High Field Laboratory for Superconducting Materials

Institute for Materials Research, Tohoku University

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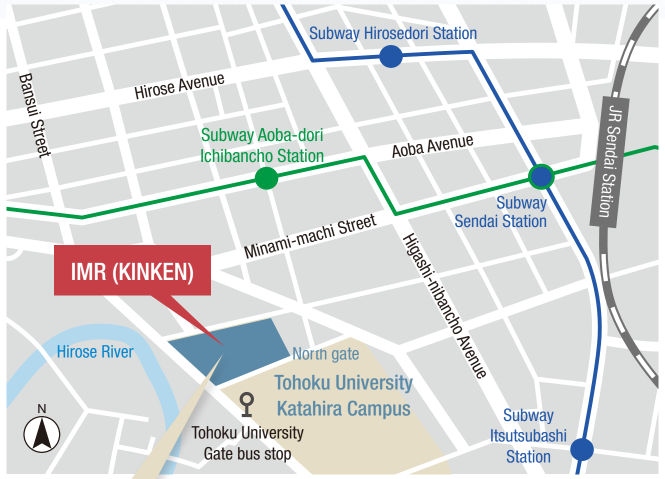
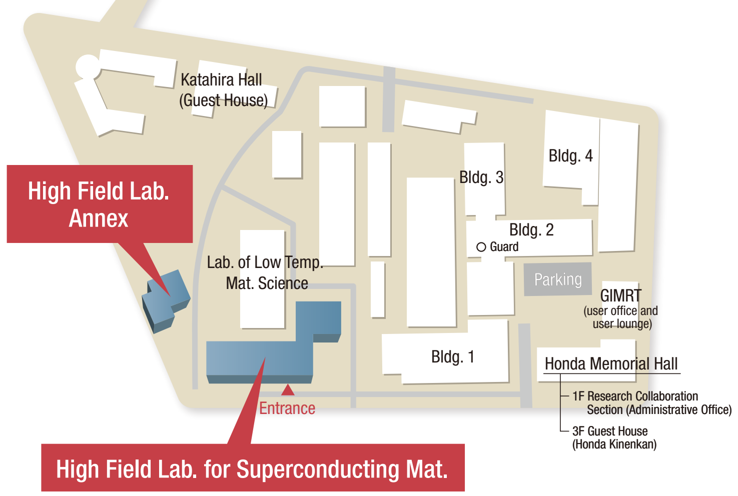
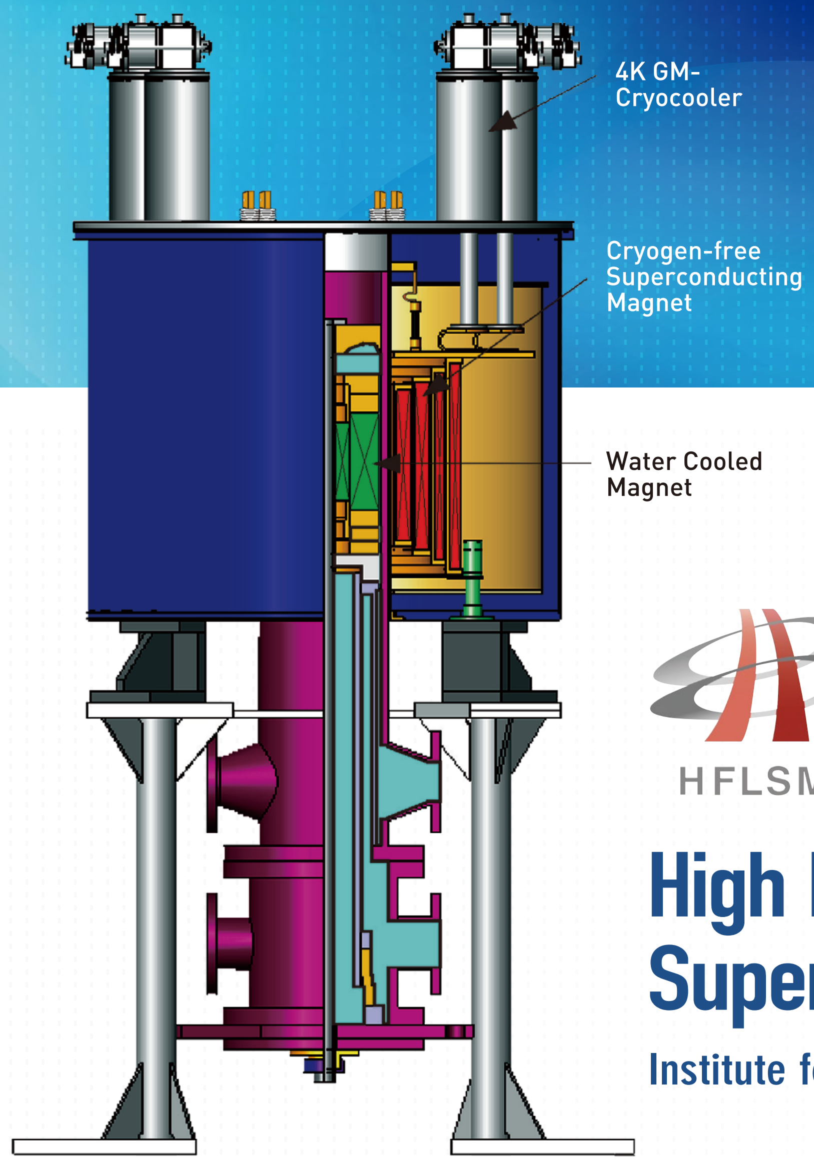
Access

- From the Sendai Airport to Sendai Station, 25 min by Airport Access Train
- 15 min on foot from the Sendai Station West Exit
- 10 min on foot from the Aoba-dori Ichibancho Subway Station South Exit 1







HFLSM

High Field Laboratory for Superconducting Materials

Institute for Materials Research, Tohoku University

HFLSM

Milestones

1916	Initiation of the Second Division of "the Provisional Institute of Physical and Chemical Research" at Tohoku University
1922	Establishment of Research Institute for Iron, Steel and Other Metals (RIISOM)
1939	Construction of Kapitza-type pulse field magnet (27.3 T, 5 ms)
1959	Construction of Bitter-type magnet (former High Field Lab.) (10 T with 3.5 MW and 60 m³/h water flow)
1972	Establishment of Michikawa Explosion High Field Laboratory (100 T pulsed field by flux compression)
1977	Upgrading water cooling system for a bitter-type magnet (12.5 T with 130 m³/h water flow)
1981	**Establishment of High Field Laboratory for Superconducting Materials (1st. Phase)**
1982	Installations of the 16.5 T superconducting magnet and a 8 MW electrical power source/water cooling system.
1983	Completion of the 20 T hybrid magnet, 20T-HM (20.5 T)
1984	Completion of the 23 T hybrid magnet, 23T-HM (23.2 T)
1986	Completion of the 31 T hybrid magnet, 31T-HM (31.1 T)
1987	The institute was redesignated as the Institute for Materials Research (IMR) and was reorganized as a national collaborative research institute.
1991	**Reorganization of the High Field Laboratory for Superconducting Materials (2nd. Phase)**
1992	World's first successful practical cryogen-free superconducting magnet (4 T).
1998	Development of a 15 T cryogen-free superconducting magnet
2001	**Reorganization of the High Field Laboratory for Superconducting Materials (3rd. Phase)**
2003	Development of the world's first cryogen-free hybrid magnet
2004	Development of an 18 T cryogen-free superconducting magnet (upgraded to 20 T in 2012)
2005	Development of a 28 T cryogen-free hybrid magnet
2011	Upgrade of electrical power source, achieving high-precision of 100 ppm
2016	Development of a 25 T cryogen-free superconducting magnet World-record 24.6 T was achieved
2020	The world record is updated to 25.1 T
2022	25T cryogen-free superconducting magnet has achieved 1000 days operation
2024	33T cryogen-free superconducting magnet instllaton has been started
2025	Operations of hybrid magnets are closed

31T-HM

4T-CSM

15T-CSM

20T-CSM

28T-CHM

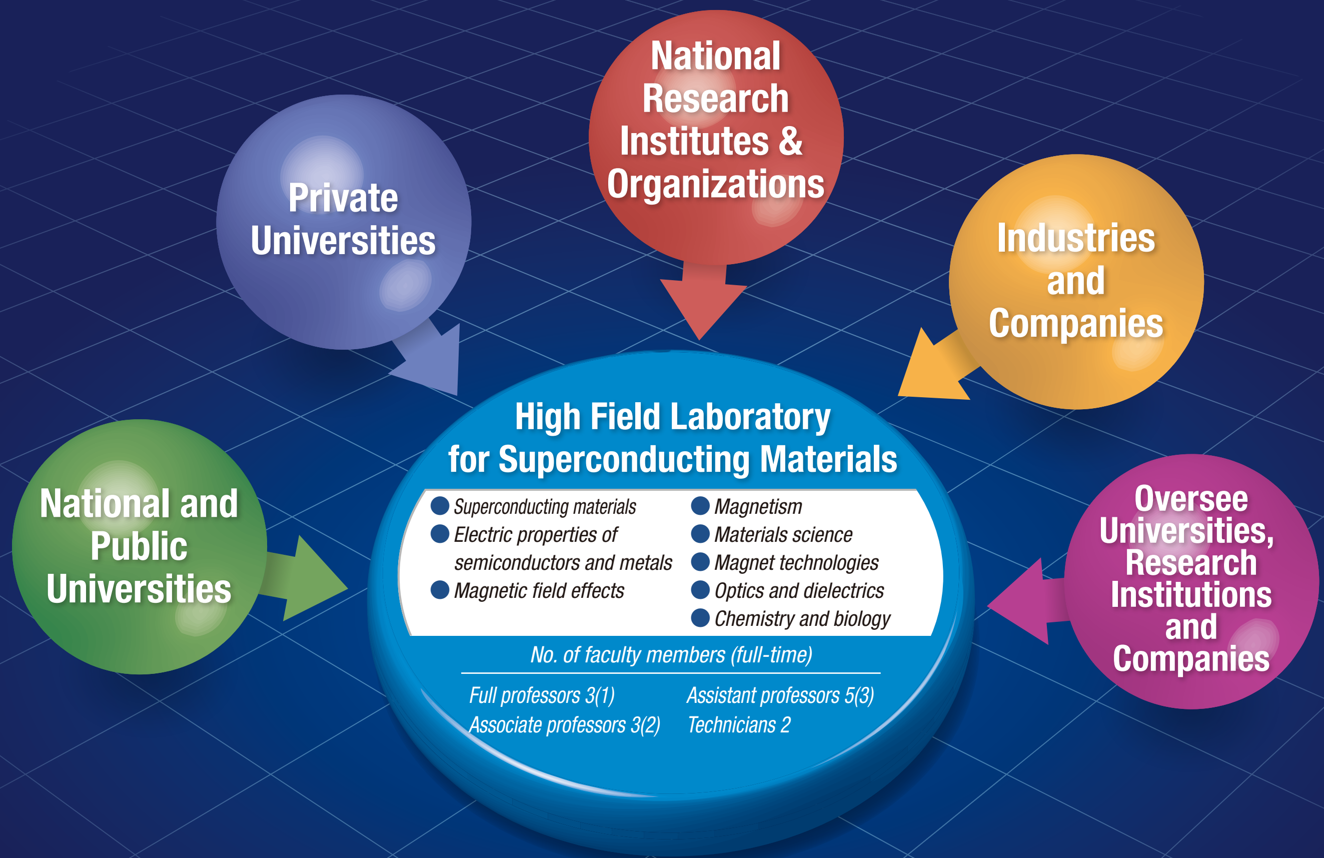
25T-CSM

High Field Laboratory for Superconducting Materials

The High Field Laboratory for Superconducting Materials (HFLSM), one of five premier steady field facilities in the world, is a research center developing innovative functional materials such as magnetic or superconductive materials. As a research center founded at Institute for Materials Research, one of the global leaders in materials science, the laboratory is conducting a variety of basic and applied studies of materials in extremely high magnetic fields. The center provides high field magnets including a hybrid magnet, a cryogen-free hybrid magnet and various cryogen-free superconducting magnets, and unique instruments for investigating materials in high magnetic fields for numerous domestic and overseas users. HFLSM is one of the core facilities in the new international collaboration scheme of IMR stated in 2018, Global Institute for Materials Research Tohoku(GIMRT), which is designated as the one of six International Joint Usage / Research Center Program of the MEXT.

The 1st phase of the HFLSM started in 1981 as part of the national fusion reactor project. It eventually grew to a more general user oriented High Field Laboratory. A core of the laboratory is a hybrid magnet combining an outer superconducting magnet and an inner water-cooled magnet, which can generate stronger magnetic fields than those generated by the superconducting magnet alone. It established the world record of 31.1 T in 1986. The stored energy of the superconducting outsert magnet is roughly 20 MJ and the electrical power consumptions of water-cooled magnet is 8 MW, The laboratory succeeded in development of the world's first and the unique cryogen-free hybrid magnet of 28 T in 2005.

The Laboratory has devoted tremendous efforts over many years to the development of cryogen-free superconducting magnets, which can produce high-quality and long stable high magnetic fields. In 2004, the 18 T cryogen-free superconducting magnet was operated successfully, then later upgraded to 20 T. In 2015, the 25 T cryogen-free superconducting magnet was installed successfully as the highest field superconducting magnet for user programs. For next years, the Laboratory is going to install 30 T cryogen-free superconducting magnet.

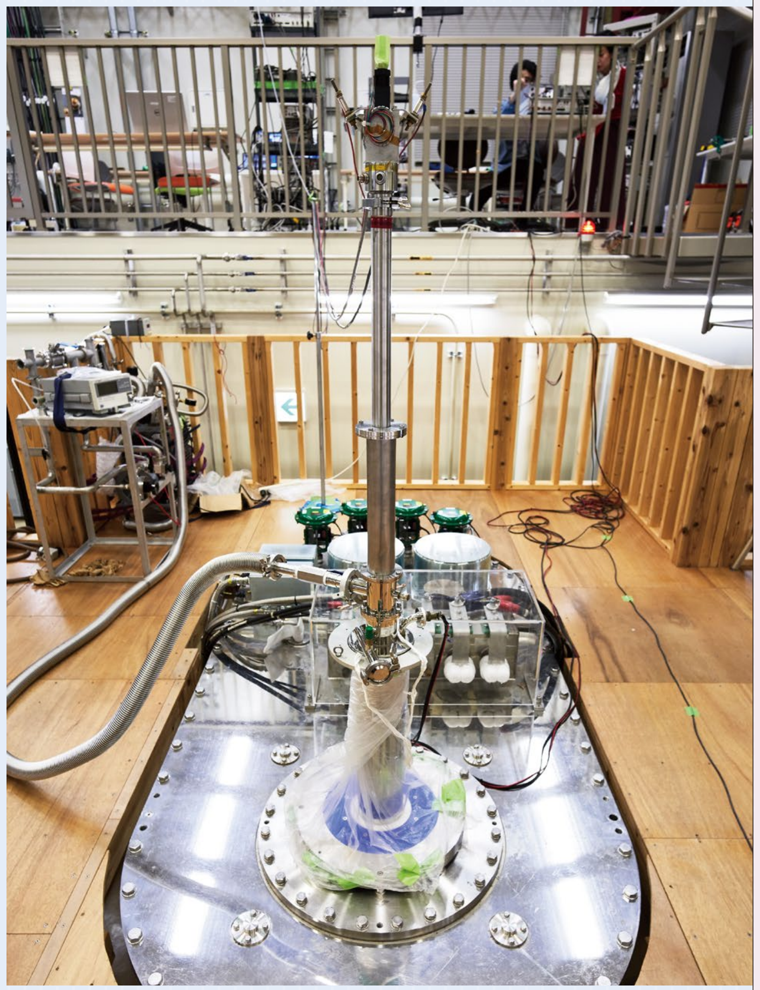


At the world's vanguard of advanced studies in high magnetic fields.

Core studies and the missions

1 Materials science in high magnetic fields

Cryogen-free superconducting magnets can produce long-lasting and high-quality magnetic fields that enable us to use advanced environments for studies of phenomena such as high quality material characterizations, magnetic field orientation, magnetic levitation, and heat treatment in magnetic fields. The development of new materials and the discovery of new material processing methods are investigated using these unique opportunities.



2 Discovering new physical phenomena under extreme conditions

Under multiple extreme conditions combining high magnetic fields with other extremes such as ultra-low temperatures down to 20 mK, high pressures up to 2.5 GPa, and temperatures as high as 1200°C, varieties of studies are conducted with the objective of discovering new states of matter and novel physical phenomena.

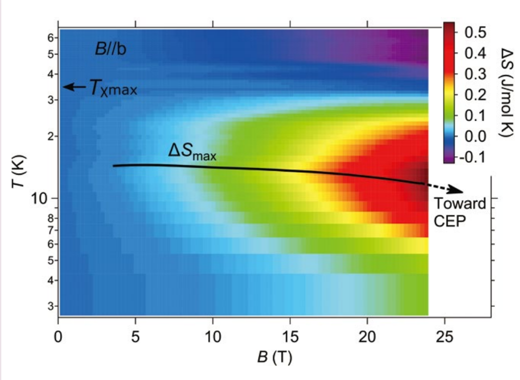
3 High magnetic field technologies based on superconductivity

The laboratory is the first in the world to develop cryogen-free hybrid magnets and 25 T cryogen-free superconducting magnet successfully using our unique magnet technology based on the superconductivity. The next missions are the developments of a 30 T or higher superconducting magnet and the highly efficient advanced hybrid magnet system.

From recent research results

1 Study of unconventional superconductivities in high magnetic fields

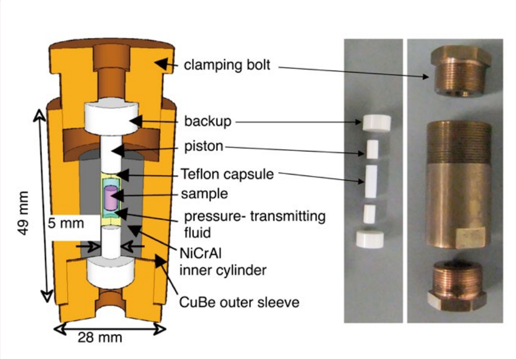
Phase diagrams of unconventional superconductors such as UTe_2 have been examined by the precise physical property measurement in 25 T cryogen-free superconducting magnet. The entropy analysis reveals its enhancement toward the critical end point (CEP) when the magnetic field is applied along the b axis. The combination of the very clean, extremely low-noise high magnetic fields, varieties of advanced instrumentation and unlimited magnet operation time offers the one of the best high magnetic field experimental environments for global users.



H. Sakai *et al.*, Phys. Rev. Lett. **130** (2023) 196002.
Y. Tokiwa *et al.*, Phys. Rev. B **109** (2024) L140502.

2 2.5 GPa-25 T high-pressure-high-field electron spin resonance confirmed a new type of singlet state

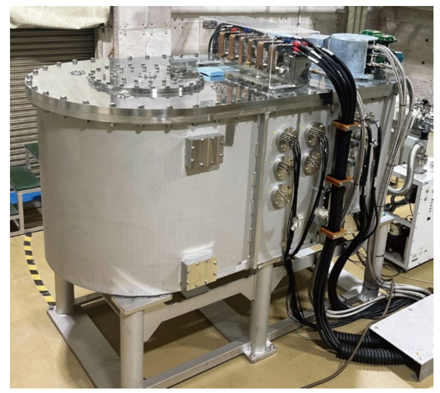
A high-pressure electron spin resonance probe has successfully installed into the world's highest-field cryogen-free superconducting magnet having a maximum central field of 24.6 T. The high pressure of 2.5 GPa is achieved by the specially designed piston-cylinder pressure cell using THz-wave-transparent components. As the first application, we observed that the orthogonal dimer spin system $SrCu_2(BO_3)_2$ undergoes a quantum phase transition from the dimer singlet ground to the plaquette singlet ground states.



T. Sakurai *et al.*, J. Magn. Reson. **296** (2018) 1.
K. Y. Povarov *et al.*, Nature Commun. **15** (2024) 2295.

3 Development of a cryogen-free superconducting magnet

We successfully generated 25.1 T at a 52 mm room temperature bore based the original cryogen-free superconducting magnet technology. The magnet, which comprises an inner coil using high-strength $(Bi,Pb)_2Sr_2Ca_2CuO_y$ high-temperature superconducting wire, a middle coil made of high-strength CuNb/Nb Sn Rutherford cable, and the NbTi outer coil, generates a high-quality, extra stable, and long-lasting stable steady field for user experiments. For the new development aiming at 40 T cryogen-free superconducting magnet, 33 T cryogen-free superconducting magnet installation has been started in 2024 by the support of Roadmap 2020 by MEXT.



K. Takahashi *et al.*, IEEE Transactions on Applied Superconductivity **34** (2024) 4601905.
S. Awaji *et al.*, *ibid.* **35** (2025) 4300406.

Joint Research at the High Field Laboratory for Superconducting Materials

(2010–2025)

Joint research with private enterprises

Twelve enterprises

- Sumitomo Heavy Industries Ltd.
- Furukawa Electric Co., Ltd.
- Toshiba Corporation
- Chubu Electric Power Co. Inc.
- Keihin Corporation
- Fujikura Ltd.
- Railway Technical Research Institute
- Daidoh Steel
- Nippon Steel
- Faraday Factory Japan (LLC)
- SWCC co. ltd.
- SuNAM co. ltd.
- Shanghai Superconductor Technology co. ltd.

National Research and Development Agencies

Eight institutions

- National Institute for Fusion Science
- High Energy Accelerator Research Organization
- Japan Aerospace Exploration Agency
- National Institute of Advanced Industrial Science and Technology
- Japan Atomic Energy Agency Advanced Science Research Center
- National Institute for Materials Science
- Institute of Physical and Chemical Research (RIKEN)
- Institute for Molecular Science

Joint research with foreign institutions

Twelve institutions

- Institute of Metallurgy and Materials Science, RAS
- Max Planck Institute for Solid State Physics
- Andong National University
- Institute of Electrical Engineering, Chinese Academy of Sciences
- National Taiwan Normal University
- Helmholtz-Zentrum Dresden-Rossendorf
- Dankook University
- Durham University
- Massachusetts Institute of Technology
- Chung-Ang University
- Universitas Indonesia
- The University of Manchester

Universities

56 universities

- Hirosaki Univ.
- Hokkaido Univ.
- Iwate Univ.
- Sophia Univ.
- Kagoshima Univ.
- Kyoto Univ.
- Kyushu Univ.
- Nagoya Univ.
- Nihon Univ.
- Ryukoku Univ.
- Shizuoka Institute of Science and Technology
- Tokyo Metropolitan Univ.
- Tokushima Univ.
- The Univ. of Tokyo
- Fukushima Medical Univ.
- Keio Univ.
- Tohoku Gakuin Univ.
- Tokai Univ.

(and 38 other universities)

International Collaboration Network-GIMRT

Japan High Magnetic Field Co-laboratory-Sendai Branch

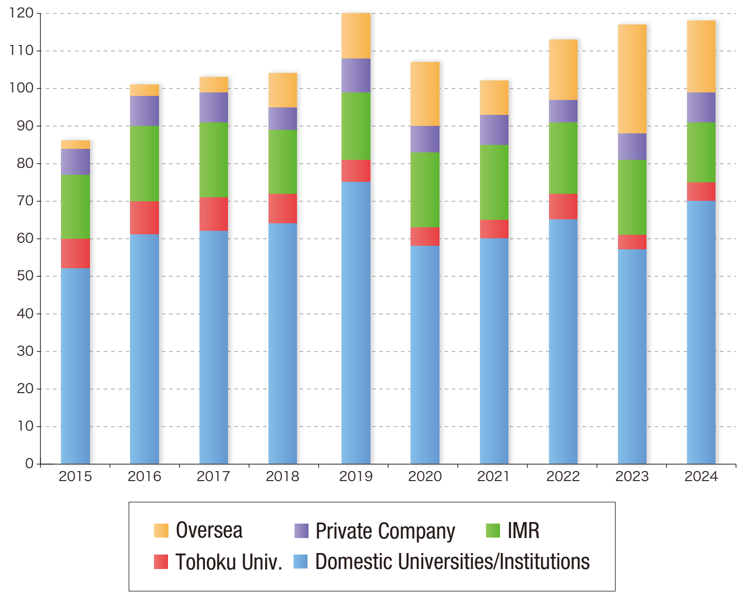
Tohoku University

Five faculties

- Graduate School of Science
- School of Engineering
- Advanced Institute for Materials Research
- Center for Low Temperature Science
- Institute for Materials Research

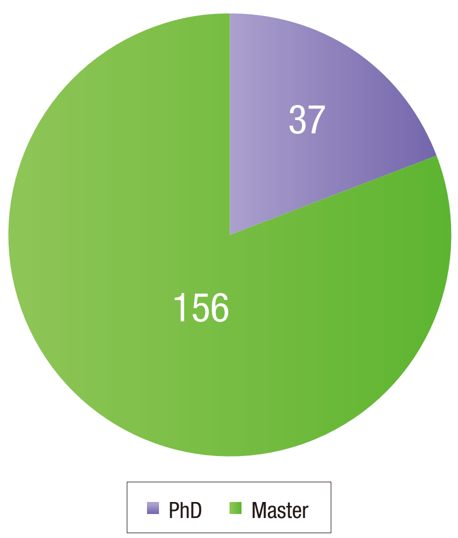
Joint use and Research Proposals

(2015–2024)



Degrees awarded

(2015–2024)



Magnets and experimental equipments at the High Field Laboratory for Superconducting Materials

Magnets		20T-SM	18T-SM	15T-SM	25T-CSM	15T-CSM	10T-CSM	11T-CSM	8T-CSM	6T-CSM	5T-CSSM
Effective bore diameter (mm)		52	52	52	52	52	100	52	220	220	52×10
Magnetic field (T)		20	18	15	25	15	10	11	8	6	5
装　置											
Magnetic levitation					●						
Heat treatment (1200°C)					●	●	●				
X-ray diffraction											●
Specific heat		●	●	●	●						
Thermal conductivity			●	●							
Differential thermal analysis					●	●	●				
Extremely low temperatures	^{3}He refrigerator	●	●	●	●						
	Dilution refrigerator	●									
Ultrasound				●	●						
Transport characteristics	Electrical resistance	●	●	●	●						
	Two axis rotator	●	●	●	●	●					
Critical current		●	●	●	●				●		
Electrochemistry					●	●			●	●	
Near infrared and visible spectroscopy			●	●	●						
NMR		●			●	●	●				
ESR		●	●	●	●	●	●				
Dielectric constant		●	●	●	●						
Magnetization	VSM				●	●					
	Extinction method	●	●								
	AC			●	●	●	●				
Magnetization (high temperature)	VSM				●	●	●	●			

From recent press releases and news

Thermodynamic approach for enhancing superconducting critical current performance

https://doi.org/10.1038/s41427-022-00432-1

M. Miura *et al.*, NPG Asia Materials **14** (2022) 85.

Field induced multiple superconducting phases in UTe2 along hard magnetic axis

https://doi.org/10.1103/PhysRevLett.130.196002

H. Sakai *et al.*, Physical Review Letters **130** (2023) 196002.

One-ninth magnetization plateau stabilized by spin entanglement in a kagome antiferromagnet

https://www.nature.com/articles/s41567-023-02318-7

S. Jeon *et al.*, Nature Physics **20** (2024) 435.