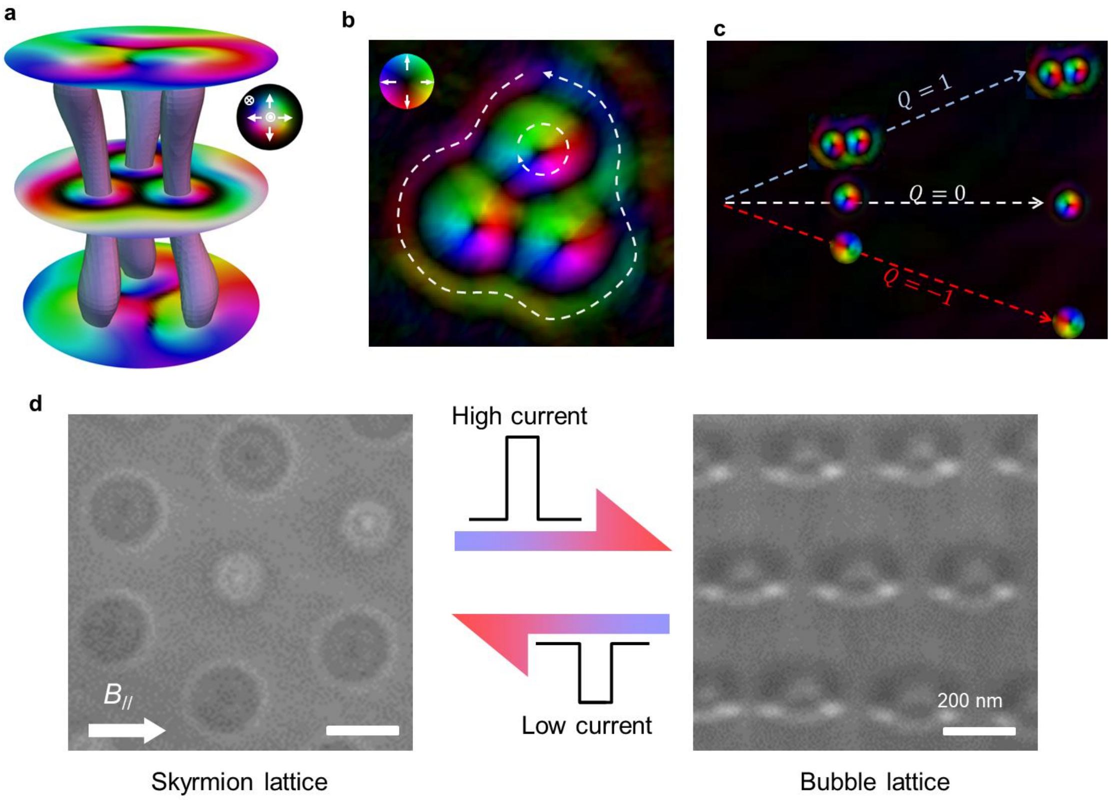

Fig.2 (a) 3D spin texture of a skyrmion bundle; (b) Observation of a skyrmion bundle; (c) Current-driven dynamic motion of skyrmion bundles; (d) Current-controlled topological skyrmion-bubble transformations

- **Extrinsic and intrinsic anomalous metallic states in transition metal dichalcogenide Ising superconductors**

Two-dimensional (2D) crystalline superconductor has attracted much attention due to its novel properties. However, the high frequency noise from the external environments usually affects the measurement results in the ultralow temperature region, especially for the nanosystems showing fragile 2D superconductivity. Recently, Professor Wang Jian from International Center for Quantum Materials, School of Physics, Peking University, in collaboration with Prof. Lin Xi at Peking University, Prof. Xing Ying at China University of Petroleum (Beijing), Prof. Liu Yi at Renmin University of China and others, observed the external radiation induced resistance saturation (named as the extrinsic anomalous metallic state) at low temperatures in 4*Ha*-$TaSe_2$ nanodevices. Interestingly, by sufficiently filtering the external perturbations, the lower temperature and higher magnetic field measurements of SHMFF manifest that the intrinsic anomalous metallic ground state still exists when approaching zero temperature. This work demonstrates the presence of an intrinsic anomalous metallic state even in the nanosystems with relatively fragile 2D superconductivity and confirms the necessity of effective filtering for low-temperature measurements in the research of quantum ground states. The research article was published in *Nano Letters*. (Fig.3)

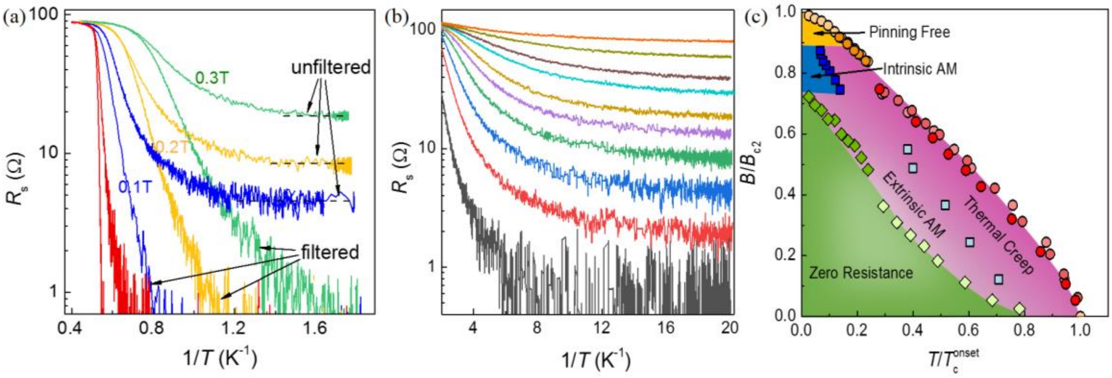

Fig.3 Extrinsic (a) and intrinsic (b) experimental evidences of anomalous metallic states in superconducting $TaSe_2$ nanodevices; (c) Phase diagram of 2D $TaSe_2$ showing zero resistance and intrinsic anomalous metallic (AM) state as quantum ground states of 2D crystalline superconductors

- **Experimental evidence of Non-trivial electronic band structure in Kagome material CsV_3Sb_5**

Due to the special crystal structure, Kagome materials exhibit many new physics properties, which make them become the important research platform for new condensed matter and new physics. Recently, one type of quasi two-dimensional Kagome system was found to exhibit superconductivity and charge density wave, which aroused intensive research intension. Prof. Lei Hechang from Renmin University and Prof. Zhu Xiangde from CHMFL recently studied the quantum transport properties of CsV_3Sb_5 under 35T high magnetic field of SHMFF. This work provided strong evidence of non-trivial electronic band structure in Kagome material CsV_3Sb_5, and that was published in *Physical Review Letters*. (Fig.4)

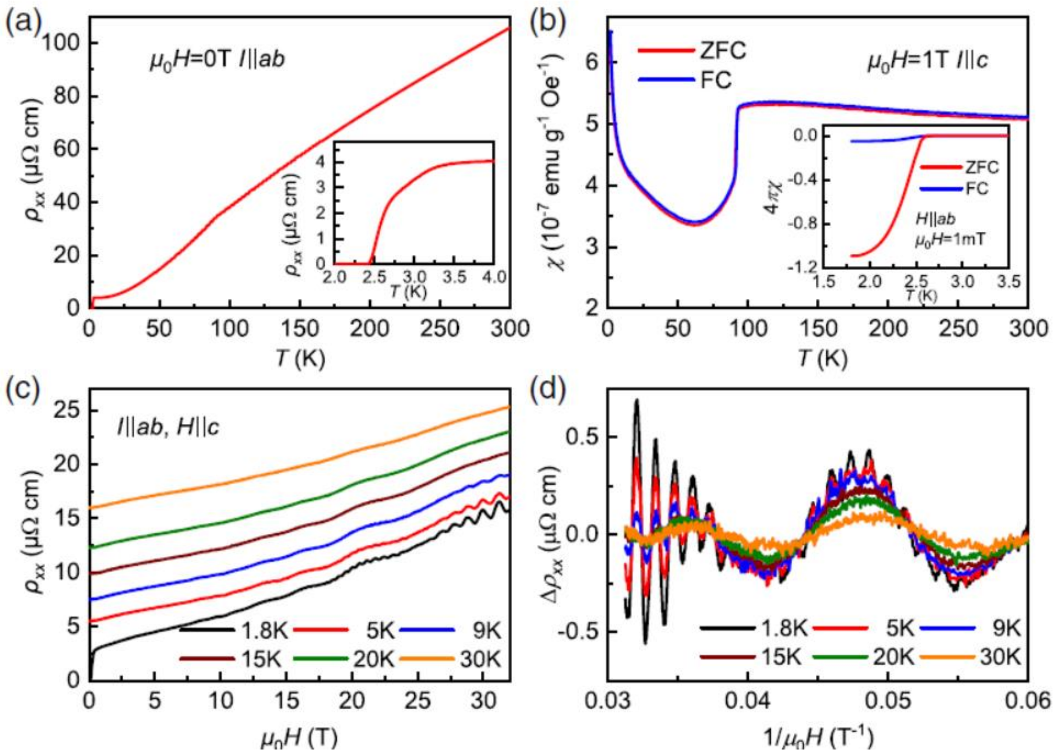

Fig.4 (a) temperature dependence of in-plane resistivity; (b) temperature dependence of susceptibility; (c) field dependence of magnetoresistance; (d) SdH oscillation part from magnetoresistance versus 1/H

- **Altering hydrogenation pathways in photocatalytic nitrogen fixation**

Photocatalytic N_2 fixation is an attractive alternative NH_3 synthesis method to the Haber-Bosch process. It is a fundamental yet challenging task to gain comprehensive understanding on how the associative pathways are influenced and altered by the fine structure of catalysts, which eventually holds the key to significantly promote the practical implementation. The research team led by Prof. Xiong Yujie and Prof. Gao Chao from the University of Science and Technology of China (USTC) cooperated with the computational research team led by Prof. Wu Xiaojun in USTC. Taking the TiO_2 as a catalyst model, they revealed that tuning the local electronic structure of surface oxygen vacancies by Fe dopants altered the hydrogenation of N_2 from associative alternating pathway to more favorable associative distal pathway. The characterization demonstrated that the doped Fe could induce the formation of oxygen vacancies by SHMFF, which brought about abundant active sites for N_2 reduction reaction. This work provided fresh hints for rationally controlling the reaction pathways toward efficient photocatalytic nitrogen fixation, which was published in *Angewandte Chemie-International Edition.* (Fig.5)

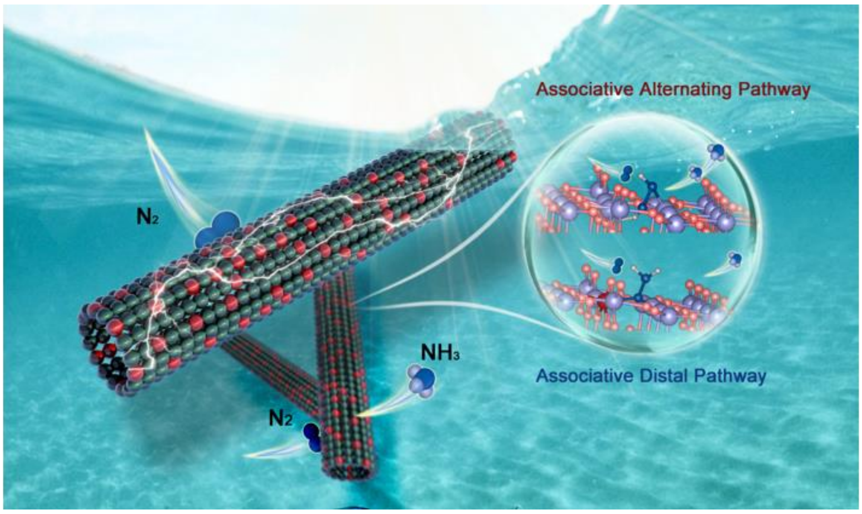

Fig.5 Illustration for altering hydrogenation pathways in photocatalytic N_2 fixation by tuning local electronic structure of oxygen vacancy with dopant

- **Development of a modular photoswitch cpLOV2 for optogenetic engineering**

Light-oxygen-voltage 2 (LOV2) domain is a blue light-sensitive photoswitch, which affords a limited interaction surface for caging the effector. It often takes tremendous engineering efforts to design a successful optogenetic tool. Prof. Wang Junfeng from CHMFL, collaborated with Prof. Yun Huang and Prof. Yubin Zhou from Texas A&M University, and Prof. Gang Han from University of Massachusetts Medical School, by taking the advantage of the NMR spectrometers of SHMFF, designed a circular permutated LOV2 (cpLOV2), which provided more choices for optogenetic application developments. Researchers demonstrated the use of cpLOV2-based optogenetic tools to reversibly gate ion channels, antagonize CRISPR–Cas9-mediated genome engineering, control protein subcellular localization, reprogram transcriptional outputs, elicit cell suicide and generate photoactivatable chimeric antigen receptor T cells for inducible tumor cell killing. This work was published in *Nature Chemical Biology*. (Fig.6)

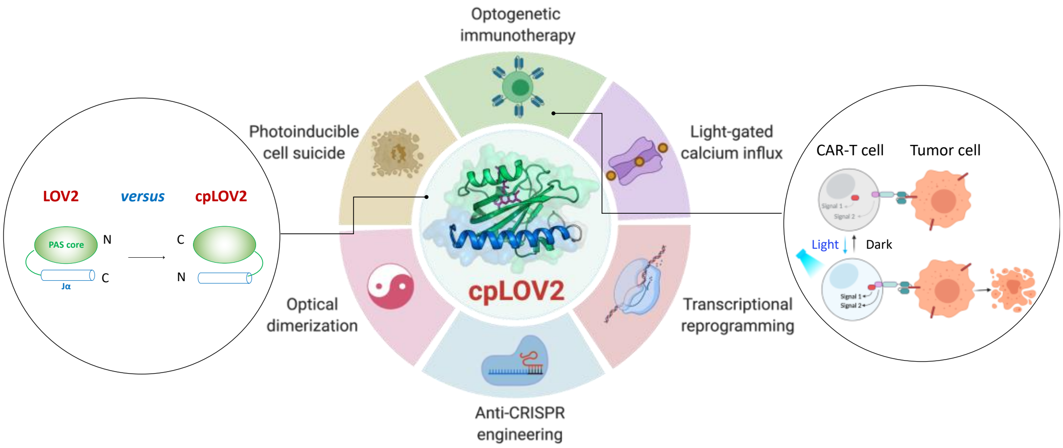

Fig.6 The design of cpLOV2 and its extended application in optogenetic engineering

- **Structures of novel G-quadruplexes and their interactions with ligands provide new targets for tumor therapy**

Telomere, segment of DNA occurring at the ends of chromosomes, displays a high relationship with aging, revolution of stem cell, and proliferation of tumor. Characterized with G-quadruplexes folding, telomeric DNA attracts a lot of research interest. Relying on the NMR spectrometers of SHMFF, the folding properties of telomeric DNA were investigated and two novel G-quadruplexes were found by the Prof. Zhang Na team from CHMFL.

First, a trimolecular GQ (tri-GQ) is assembled by the self-trimerization of d(GTTAGG). Interestingly, conformation exchange occurs spontaneously between folded tri-GQ and un-folded single-strand (Fig.7). Second, coexisting pseudo-mirror heteromolecular telomeric G-quadruplexes are assembled by sequence d(GGGTTAGGGTTAGGGT) and d(TAGGGT). Moreover, the two similar conformations can be differentially recognized by Thioflavin T (Fig.7). Both findings above were published in the journal of *Nucleic Acids Research*.

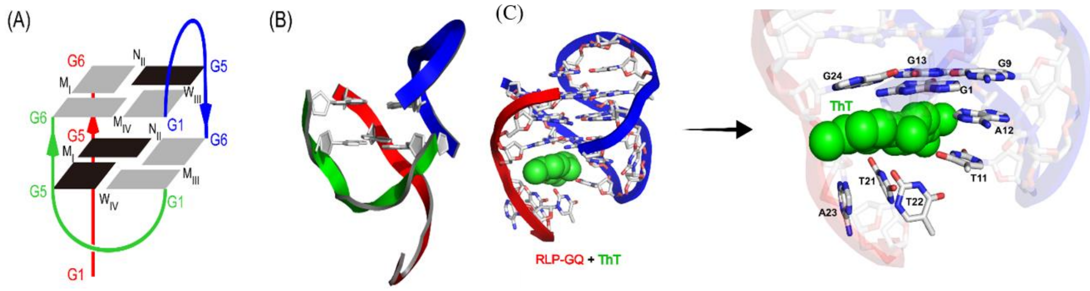

Fig.7 (A)(B)Tri-GQ assembled by d(GTTAGG) (PDB: 6M05); (C) The representation of binding site between RLP-GQ and ThT.

- **Nano-scale borate bioactive glass efficiently repairs damaged skin**

In the field of skin tissue repair, how to prepare a borate bioglass that has both non-biological toxicity and excellent tissue repair properties is an urgent problem to be solved. Prof.Wang Junfeng's team from CHMFL innovatively used flow phase micron-scale borate bioglass for in vitro pretreatment by NMR spectrometers of SHMFF, and finally obtained Nano-HCA@BG with a nano-scale (~50 nm) surface covered with an amorphous HCA (Hydroxy-Carbonated Apatite) layer. Compared with 45S5®, Hydroxyapatite and micron-sized borate bioglass, the sustained-release B, Ca and other elements of nano-HCA@BG not only effectively accelerate the migration of cells in the wound but also upregulate the expression of vascular-related growth factors in the wound. Moreover, the amorphous HCA layer on the glass surface reduces the rapid release of the glass and accelerates the deposition of collagen at the wound to promote wound healing. The technology is expected to carry out joint research with companies and complete preclinical experiments within 2-3 years. The related results were published in *Chemical Engineering Journal*. (Fig. 8)

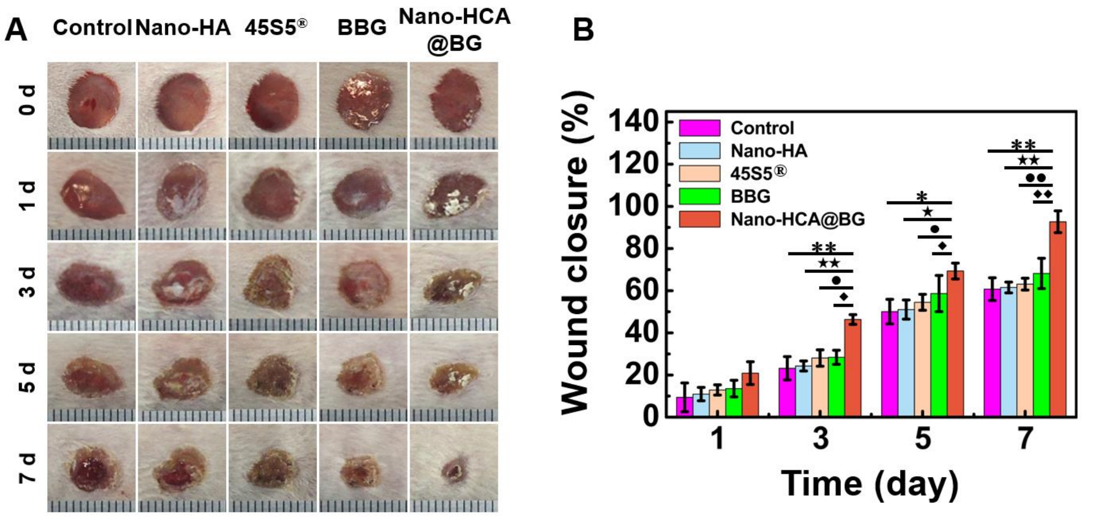

Fig.8 Wound healing process in a mouse skin defect model. A. The wound healing images of the mouse skin on the 0th, 1st, 3rd, 5th, and 7th days of different control groups and Nano-HCA@BG (the unit scale of the scale in the photo is 1mm); B. the corresponding wound healing of mice rate statistics

Construction, Operation and Upgrading

In 2021, SHMFF served users from 64 universities and institutes, covering 300 projects. Planned running time is 49009 hrs, and actual running time is 51407 hrs.

	HW/WM	SM3+NMR	SM4+MRI
Planned time(hrs)	**1500**	**8228**	**2700**
Actual time(hrs)	**1567**	**8293**	**2694**

	Planned time（hrs）	Actual time(hrs)
SM1	2968	3040
SM2	6552	6984
PPMS	6600	7368
Cryostat	880	800
MPMS	7440	7704
ESR	1200	1585
Raman	900	930
FTIR	790	793
XRD	1135	1097

	Planned time（hrs）	Actual time(hrs)
Extreme Low Temperature Transport System	2100	2280
Ultra-pressure Physical Measurement System	940	1100
STM-MFM-AFM Combo	4096	4128
Condensed Nuclear Magnetic Resonance	980	1044

Scientific & Technical Personnel and Talent Training

CHMFL has a total of 196 employees including 55 professors, 52 associate professors, and 89 other staff. CHMFL also has 26 postdocs and 296 graduate students.

Total number of facility staff	Classified by positions			Classified by professional titles			Students			In-house post-doctor	Introduced talents *
	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		
196	105	79	12	107	72	17	32	17	296	26	1

Cooperation and Exchange

International cooperation and exchanges were carried out mostly online in 2021. Domestic scholars and experts were invited to visit SHMFF and gave academic presentations. The numbers of forums in recent five years are as follows:

Year	2021	2020	2019	2018	2017	2016
No. of presentations	9	7	17	23	15	28

From October 21st to 23rd, the 9th "Magnetotactic Bacteria Research and Its Application" conference co-organized by CHMFL was successfully held in Hefei. Focusing on the theme of "Magnetotactic Bacteria and Their Applications", the conference exchanged the latest frontier trends and future development trends in the field, and built a platform for the participants to exchange academic ideas. This conference promotes the cross-integration, cooperation and exchange of different disciplines in the field of magnetic biology.

The 9th Conference of "Magnetotactic Bacteria Research and Its Application"

Chronicle of Events

- Apr. 17th-18th "SHMFF Users' Workshop of Transport Characteristics in High Magnetic Field" was held.
- Apr. 27th SHMFF was awarded "National Worker's Pioneer".
- May 13rd The maintenance and transformation project of cooling water system in SHMFF successfully passed the acceptance.
- Jun. 29th-30th "SHMFF Users' Workshop of High Resolution Imaging in Real Space under High Magnetic Field" was held.
- Oct.21st-23rd The 9th conference of "Magnetotactic Bacteria Research and Its Application" was held.
- Nov.26th-27th The meeting of the SHMFF Science&Technology Committee and User Committee was held.

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