

Selected Topics in 2024 Research Highlight at HFLSM



28T-CHM



25T-CSM



High Field Laboratory for Superconducting Materials,
Institute for Materials Research, Tohoku University

< FRONT COVER EXPOSITION >

**Cryogen-Free 28 T Hybrid Magnet and
25 T Cryogen-Free Superconducting Magnet**

The world's first 28 T cryogen-free hybrid magnet developed by the HFLSM. The inner double Bitter type water-cooled resistive magnet generates 19.0 T in a room temperature experimental bore of 32 mm with the electric power of 7.2 MW. The outer cryogen-free superconducting magnet generates 9.0 T in a 360 mm room temperature bore. The cryogen-free superconducting magnet generates 25.1 T in 52 mm room temperature bore by the combination of metallic and high- T_c superconductors.

◇◆◇ Preface ◇◆◇

This booklet reports the highlights of research and the new improvements during FY2024 conducted at HFLSM: High Field Laboratory for Superconducting Materials at Sendai. Topics related to practical superconducting materials and magnets have been selected. These topics are important not only to the 33T-CSM projects, but also to various applications, such as fusion. Additionally, two-axis rotating probes are effective. They can now be combined with various measurements, such as transport, specific heat, NMR, and so on. Some of the selected topics are related to the two-axis rotation probe.

The hybrid magnet 30T-HM has supported the forefront of high-field research at HFLSM for more than 30 years, ever since it achieved the world record in 1986. The cryogen-free hybrid magnet 28T-CHM, incorporating a large-bore cryogen-free superconducting magnet, is the world's only cryogen-free hybrid magnet. Together with dilution refrigerators and ^3He refrigerators, these magnets have long underpinned ultra-low-temperature high-field experiments. As the realization of a 33 T cryogen-free superconducting magnet has become foreseeable, we have decided to conclude the operation of the hybrid magnets. We continue to advance our user program through the deployment of high-field cryogen-free superconducting magnets.

We hope that the booklet helps you to see the overview of our activities and stimulate future research collaborations with domestic and overseas users in HFLSM and in the High Magnetic Field Co-laboratory of Japan.

25 November 2025

Satoshi Awaji

Director of HFLSM

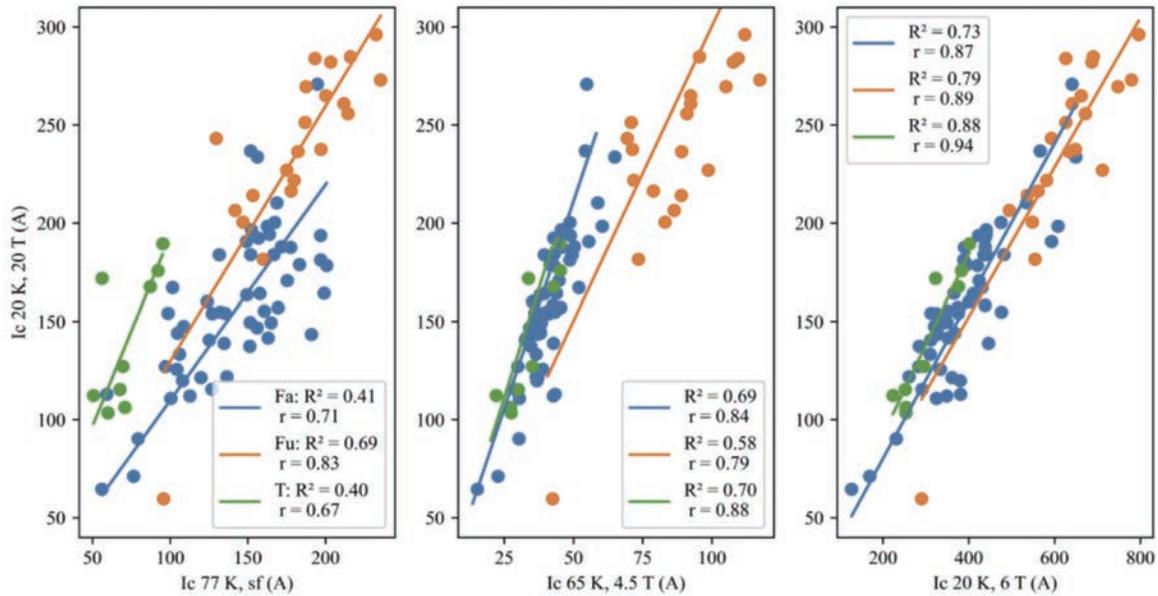
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Critical Current Correlations and Regressions Across the Superconducting Parameter Space of REBCO Wires, B||C



Commonwealth Fusion Systems (CFS) is pursuing the high-field approach to fusion energy, enabled by magnets composed of 4mm 2G REBCO wire. Most of these magnets will operate in the high field (20 T) and low temperature (~ 20 K) regime and therefore require characterization of the critical current at those parameters. The industry standard is to use (77 K, self-field) data for rapid characterization of critical current. However, I_c (77 K, SF) is a poor predictor of performance at high (> 6 T) field, low temperature applications, and so more predictive correlations are extremely desirable. This study examines critical current correlations between high temperature (44-77 K) with low field (0-5 T) and low temperatures (20 K) with high field (6-20 T) from multiple manufacturers. Employing these correlations will allow for the use of cheaper and simpler critical current test systems that can still accurately predict high field, low temperature performance. Moreover, they will provide higher confidence in the predicted performance of magnets. This paper presents the predictive ability of these correlations and the associated error analysis.

A. Greenberg¹, J.L. Cheng¹, A. Francis¹, M. Shepherd¹, T. Okada², S. Awaji², B. Sorbom¹

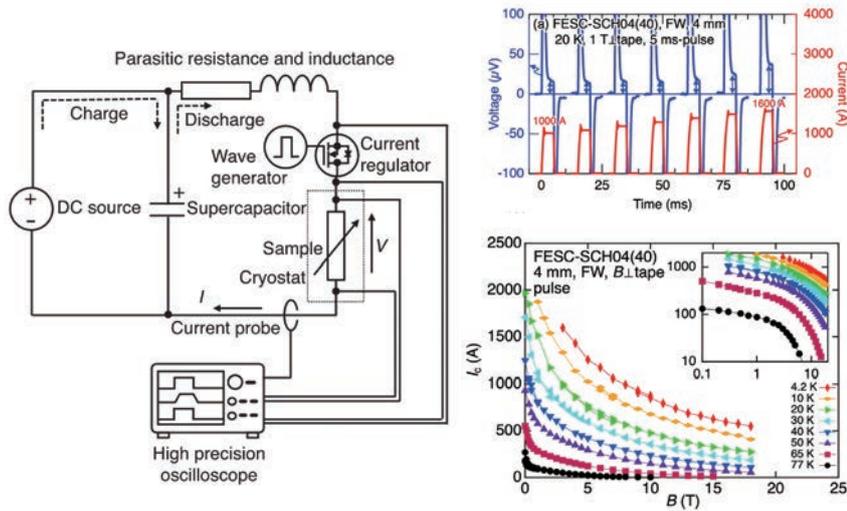
¹Commonwealth Fusion Systems, Devens, Massachusetts

²IMR, Tohoku Univ.

Reference: A. Greenberg *et al.*, "Critical Current Correlations and Regressions Across the Superconducting Parameter Space of REBCO Wires, B||C", *IEEE Trans. Appl. Supercond.* **34** (2024) 6602105

Characterization of In-Field Critical Currents in REBCO Tapes over Wide Temperature Range by Pulsed Current Source with Supercapacitor

5 kA パルス電流を用いた REBCO 線材の強磁場中臨界電流評価



A pulsed-current system using supercapacitors was developed to measure the critical current (I_c) of REBCO tapes under high magnetic fields and variable temperatures. The system generates up to 2 kA pulses, enabling precise I_c measurements at 4.2–77 K and up to 19 T. Such kA-class measurement capability is essential for evaluating full-width REBCO tapes but has not previously existed. Results agree with DC data within 4%, demonstrating reduced heat generation and validating this method for high-field I_c characterization.

Y. Tsuchiya¹, K. Mizuno², Y. Kohama³, A. Zampa³, T. Okada¹, and S. Awaji¹

¹ IMR, Tohoku Univ., ² MTL, ³ ISSP, Univ. Tokyo

Reference: Y. Tsuchiya *et al.*, “Characterization of In-Field Critical Currents in REBCO Tapes Over Wide Temperature Range by Pulsed Current Source with Supercapacitor”, IEEE Trans. Appl. Supercond. **34** (2025) 9500207.

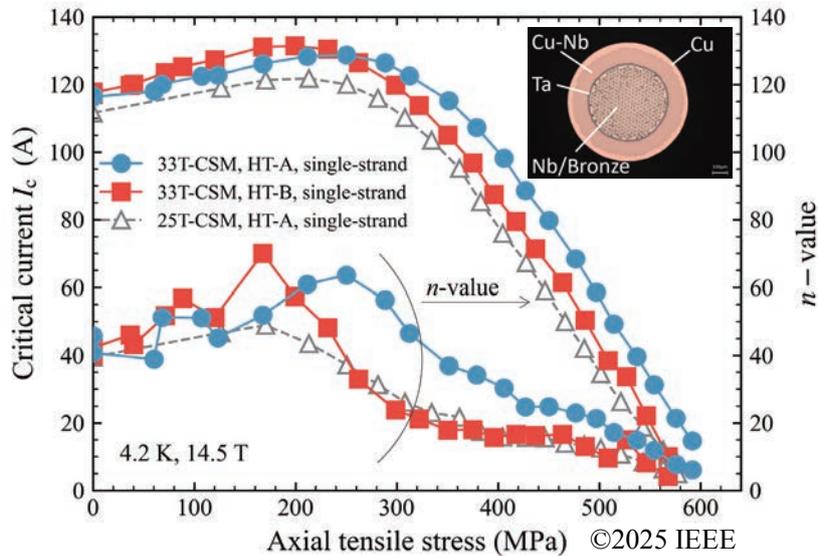
スーパーキャパシタを用いたパルス電流システムを開発し、高磁場・可変温度下で REBCO 線材の臨界電流 (I_c) を測定した。本システムは最大 2 kA のパルスを発生し、4.2–77 K, 19 T までの精密測定を可能にした。kA 級の測定能力は全幅 REBCO 線材の評価に不可欠であるが、これまで実現例はなかった。直流法との結果は 4% 以内で一致し、発熱を抑制した高磁場 I_c 評価法として有効であることを確認した。

土屋 雄司¹, 水野 謙一郎², 小濱 芳允³, Alexandre Zampa³, 岡田 達典¹, 淡路 智¹

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Conduction Characteristics Under Stress of Cu-Nb/Nb₃Sn Wires for 33T Cryogen-Free Superconducting Magnets

33 T 無冷媒超伝導磁石用 Cu-Nb/Nb₃Sn 超電導線材の応力下通電特性



Nb₃Sn wires reinforced with Nb-rod method Cu-Nb exhibit excellent superconducting properties under stress. For the 33 T cryogen-free superconducting magnet (33T-CSM) under development at Tohoku University, we designed a high-strength, high- I_c wire based on the Cu-Nb/Nb₃Sn wire used in the 25 T cryogen-free magnet. Enhancements include increasing the Cu-Nb reinforcement fraction from 35% to 38%, Nb content from 20% to 25%, and modifying the bronze composition to Cu-15.7 wt% Sn-0.3 wt% Ti. These changes improved strength and I_c , allowing the wire to maintain critical current density without degradation up to 345 MPa, exceeding the 275 MPa tensile stress expected in 33T-CSM.

R. Tanituchi¹, M. Sugimoto¹, H. Fukushima¹, K. Nakao¹, K. Hirose¹, S. Awaji² and H. Oguro³
¹ Furukawa Electric Co. Ltd., ² IMR, Tohoku Univ., ³ Fac. of Eng., Tokai Univ.

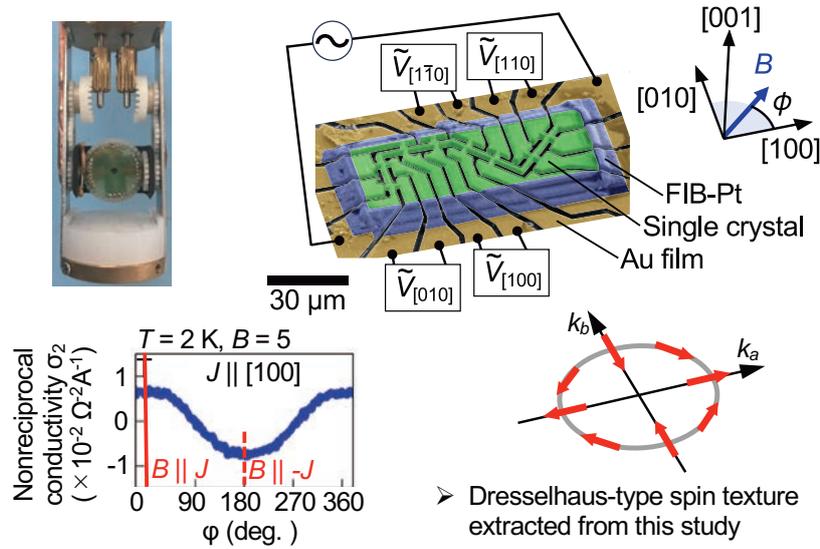
Reference: R. Taniguchi *et al.*, “Tensile/Transverse Compression Stress Characteristics of Cu-Nb Reinforced Nb₃Sn Wires for 33T Cryogen-Free Superconducting Magnet”, IEEE Trans. on Appl. Supercond. **35** (2025) 6001605.

Nb ロッド法 Cu-Nb により強化された Nb₃Sn 線材は優れた応力下超電導特性を示す。我々は、東北大学で開発中の 33 T 無冷媒超伝導磁石 (33T-CSM) 用に、25T 無冷媒超伝導磁石用 Cu-Nb/Nb₃Sn 線材を基に、断面積に占める Cu-Nb の割合を 35%から 38%、Cu-Nb 中の Nb の量を 20%から 25%に増やし、ブロンズ原料を Cu-14wt%Sn-0.2wt%Ti から Cu-15.7%Sn-0.3wt%Ti に変更することで高強度化と高 I_c 化を図った線材を開発した。その結果、33T-CSM で Nb₃Sn 線材にかかる最大引張応力 275 MPa を超える 345 MPa まで I_c が低下しないことが分かった。

谷口 諒¹, 杉本 昌弘¹, 福島 弘之¹, 中尾 健吾¹, 廣瀬 清慈¹, 淡路 智², 小黒 英俊³
¹ 古河電工, ² 東北大金研, ³ 東海大工

Probing Spin Texture through Nonreciprocal Transport

非相反伝導で探るスピントクスチャ —磁性半導体 $\text{EuIr}_4\text{In}_2\text{Ge}_4$ を例に—



Spin textures, where a spin of electron couples with its momentum, play a key role in spintronic functionality, yet experimental methods to probe them are limited. In this study, we developed an electrical approach to detect spin textures by precisely measuring nonreciprocal transport, where resistance changes with current polarity, in the magnetic semiconductor $\text{EuIr}_4\text{In}_2\text{Ge}_4$. The observed Dresselhaus-type spin texture was confirmed using focused-ion-beam microfabrication combined with angle-dependent measurements. This technique offers a new way to electrically probe spin textures in bulk materials and opens paths toward discovering functional quantum materials.

M. Kimata^{1,2}, A. Yokoyama¹, R. Nakachi³, Y. Homma¹, A. Nakamura¹, Y. Shimizu¹, D.X. Li¹, A. Miyake¹, F. Honda⁴, D. Aoki¹, Y. Ōnuki^{3,5}, T. D. Matsuda³
¹IMR, Tohoku Univ., ²ASRC, JAEA, ³Dep. of Phys., Tokyo Metropolitan Univ., ⁴Cent. Inst. of Rad. Sci. and Safety, Kyushu Univ., ⁵RIKEN CEMS

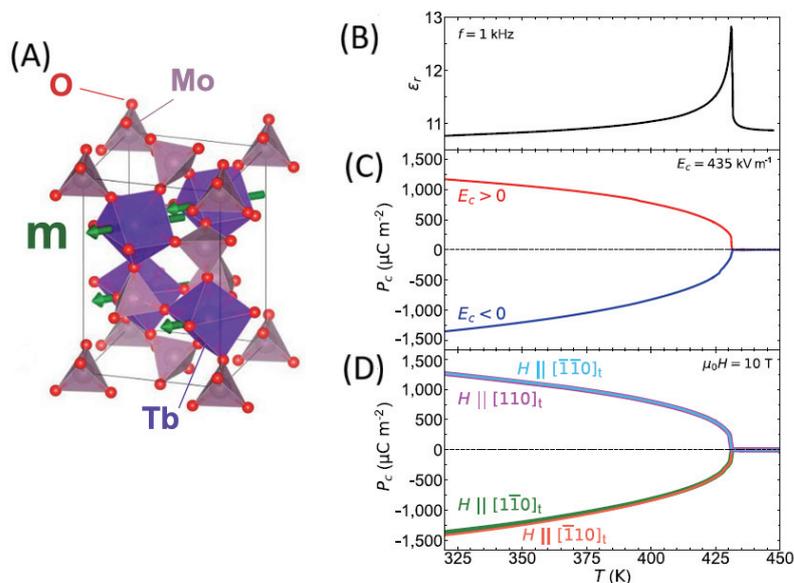
Reference: A. Yokoyama, M. Kimata, *et al.*, "Two-Dimensional Dresselhaus-Type Spin Texture and Nonreciprocal Magnetoresistance in Magnetic Semiconductor $\text{EuIr}_4\text{In}_2\text{Ge}_4$ ", *J. Phys. Soc. Jpn.* **94**, (2025) 023701.

電子のスピンと運動量が結びつく「スピントクスチャ」は、スピントロニクス機能を担う重要な電子状態ですが、その観測手法は限られていました。本研究では、磁性半導体 $\text{EuIr}_4\text{In}_2\text{Ge}_4$ において、電流の正負で抵抗が変化する非相反電気伝導を精密に測定し、ドレッセルハウス型スピントクスチャの存在を実証しました。集束イオンビーム(FIB)加工と角度依存測定を組み合わせた本手法は、バルク試料のスピン構造を電氣的に探る新たな手段を示すものです。

木俣基^{1,2}, 横山旭¹, 仲地立³, 本間佳哉¹, 仲村愛¹, 清水悠晴¹, 李徳新¹, 三宅厚志¹, 本多史憲⁴, 青木大¹, 大貫惇睦^{3,5}, 松田達磨³
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A High-Temperature Multiferroic $\text{Tb}_2(\text{MoO}_4)_3$

高温マルチフェロイック $\text{Tb}_2(\text{MoO}_4)_3$



We have demonstrated the high-temperature multiferroicity in a paramagnetic ferroelectric $\text{Tb}_2(\text{MoO}_4)_3$ (Fig. (A)). The dielectric constant is sharply enhanced at $T_c=432$ K (Fig. (B)), below which ferroelectric polarization emerges as shown in Fig. (C). We show that the ferroelectric polarization can be controlled solely by a magnetic field as shown in Fig. (D). When the magnetic field is applied along the $[110]$ or $[-1-10]$ directions, the polarization aligns in the positive direction. On the other hand, the negative electric polarization is stabilized in a magnetic field along the $[1-10]$ or $[-110]$ direction. This is the highest operating temperature of magnetic control of ferroelectric polarization, which is a hallmark of multiferroicity. The figures are taken from the reference paper.

S. Tajima, H. Masuda, Y. Nii, S. Kimura, Y. Onose
IMR, Tohoku Univ.

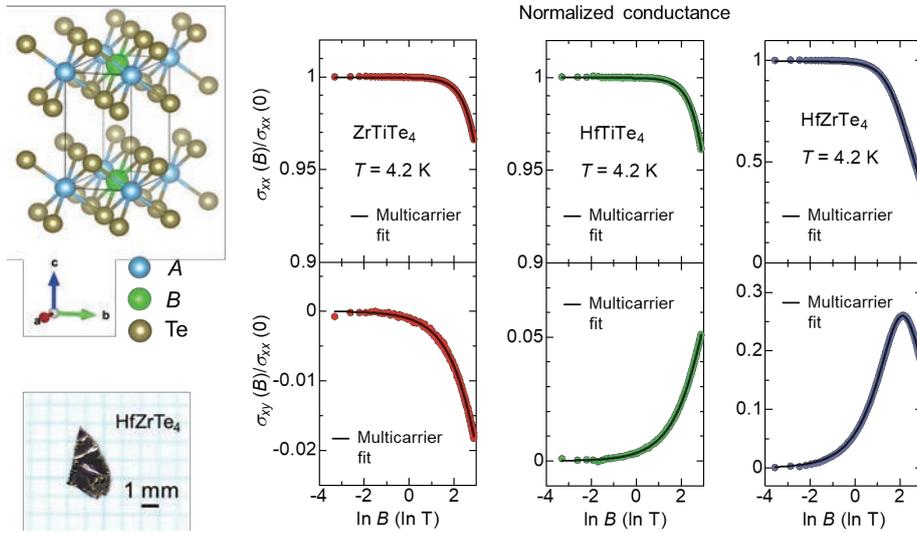
Reference: S. Tajima *et al.*, “A high-temperature multiferroic $\text{Tb}_2(\text{MoO}_4)_3$ ”, *Commun. Mater.* **5** (2024) 267.

我々は、常磁性強誘電体 $\text{Tb}_2(\text{MoO}_4)_3$ (図(A)) において、高温マルチフェロイック動作を確認いたしました。この物質では、強誘電転移温度 $T_c=432$ K において誘電率がピークを示し (図(B))、それ以下の温度で強誘電分極が観測されます (図(C))。我々は、この強誘電分極が磁場のみにコントロールできることを示しました (図(D))。磁場を $[110]$ もしくは $[-1-10]$ に印加した場合には正の電気分極を持ちますが、 $[-110]$ もしくは $[1-10]$ に印加しますと負の電気分極を持ちます。これは、マルチフェロイックの特徴の一つである強誘電分極の磁場制御の最高温度での動作です。なお、上図は Reference 論文から転載されたものです。

田島史門, 増田英俊, 新居陽一, 木村尚次郎, 小野瀬佳文
東北大金研

High-Field Transport Properties of van der Waals Materials $ABTe_4$ ($A/B = \text{Ti, Zr, Hf}$)

ファンデルワールス物質 $ABTe_4$ ($A/B = \text{Ti, Zr, Hf}$) における強磁場輸送特性



The van der Waals materials $ABTe_4$ ($A/B = \text{Ti, Zr, Hf}$) have been predicted to be two-dimensional topological insulators when reduced to monolayers [Macam *et al.*, APL. **118**, 111901 (2021)]. However, detailed measurements of their physical properties using single crystals had not been reported. Therefore, we grew single crystals of these compounds for the first time and measured their magnetotransport properties up to 18 T at HFLSM. By performing multi-carrier analysis on these results, we clarified the properties of the carriers. Interestingly, we found the presence of carriers with a very high mobility exceeding $1000 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ for $HfZrTe_4$.

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³ IMass, Nagoya Univ., ⁴IMR, Tohoku Univ., ⁵ RCCME, Nagoya Univ.

Reference: Y. Hasuo *et al.*, “Single Crystal Growth and Transport Properties of van der Waals Materials $ABTe_4$ ($A/B = \text{Ti, Zr, Hf}$)”, J. Phys. Soc. Jpn. **93**, 014705 (2024).

van der Waals 物質 $ABTe_4$ ($A/B = \text{Ti, Zr, Hf}$)は、単層にすると2次元トポロジカル絶縁体となることが予言されている[Macam *et al.*, APL. **118**, 111901 (2021)]。しかし、本系の単結晶試料を用いた詳細な物性測定は報告されていなかったため、我々は単結晶試料を初めて育成し、強磁場センターにて18 Tまでの磁気輸送特性を測定した。この結果に対してマルチキャリア解析を行うことで、キャリア特性を明らかにすることが出来た。興味深いことに、 $HfZrTe_4$ に関しては、 $1000 \text{ cm}^2\text{V}^{-1}\text{s}^{-1}$ を超える高移動度を持つキャリアが存在することが分かった。

蓮生雄人¹, 浦田隆広², 洗平昌晃^{1,3}, 土屋雄司⁴, 淡路 智⁴, 生田博志^{1,5}

¹ 名大院工, ² 岐阜大工, ³ 名大未来研, ⁴ 東北大金研, ⁵ 名大 RCCME

Detection of Exotic In-Gap Fermionic Quasiparticle States in a Kondo Insulator

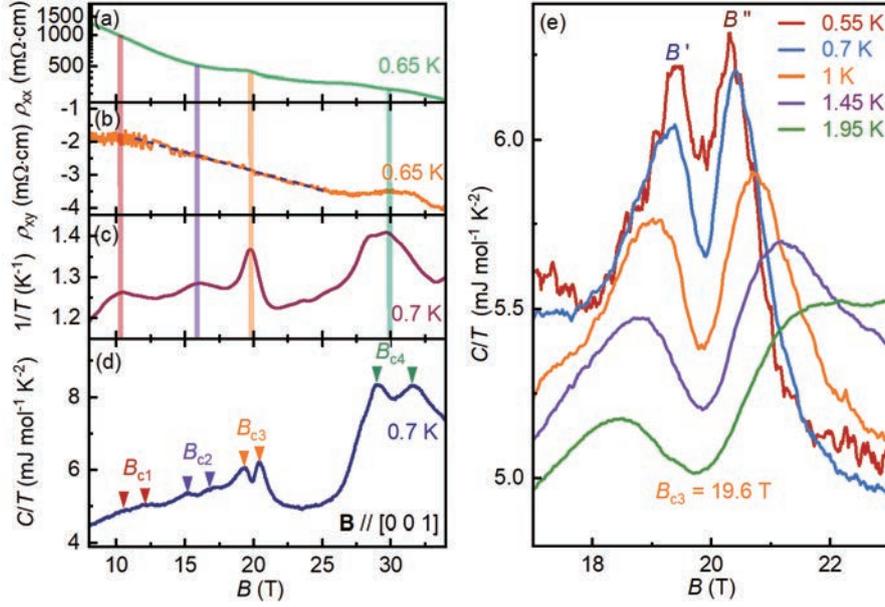


Figure 1 (a)-(d) Comparison of magnetoresistance, Hall resistivity, magnetocaloric effect and specific heat of YbB₁₂ as a function of magnetic field. (e) Specific heat as a function of the magnetic field at indicated temperature.

In the mixed-valence compound YbB₁₂, thermal-conductivity measurements at low temperatures reveal highly mobile excitations that carry heat like in a metal but do not conduct electricity. The Wiedemann-Franz law, which relates the thermal and electrical conductivity, is violated in this material by many orders of magnitude. This leads to the fundamental question of whether electrically neutral excitations in an insulator, which nominally do not have a direct orbital coupling to an external magnetic field, can nevertheless display peculiar thermodynamic signatures characteristic of metals.

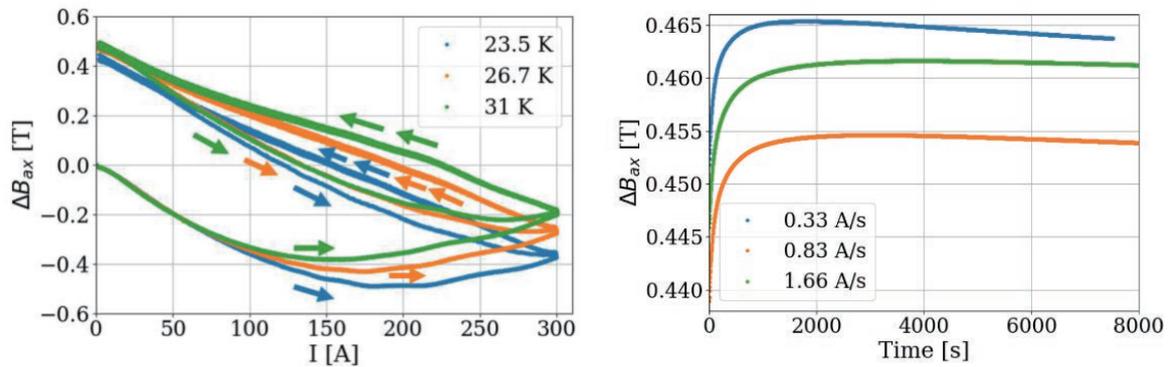
In this work, we report a sequence of increasingly pronounced singularities in both the specific heat and the magnetocaloric effect within the insulating phase of YbB₁₂, as seen in Figure 1(b)-(c). These features, characterized by a series of double-peak anomalies in the specific heat, suggest an underlying fermionic density of states (DOS). The Hall resistivity measured at IMR evolves smoothly across these field values (Figure 1(a)-(b)), ruling out an electronic origin for these anomalies and suggesting a distinct fermionic contribution to the singular DOS in YbB₁₂. These observations provide strong evidence for the existence of the exotic fermionic quasiparticles in the bulk, which is remarkable given the absence of an electronic DOS in the insulating bulk of YbB₁₂.

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Reference: Z. Yang *et al.*, “Evidence for large thermodynamic signatures of in-gap fermionic quasiparticle states in a Kondo insulator”, Nat. Commun. **15** (2025) 7801.

Magnetic Field Stability of a HTS Coil Based on the Robust REBCO Coil Concept



The Robust REBCO Coil is a HTS coil architecture aiming to enable the development of very high field magnets. One of its features is the two-tape bundle, two HTS tapes in direct contact in face-to-back configuration, improving the resilience of the HTS coil towards local thermal runaway. One drawback of its structure is the existence of coupling currents developing within the bundle, affecting the quality of the magnetic field, increasing the losses and applying additional mechanical stress to the coil, such as the screening currents.

At HFLSM, the 33 T Cryogenic-free Superconducting Magnet is under development. We conducted extensive tests on a large-scale prototype of the future HTS insert. It made it possible to show that the magnetic field error is resulting from opposite contributions of the screening currents and coupling currents in certain conditions leading to the magnetic field presenting two successive opposite directions of evolution when the coil is powered with a constant current. The impacts of several parameters such as the temperature of evolution, the index of the energization and the energization rate were assessed. The variation of the latter demonstrated no impact on the magnetic field error, denoting that the two tapes are fully coupled.

These results are highly valuable to understand the future operation of the 33 T - CSM, especially for users requiring high magnetic field stability.

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Reference: A. Zampa *et al.*, “Screening and coupling currents induced fields on a large-scale prototype REBCO insulated coil”, IEEE Trans. Appl. Supercond. **34** (2024) 4700205.

