Behaviour of superconducting coils inside the sub-cooled water ice.

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Introduction

- The **helium bath** cooling becomes more **expensive** and limited ...
- Therefore, cooling alternatives e.g. **conduction cooling** or using of **another cryogens** (liquid or solid) are needed for future superconducting systems.
- **Liquid hydrogen** or **solid nitrogen** (at ~ **20 K**) have been already tested for superconducting coils.
- But, **liquid H_2** needs a special **safety conditions** and **solid N_2** is **sublimating** easily, which leads to a lack of cooling efficiency.
- A **question** is: Can be a **sub-cooled H_2O possible solution ...?**
- We have performed the measurements of different **superconducting coils** inside the **sub-cooled H_2O** at temperatures **10-80 K** and fields 0-6 T, which can give an **answer** ....

System used for measurement of coils inside the water ice

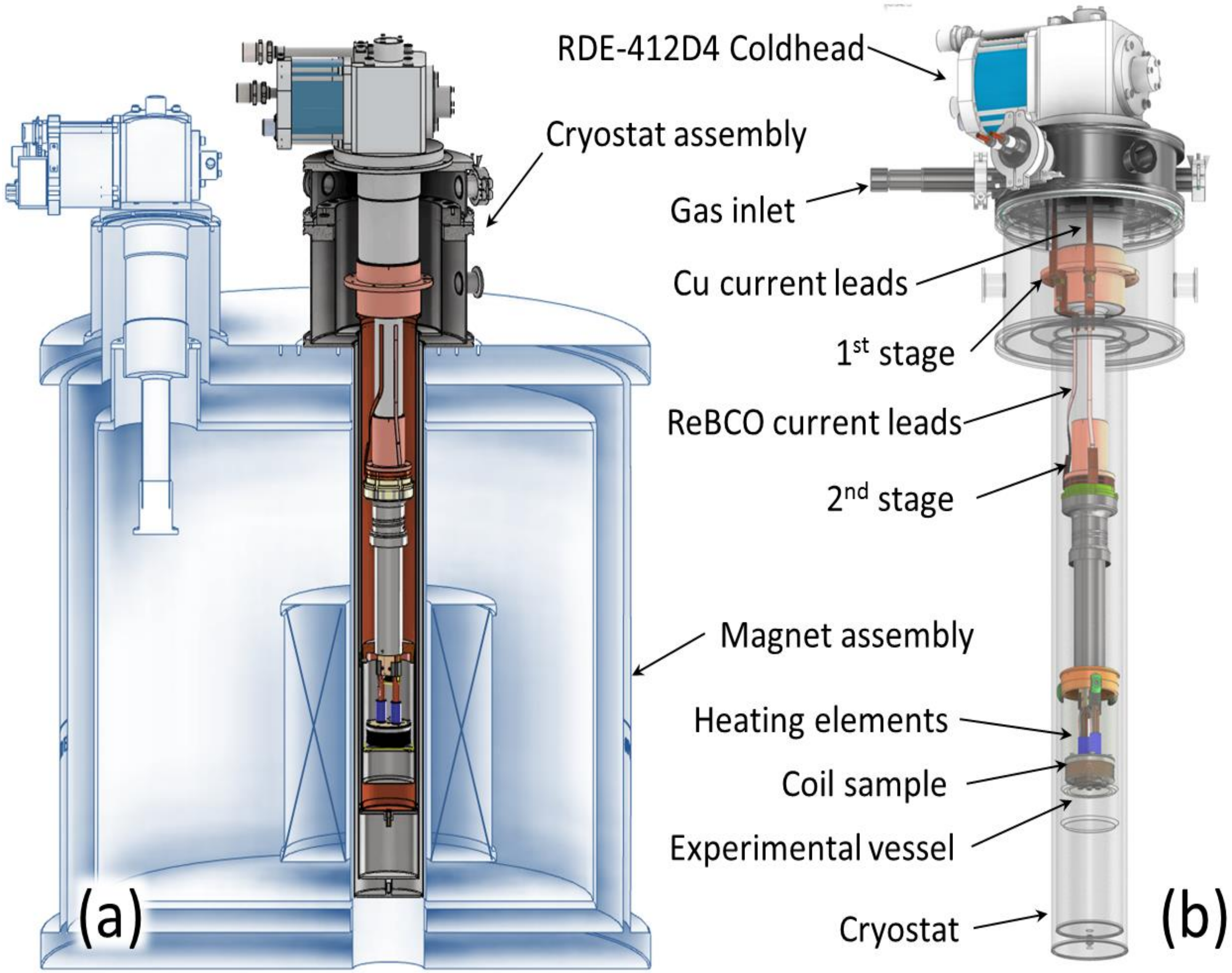
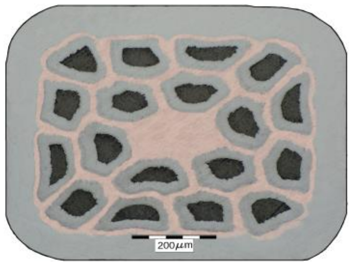


Figure (a) - a view of a cryogen-free **12 T magnet** with a inner bore of **100 mm**, in which the cryostat with an experimental vessel with subcooled water ice (**10 – 300 K**) is inserted, see Figure (b).

- The **coil** holder is fixed to the 2nd stage of Sumitomo **RDK-408D2 cryocooler**.
- Small **double-wall** container is fixed to the sample holder and filled by ~ **0.5 l of deionized water**.
- Cooling of water from room temperature down to **10 K** takes around **10 hours**.
- The **temperature** is monitored by three Pt100 thermometers.

Superconducting coils wound of MgB_2, Bi-2223 and Nb_3Sn

Sam Dong

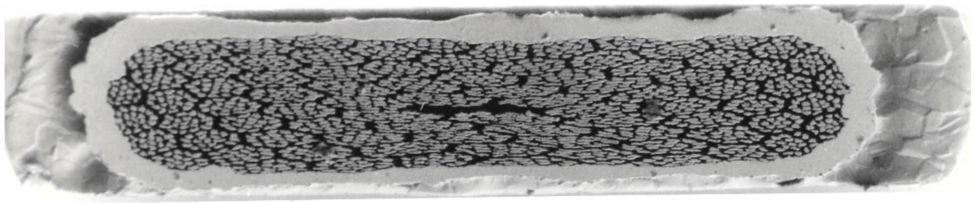


0.64 x 0.80 mm

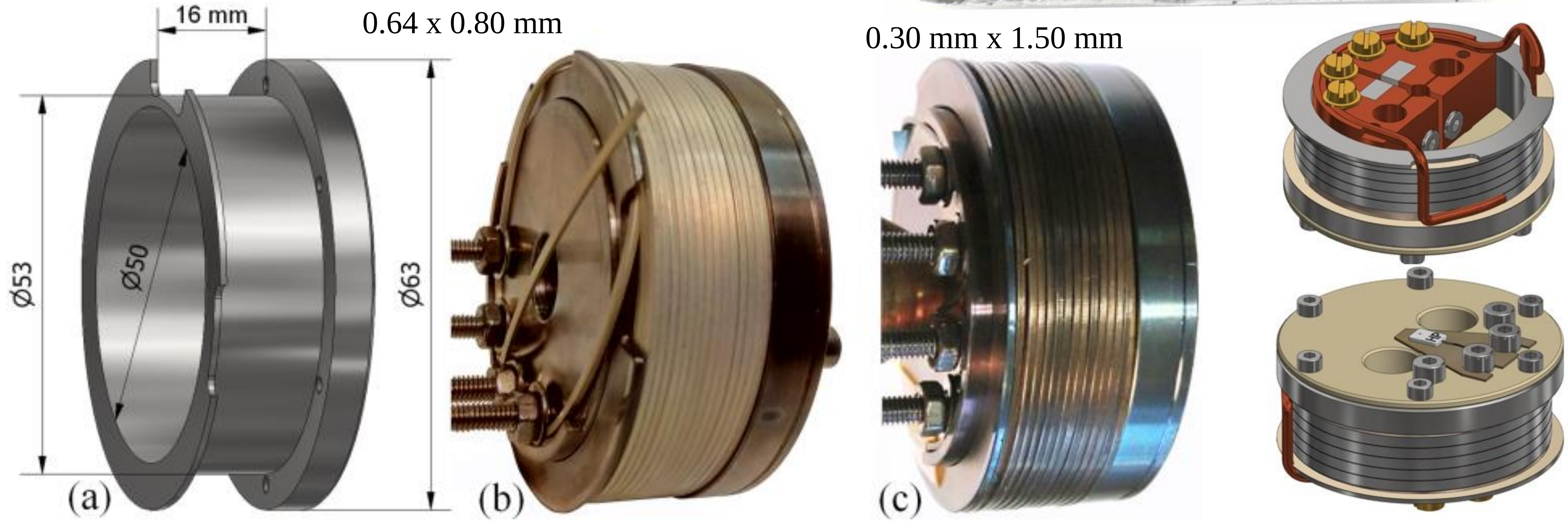
Sumitomo

0.2 mm x 2.52 mm

IEE of SAS



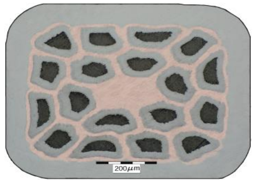
0.30 mm x 1.50 mm

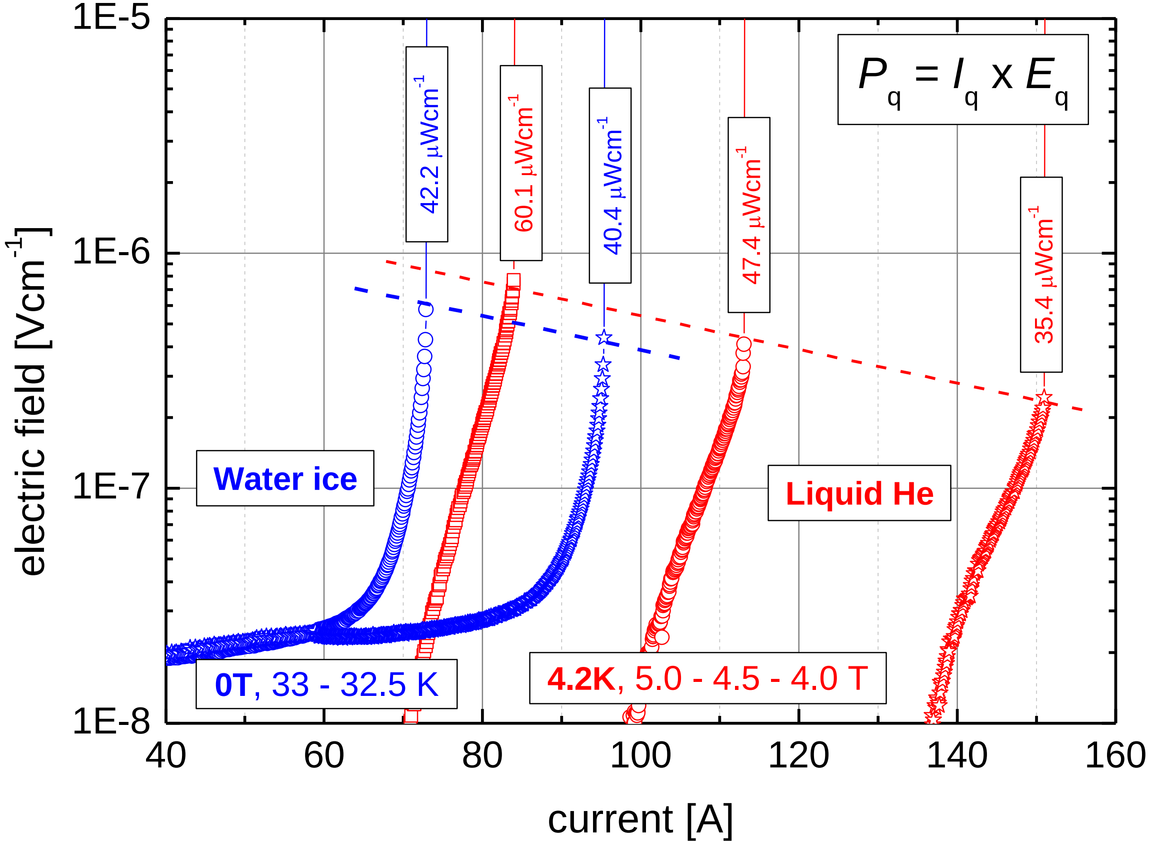


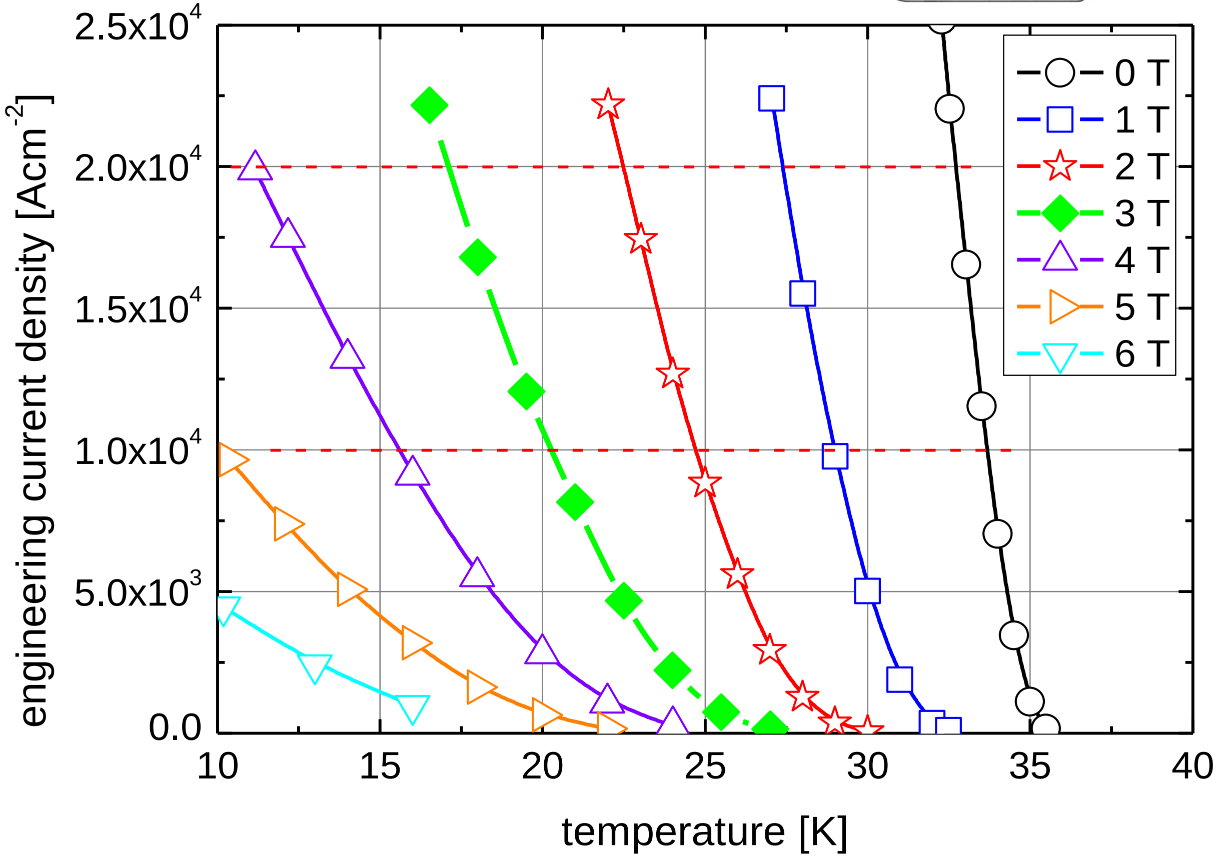
The coil steel former (a), MgB_2 winding before heat treatment (b) the coil after final heat treatment (c) and coil’s view ready for measurements (d).

Stability and current density of not insulated (NI) MgB coil

The coil has **114 turns** of 18-filament **Sam Dong MgB_2** wire (0.64 x 0.80 mm) with very **high packing factor** of **0.91**.

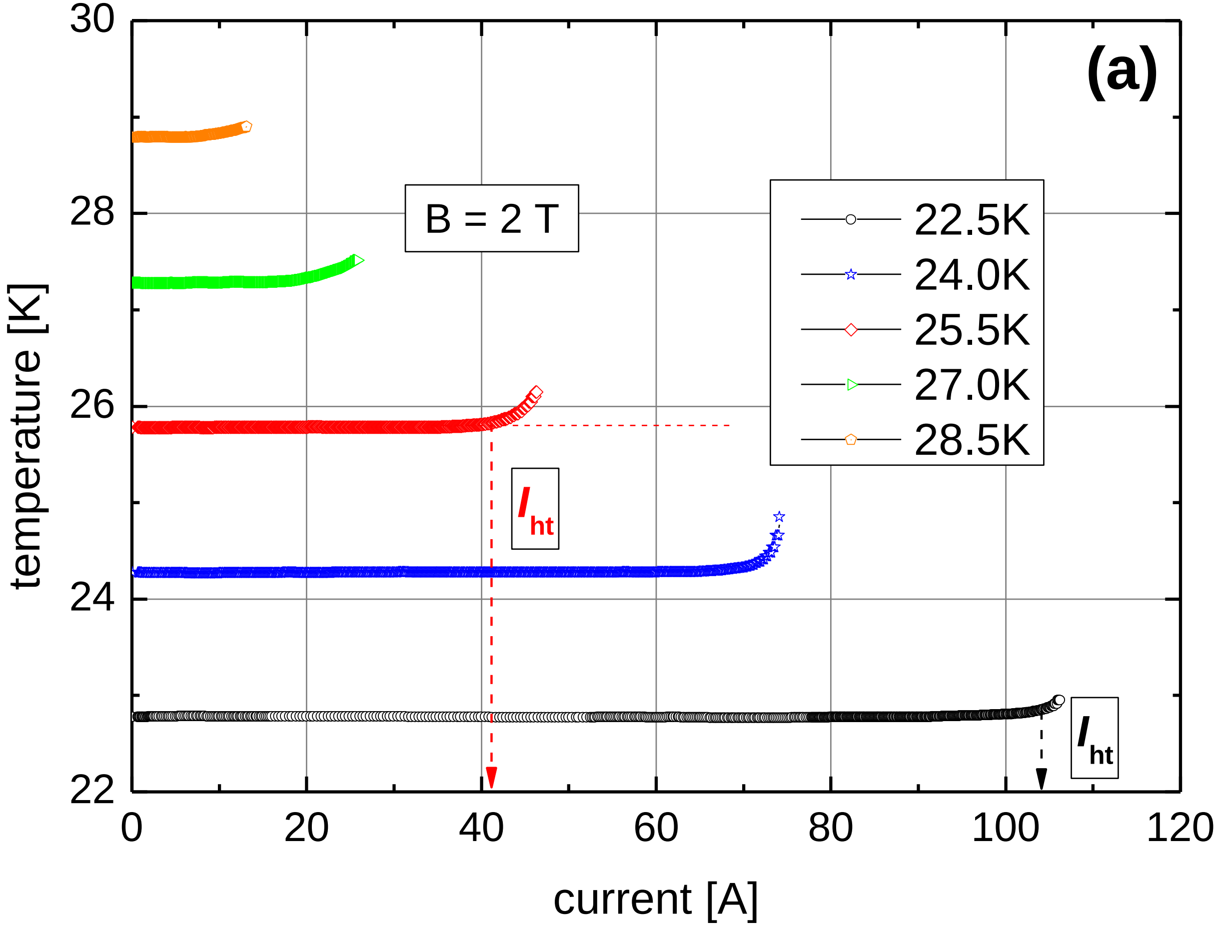


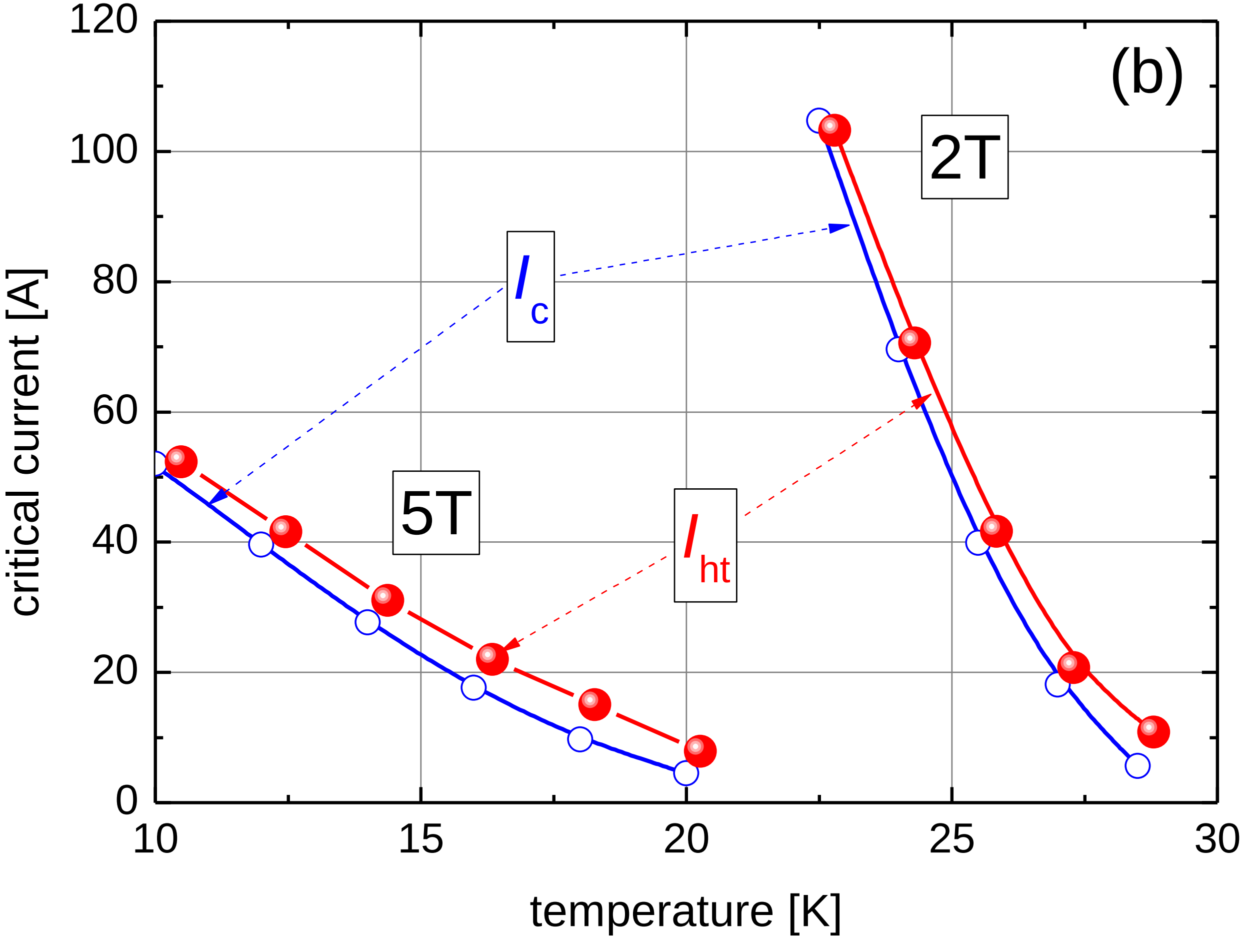




Stability (quenching) of MgB_2 coil in **water ice** is only slightly lower than in **LHe**. Due to high PF the engineering current densities J_e are similar to winding ones J_w. $J_e = 10^4$ **Acm⁻²** was measured for ***B* = 3.0 T** and **20 K,** which is **attractive** for applications.

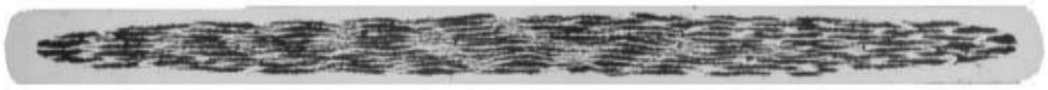
Coil's heating of NI MgB_2

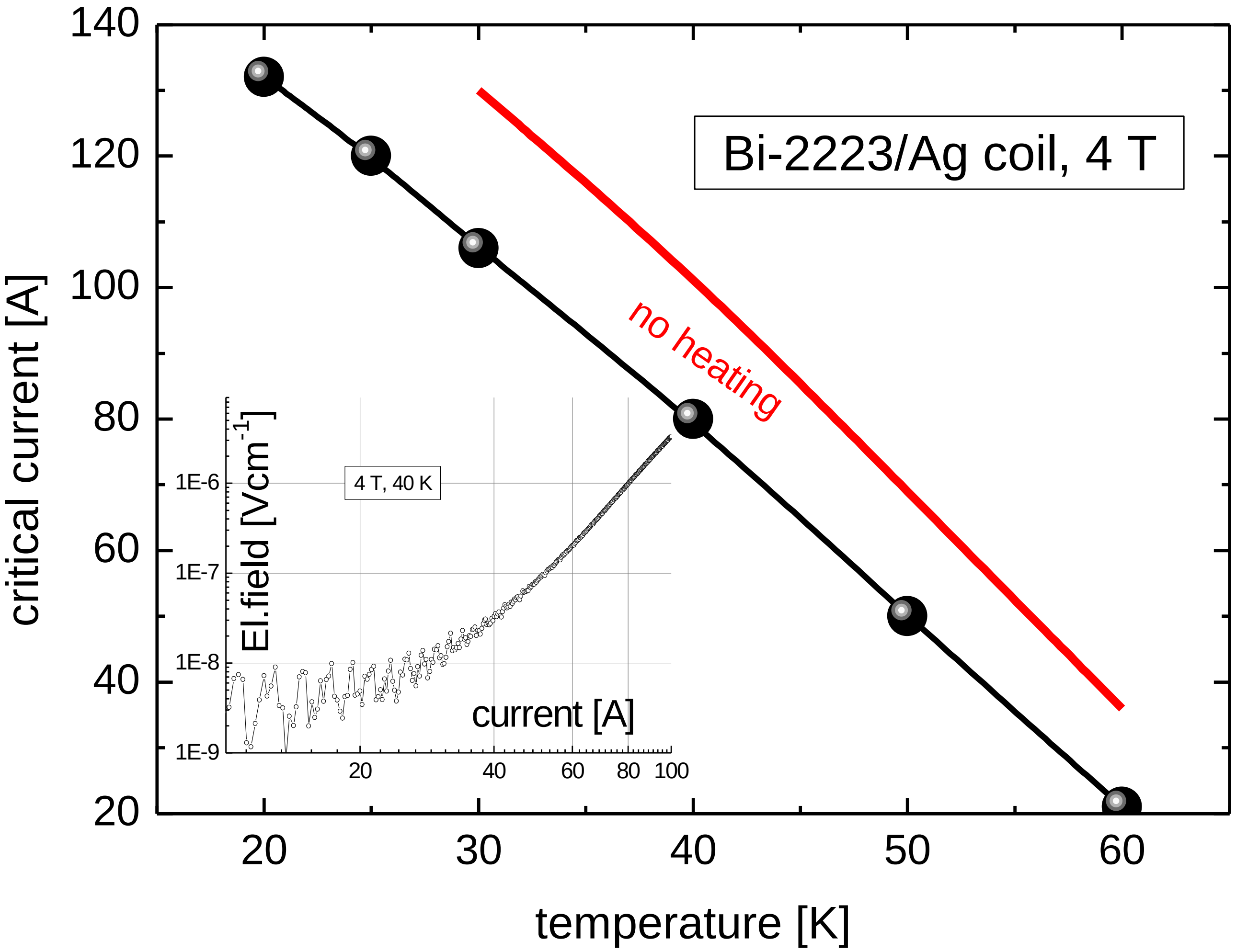




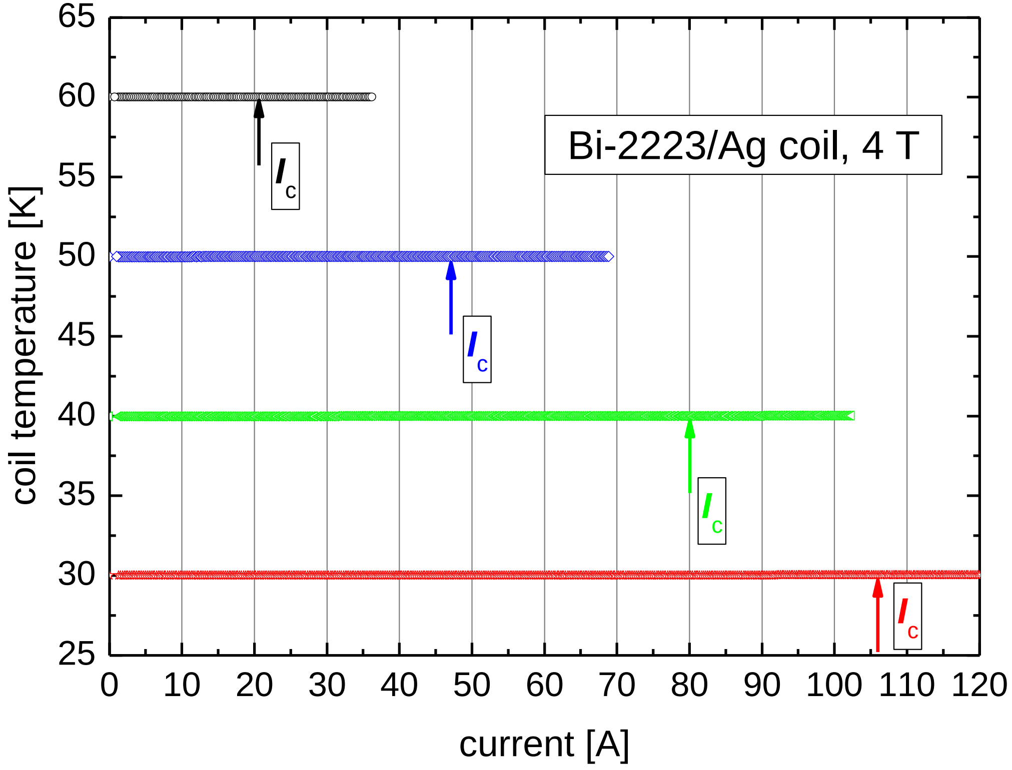
Not insulated and high **PF= 0.91** MgB_2 coil is thermally stable at $I < I_c$ ($1 \mu V cm^{-1}$) and the **heating** was observed at the transport currents $I_{ht} > I_c$. **…no water ice inside..**

Bi-2223/Ag insulated coil





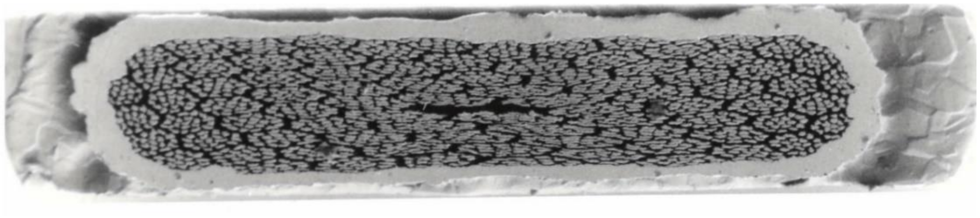
Sumitomo Electric, 0.2 mm x 2.52 mm.
40 turns on the stainless-steel former of 53 mm insulated by capton foil.

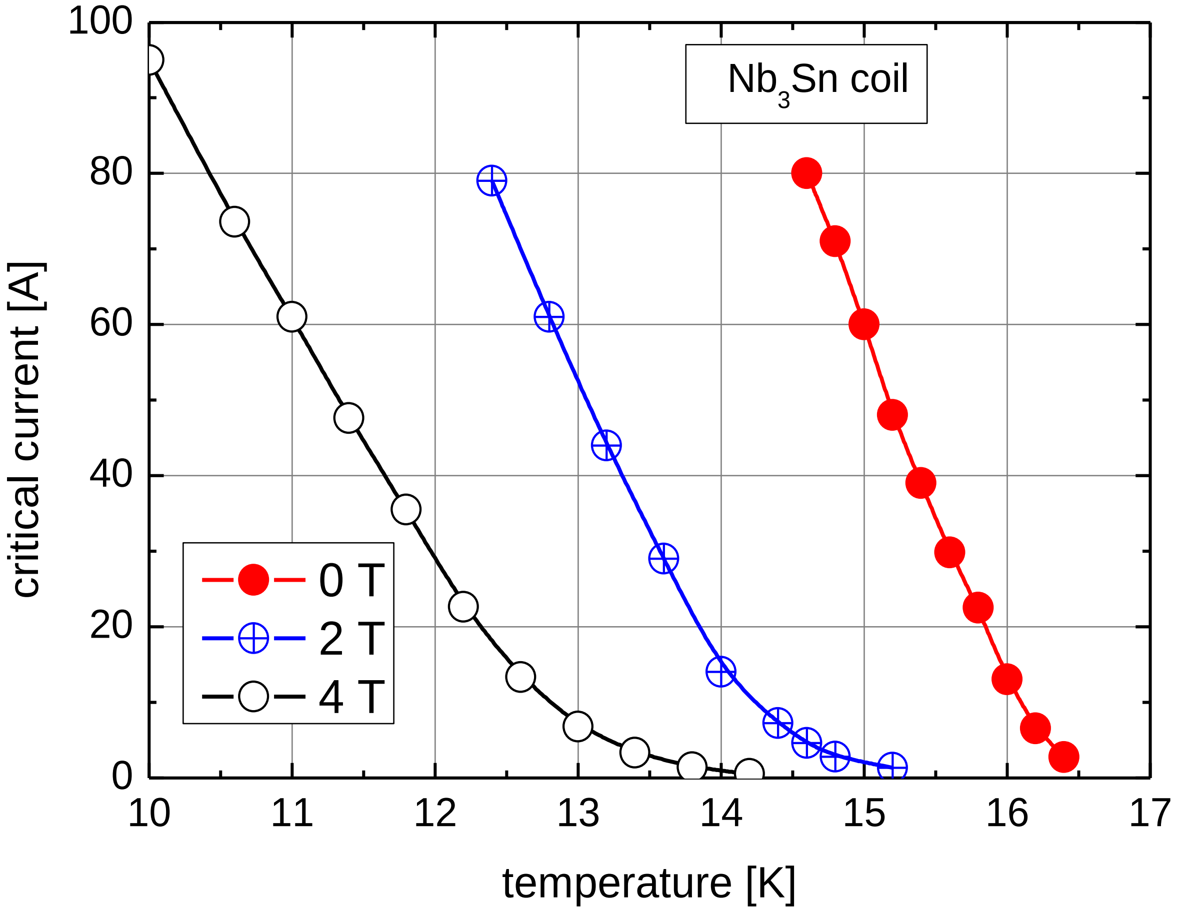


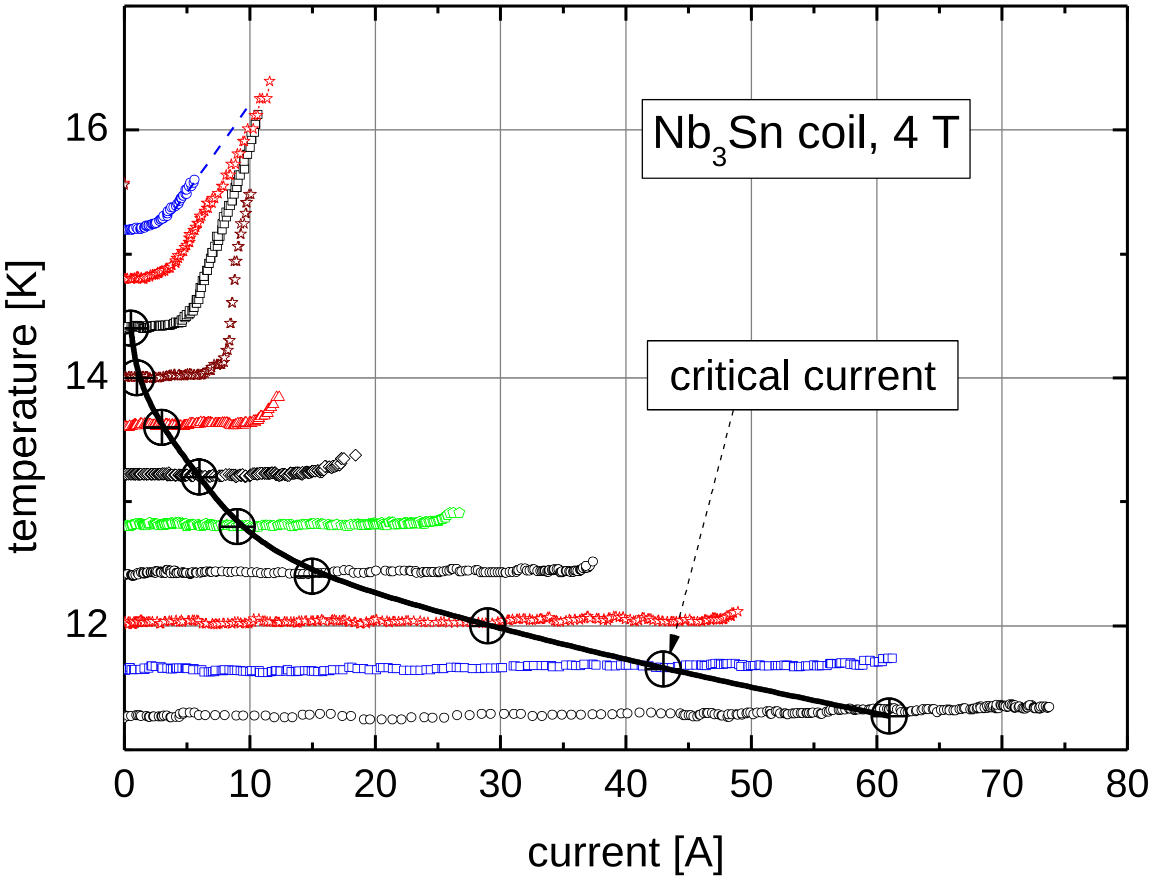
In comparison to NI MgB_2, R&W **insulated** Bi-2223/Ag coil is thermally stable far above I_c and no coil **heating** was observed up to transport currents ***$I \sim 1.25\, I_c$*****. more ice inside ..**

Nb_3Sn insulated coil

Coil has **77 turns** of 1615-filament **IEE Nb_3Sn** wire (0.30 x 1.50 mm) insulated with capton foil.

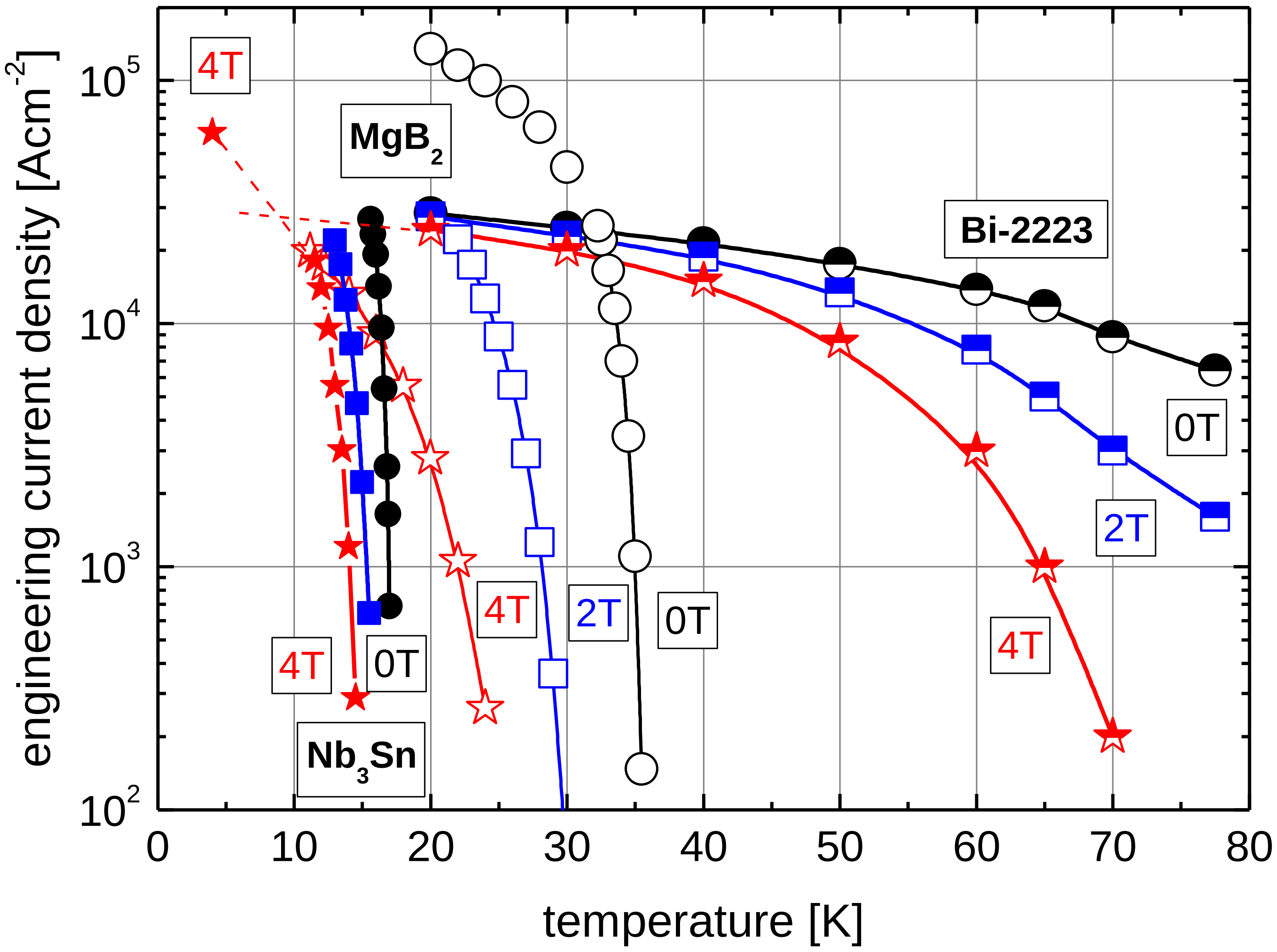






Similarly, **insulated** Nb_3Sn coil is well stable and no **heating** was observed for transport currents ***$I \geq 1.5\ I_c$*. ..Cu stabilized & water ice inside …**

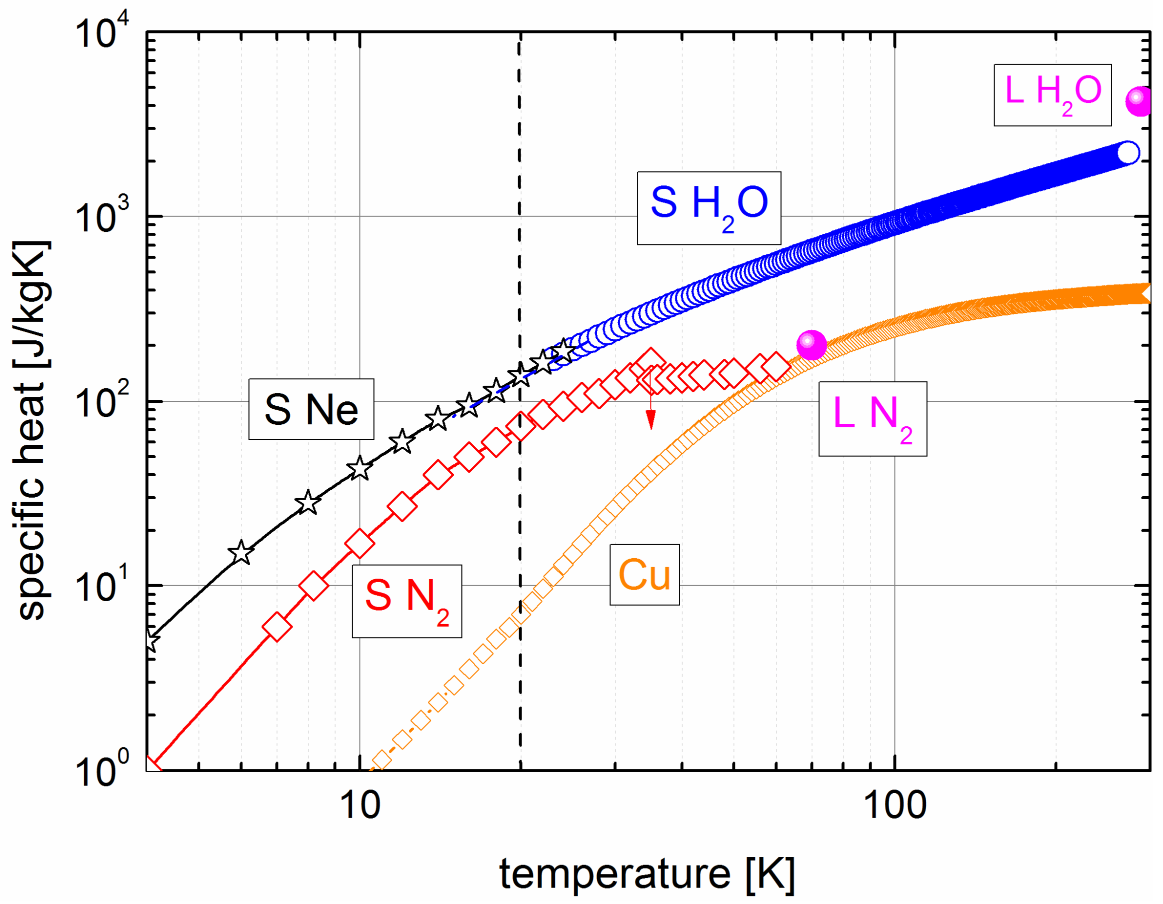
Engineering current densities of measured coils



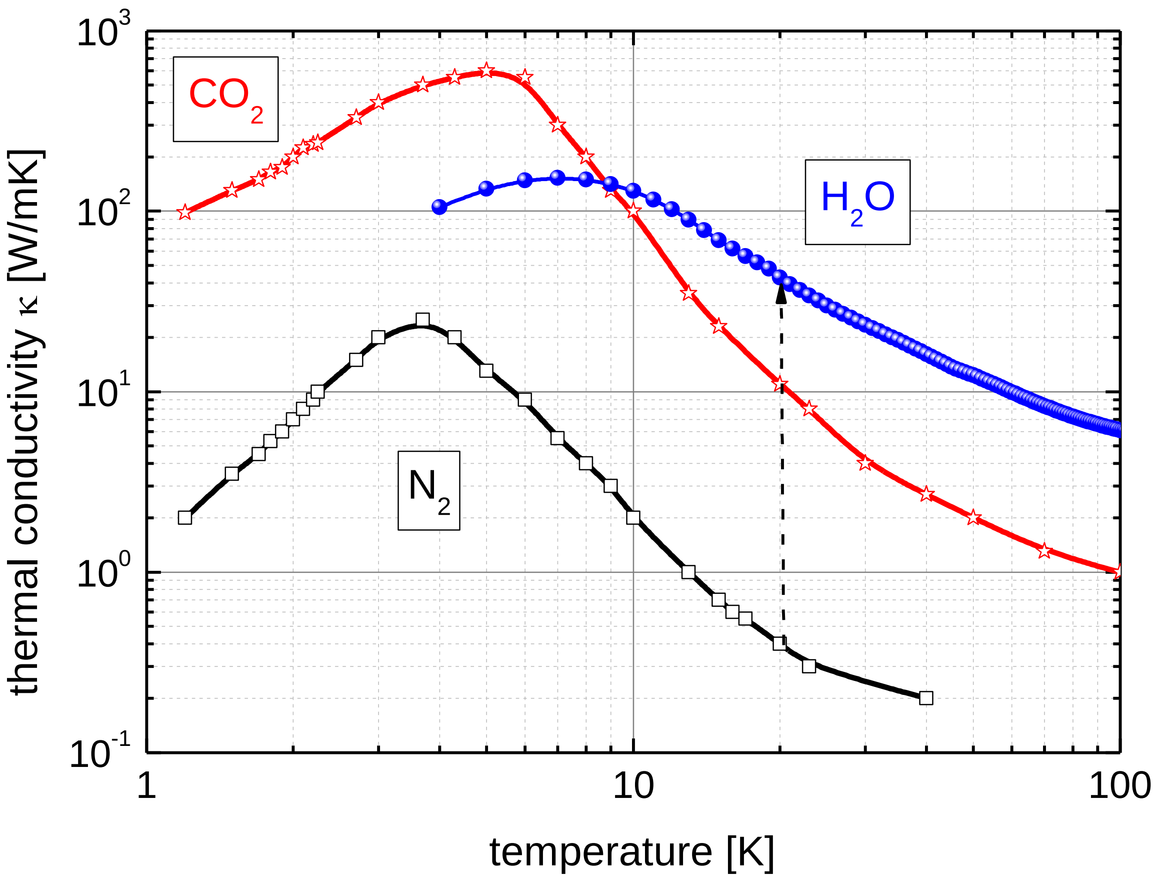
Not insulated **MgB_2** and insulated **Bi-2223/Ag** and **Nb_3Sn** coils have different critical parameters and wire design resulting in different ***J*$_e$(*B*,*T*)** performance: Practical values of ***J*$_e$ = 10^4 Acm^{-2}** are measured at **15-35 K for MgB_2** and at **47-70 K for Bi-2223/Ag.** ***J*$_e$ = 2.6x10^4** was measured for all coils at **10 K and *B* = 4.0 T .**

Essential/important water ice properties

- **Specific heat** of water (at 15°C) is **4187 J/kgK** and nearly half for water ice **2108 J/kgK** and decreasing with *T*.



Specific heat of **water ice** is comparable with **solid Ne** and doubled of **solid N_2** at **20 K**.

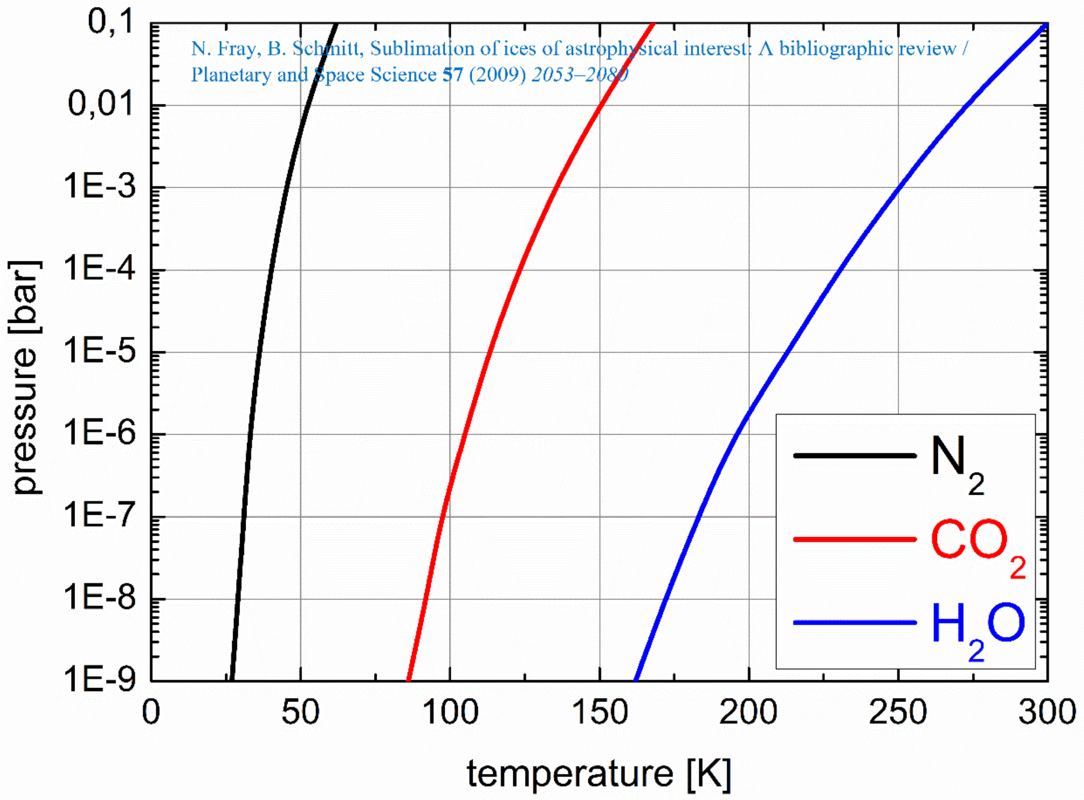


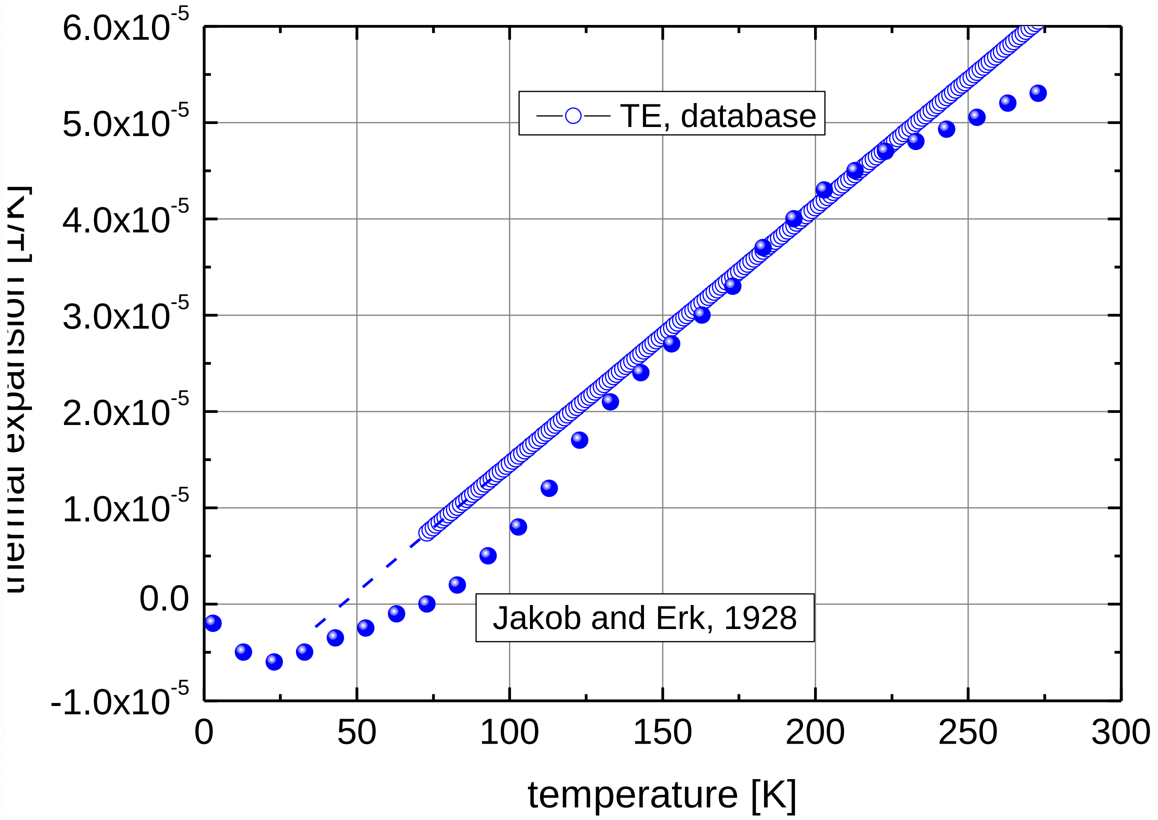
Heat conductivity of **water ice** (non-metallic crystalline solid) is low, but **ƙ(20K)** is by ~ two order of magnitude above ƙ(20K) of N_2.

Sublimation and thermal expansion

The **sublimation of SN_2** at pressure of 10^{-9} bar is measured **> 20 K**, but **> 160 K for H_2O** ice [Fray].

When water freezes, it **increases in volume (about 9%** for fresh water) [Jacob & Erk].





A local heating of winding (e.g. by over-current) and **easy sublimation** of SN_2 may reduce **thermal contact** with coolant, which is **not a case of H_2O ice.**

The expansion by **9% can be dramatic**.
Thermal expansion is linearly decreasing with temperature and reaches 0 at ~ 50 K.

Conclusions

- Can be a **sub-cooled** **H_2O used for superconducting coils...?**
- **Stable** and safety behaviour of **MgB_2, Bi-2223** and **Nb_3Sn** coils was observed inside the **water ice** due to **sufficient** thermal **stability.**
- **Warming** of **outer** turns was observed **close to** the coil's I_c (for **not insulated** coil) and far **above** I_c (for **insulated** ones).
- Water **ice expansion** in double-wall container did not make **any damage** of **insulation**, **thermometers** and installed **Hall probe**.
- In addition, water ice acts as coil's **impregnation**, which can be also easy **re-impregnated**.
- **Consequently, water ice** cooling can be **perspective, cheap and safe** mode applicable for He-free systems (**above 10 K**).

Thanks for your attention!