

Electromagnetic Properties of Iron-Based Superconducting Uninsulated Double Pancake Coils and Their Comparison with REBCO Coils

Fan Ren^{1,2}, Chunyan Li¹, Yanchang Zhu³, Jin Zhou¹, Xianping Zhang³, Min Liu², Fang Liu⁴, Yanwei Ma³ and Qingjin Xu¹

(1. Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049; 2. Key Laboratory of Advanced Functional Materials, Beijing University of Technology, Beijing 100124; 3. Institute of Electrical Engineering, Beijing 100190; 4. Institute of Plasma Physics, Hefei 230031)

Abstract

➤ Iron-based superconductors show great potential for high-field magnet applications. The electromagnetic properties of iron-based superconducting (IBS) uninsulated coils are crucial for their future practical applications, yet characteristics such as charging delay and turn-to-turn contact resistivity (R_{ct}) remain poorly understood. To address this, we fabricated metal-insulation (MI) and no-insulation (NI) iron-based superconducting double pancake coils (DPCs) and systematically tested their charging and sudden-discharging behaviors. **Experimental results revealed that the R_{ct} of the IBS-MI coil is 6.3 times higher than that of the IBS-NI coil, along with a significantly shorter charging delay.** Moreover, an interesting phenomenon was discovered: the R_{ct} of uninsulated IBS coils is much lower than that of the REBCO coils reported in previous studies. For rigorous verification of this finding, MI and NI REBCO coils were prepared and subjected to charging and sudden-discharging tests. Through comparison, it is found that the R_{ct} of the REBCO-MI coil is 73.6 times greater than that of the IBS-MI coil, while the R_{ct} of the REBCO-NI coil is 3.6 times greater than that of the IBS-NI coil. The main reasons for this difference will also be analyzed in this paper. From an application perspective, the low R_{ct} of uninsulated coils also means high thermal stability and self-protection. This work lays the foundation for investigating the proportional and integral (PI) feedback control method to eliminate magnetic field delays and for validating the thermal stability of IBS uninsulated coils in future studies.

➤ The direction of the background magnetic field was parallel to the width direction of the superconducting tape inside the coil.

Results and Discussion

➤ The coil was charged to 50 A at three current ramping rates (0.1, 1, and 10 A/s) and held at this current for a certain period; after the magnetic field stabilized, the power supply was cut off.

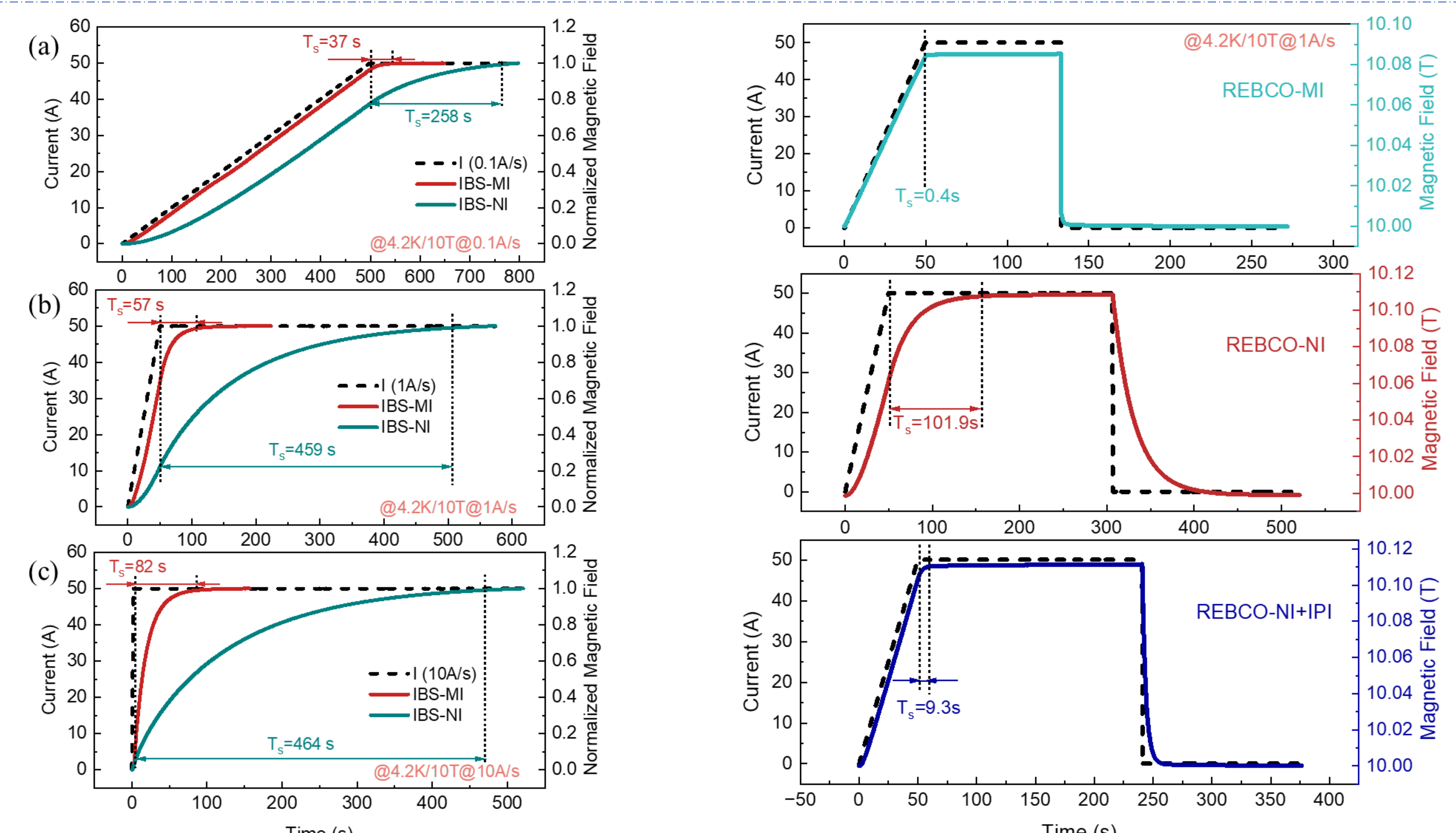


Figure 3. Time-dependent current and normalized magnetic field curves for IBS-MI and IBS-NI coils at different charging rates.

Figure 4. Charging and sudden-discharging test results of the REBCO-MI coil (a), REBCO-NI coil (b), and REBCO-NI+IPI coil (c) at 4.2 K and 10 T.

Experimental Methods

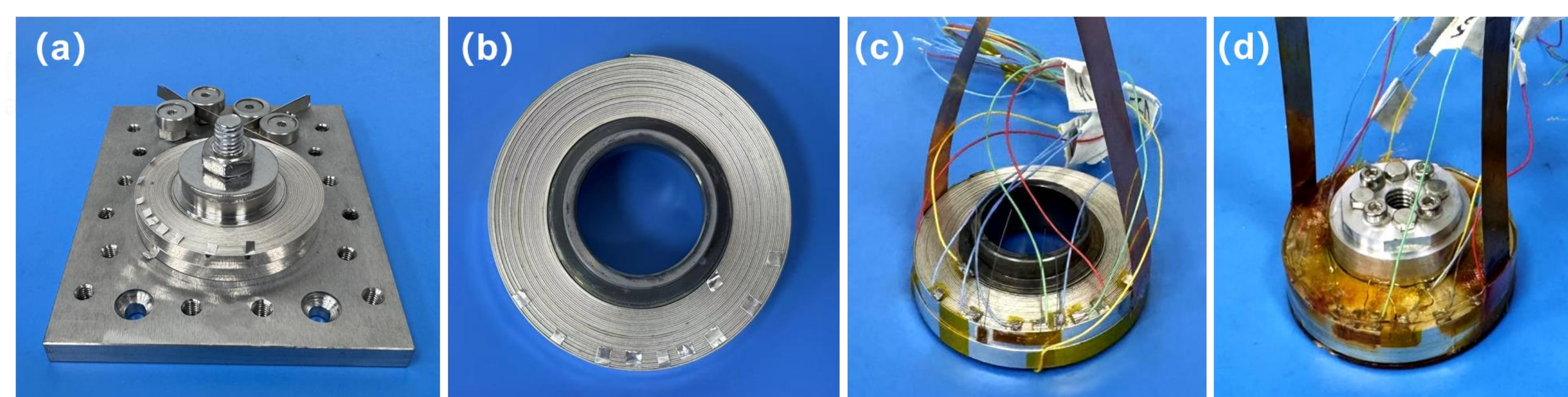


Figure 1. Detailed photographs taken during the fabrication process of IBS double pancake coils. (a) IBS-MI coil fixing. (b) IBS-MI coil after heat treatment. (c) IBS-MI coil after completing the joint and voltage leads soldering. (d) IBS-MI coil after epoxy impregnation.

✓ The IBS-MI and IBS-NI coils were wound using AgSn/Ag-sheathed Ba122 tapes under a tension of 50 N. During the winding process, the IBS-MI coil was co-wound with a 0.05 mm thick stainless steel (SS) tape. After winding, both coils underwent a heat treatment at 880 °C for 1 hour, followed by epoxy resin impregnation for curing.

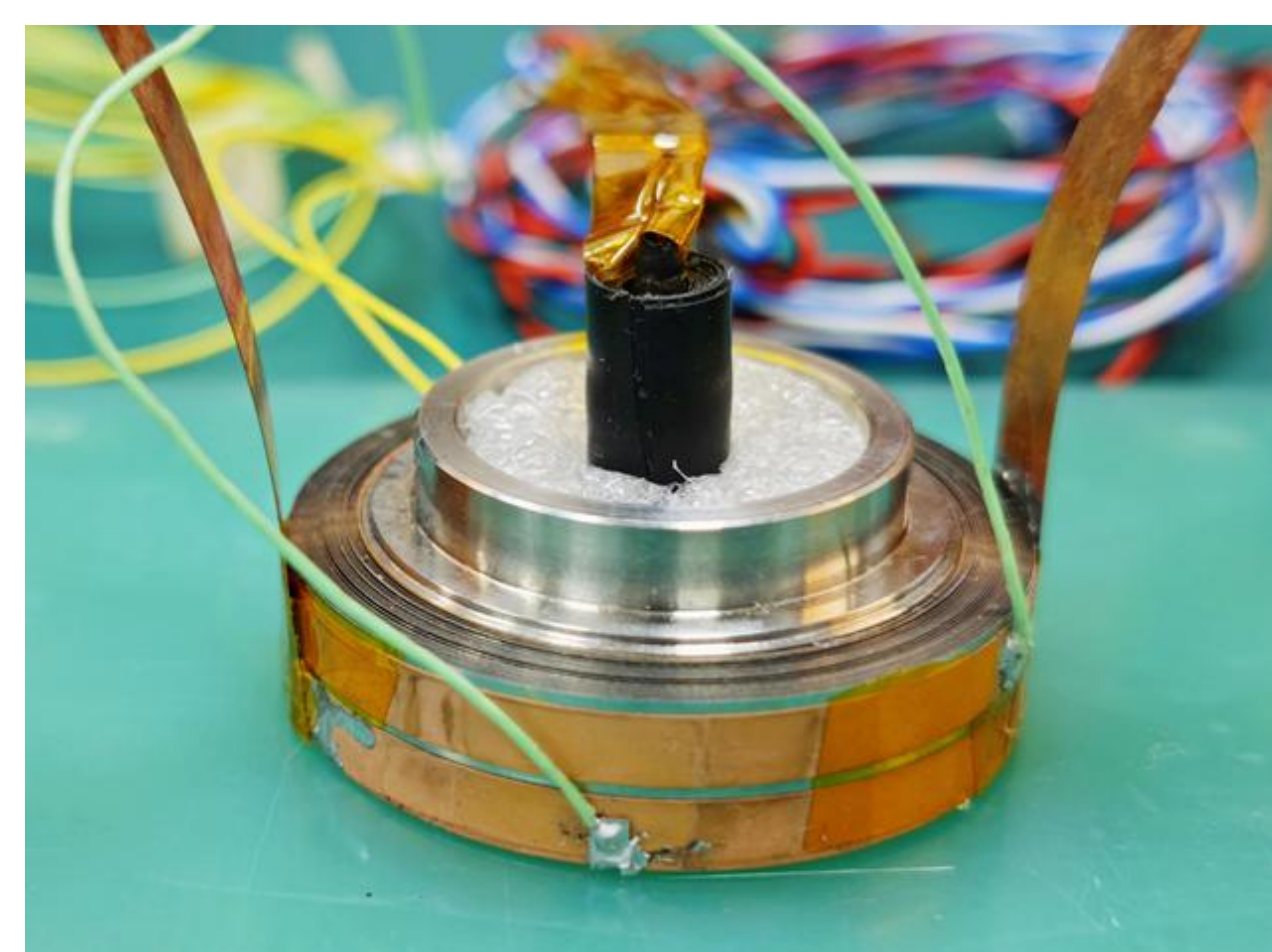


Figure 2. Photograph of the REBCO-MI coil.

✓ REBCO-MI, REBCO-NI, and REBCO-NI+IPI coil were wound using 4 mm wide REBCO tape under a constant tension of 50 N.

✓ REBCO-NI coil was wound solely with superconducting tape.

✓ REBCO-MI coil was co-wound with superconducting tape and SS tape.

✓ REBCO-NI+IPI coil was incorporated with 0.15 mm thick Kapton as inter-pancake insulation between double-pancake windings.

Table 1. Parameters of the coils.

Coil parameter	Unit	IBS-MI	IBS-NI	REBCO-MI	REBCO-NI	REBCO-NI+IPI
Inner diameter	mm	33	33	33	33	33
Outer diameter	mm	53.2	53.5	41	38.9	38.9
Winding tension	N	50	50	50	50	50
Number of turns (N)	--	28	33	28	33	33
Number of layers	--	2	2	2	2	2
Superconducting tape width	mm	4.7	4.7	4	4	4
Superconducting tape thickness	mm	0.31	0.31	0.09	0.09	0.09
I_c @4.2K/10T	A	135	135	750	750	750
Inter-pancake insulation	--	/	/	/	/	Kapton sheet
Width of co-wound SS tape	mm	5	/	5	/	/
Thickness of co-wound SS tape	mm	0.05	/	0.05	/	/
Coil inductance (L_{coil})	mH	0.1394	0.1978	0.1391	0.2034	0.2017
Coil constant (K)	mT·A ⁻¹	1.57	1.81	1.7	2.2	2.2

➤ Charging and sudden-discharging tests were conducted under the conditions of 4.2 K and 10 T.

Table 2. Key electromagnetic parameters of coils.

Coil	τ (s)	R_c ($\mu\Omega$)	R_{ct} ($\mu\Omega \cdot \text{cm}^2$)
IBS-MI	16.3	8.55	1.017
IBS-NI	123.1	1.60	0.160
REBCO-MI	0.16	869.37	74.856
REBCO-NI	25.0	8.14	0.574
REBCO-NI+IPI	3.16	63.79	4.503

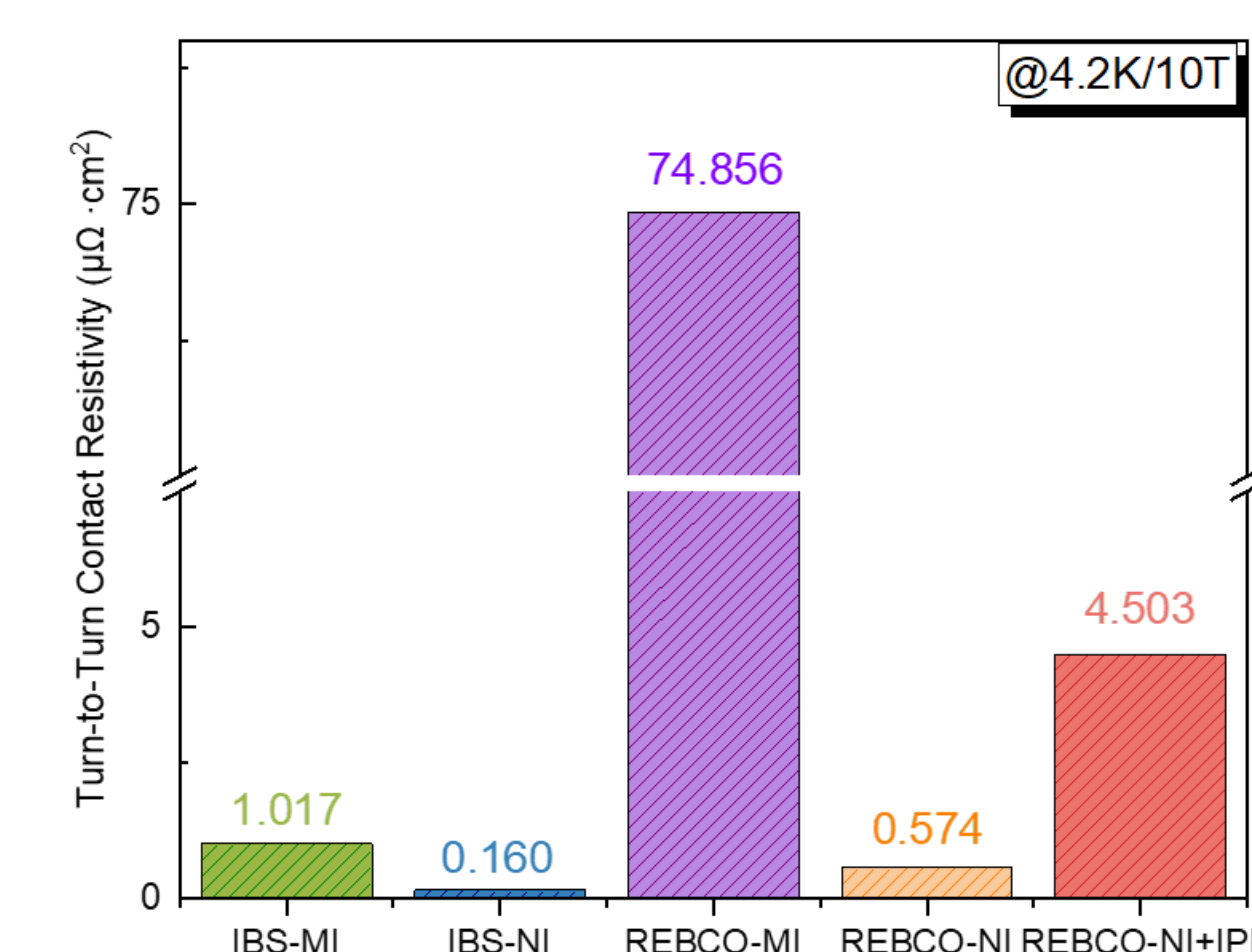


Figure 5. Comparison of R_{ct} between IBS and REBCO coils under MI and NI winding methods.

✓ The R_{ct} of the REBCO-NI+IPI coil is 4.503 $\mu\Omega \cdot \text{cm}^2$, which is 7.8 times that of REBCO-NI. This demonstrates that the 0.15 mm-thick Kapton sheet effectively serves as the layer insulation by blocking the shunting path between the pancakes.

✓ The R_{ct} of the REBCO-MI coil is 73.6 times that of the IBS-MI coil, while the R_{ct} of the REBCO-NI coil is 3.6 times that of the IBS-NI coil.



Figure 6. Photograph of the cross-section of the IBS-NI coil after heat treatment.

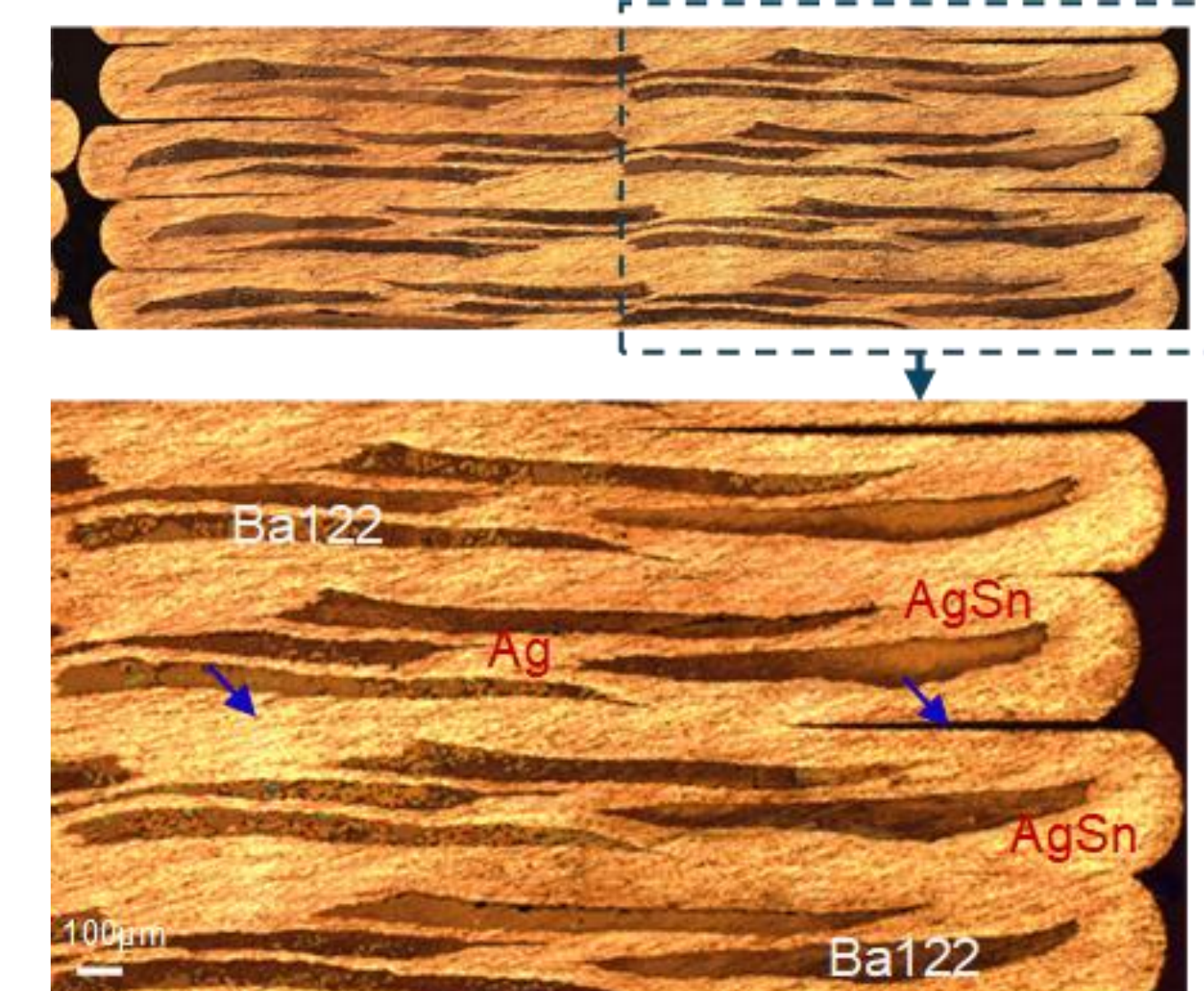


Figure 7. Cross-sectional morphology of the IBS-MI coil after heat treatment.

✓ Between adjacent IBS tapes, gaps are only visible near the edges, whereas the central regions appear effectively fused.

结论

✓ Electromagnetic properties of IBS coils are affected by winding method : the R_{ct} of the IBS-MI coil is 6.3 times that of the IBS-NI coil, with shorter charging delay.

✓ The R_{ct} of IBS coils is significantly lower than that of REBCO coils. The core reason is that adjacent turns of IBS coils form partial diffusion bonding after heat treatment at 880 °C, which increases the effective contact area.