Epoxy resin for superconducting magnets: Recent studies at LBNL

Shijian Yin, Tengming Shen

Lawrence Berkeley National Laboratory, Superconducting Magnet team

Many thanks to Andrea Haight (CTD), Steve Krave (Fermilab), Xingchen Xu (Fermilab), Chiara Tarantini (NHMFL) for collaboration and discussion, and LBNL colleagues especially Eric Anderssen, Diego Arbelaez, Soren Prestemon, Jim Swanson, Reed Teyber for assistance and discussion, and LBNL molecular foundry for instrument use.

Motivation

- **Since 2020, LBNL has been collaborating with Fermilab (S. Krave) and CTD (A. Haight) to test and verify new resin developed with subscale CCT magnets, partly supported by DOE - SBIR.**

- **We have been running three independent studies at LBNL:**
  - **Developing approach of preparing epoxy/filler suitable for superconducting magnets, especially epoxy nanocomposite.**
  - **Explore the possibility of high toughness, or high thermoconductivity (more for HTS), and high specific heat epoxy, and processing parameters.**

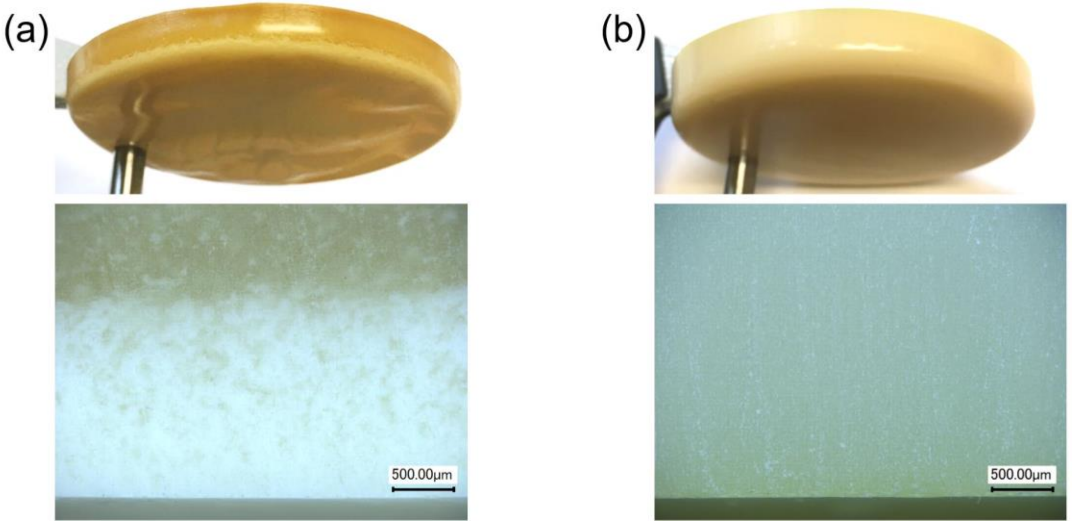
This presentation.

Disclaimer: It is an academic excise. Methods used have no connections to work at industry (CTD).

  - **Method for interfacial control.**

Preparation of the Epoxy Nanocomposite

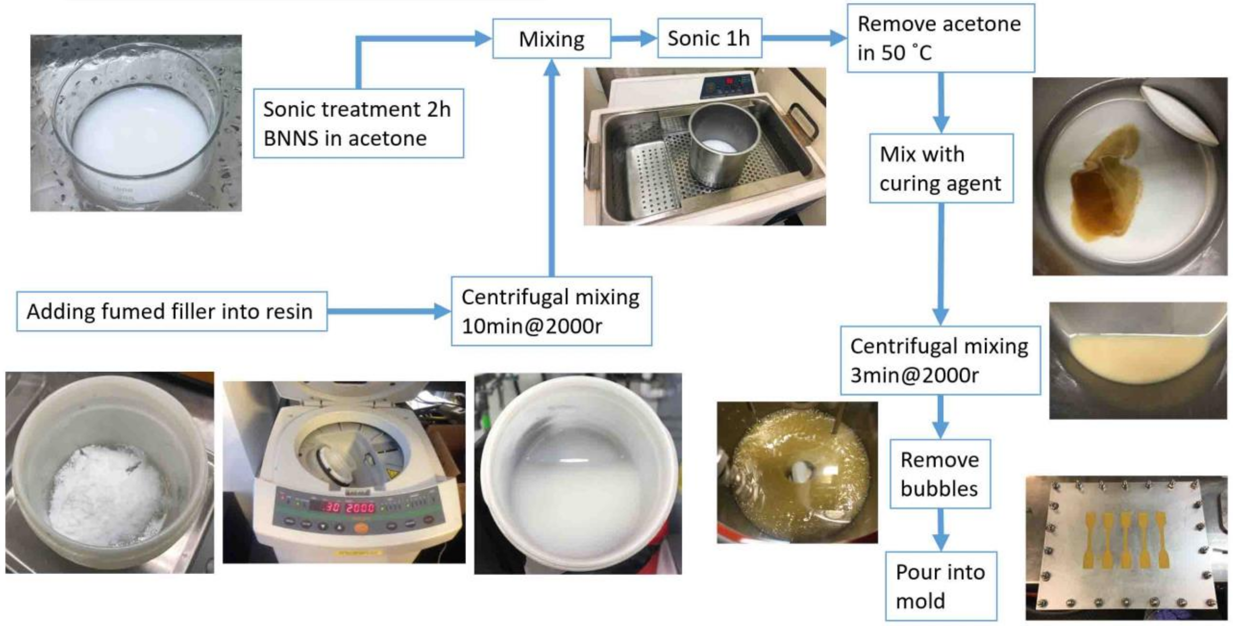
To avoid agglomeration and sediment



Sediment

Good Dispersion

Our Preparation Process



Solution used by us:

Supersonic treatment

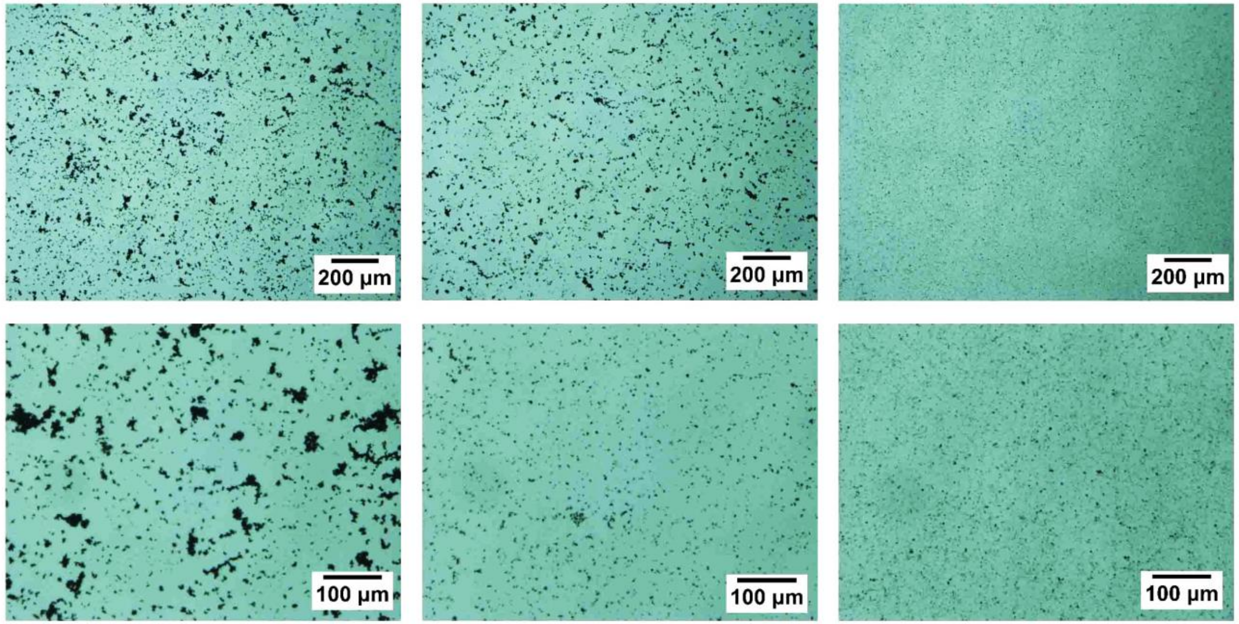
Centrifugal mixing

Adding fumed filler

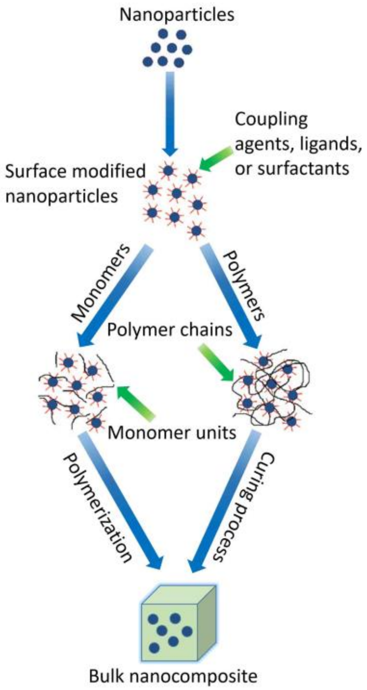
We found three approaches are useful. (Two shown)

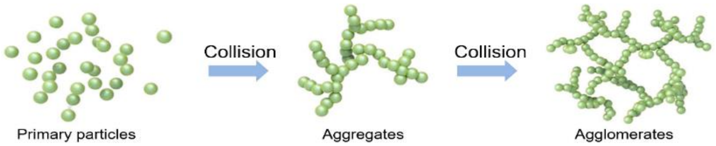
Supersonic Treatment

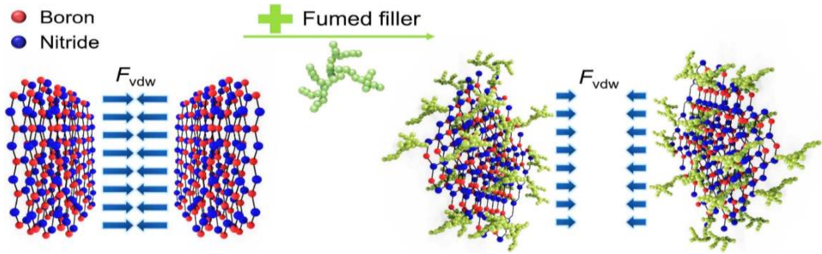
Sonic 1h | Sonic 2h | Sonic 3h



Nanoparticle surface treatment

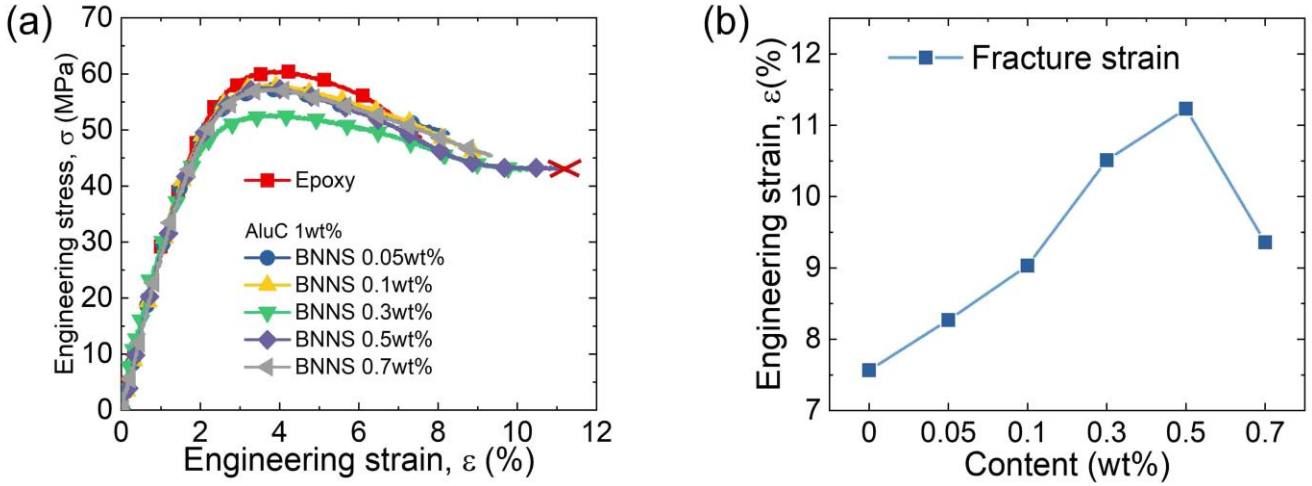




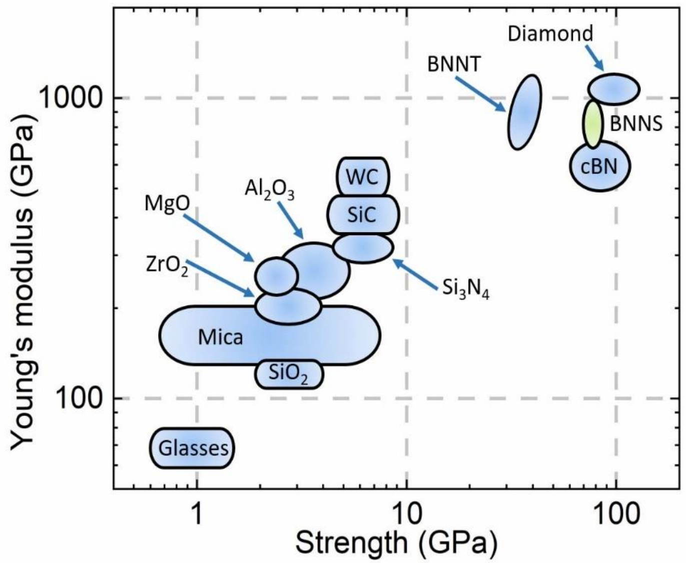


Effect of filler content on performance of composites

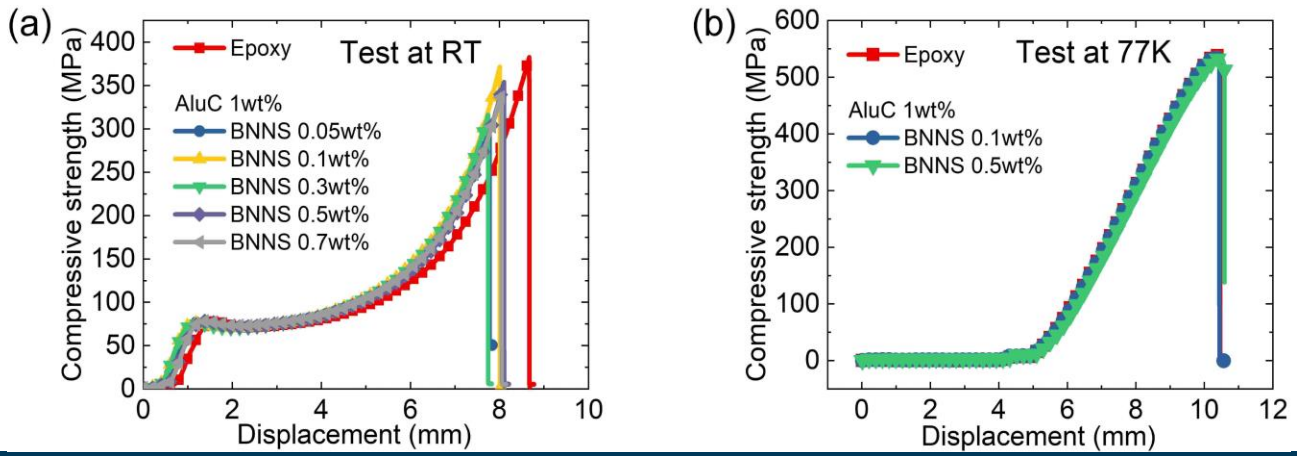
Tensile performance (RT)



Epoxy = ATLAS ECT epoxy, D. Evans. R.P. Reed.
doi: 10.1063/1.1774571



Compression performance



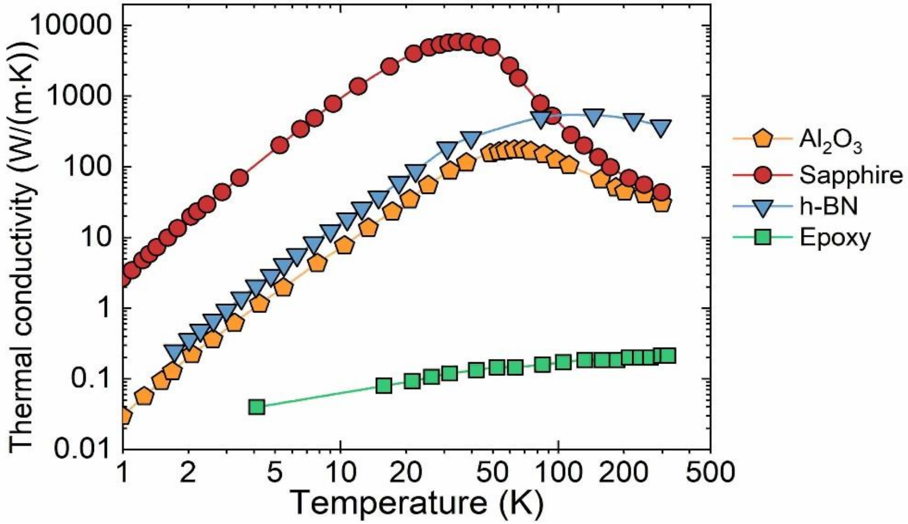
BNNS 0.5wt%

Compare to pure epoxy, fracture strain increased **48.7%.**

Design of Epoxy Composite with High Thermoconductivity

High thermoconductivity fillers

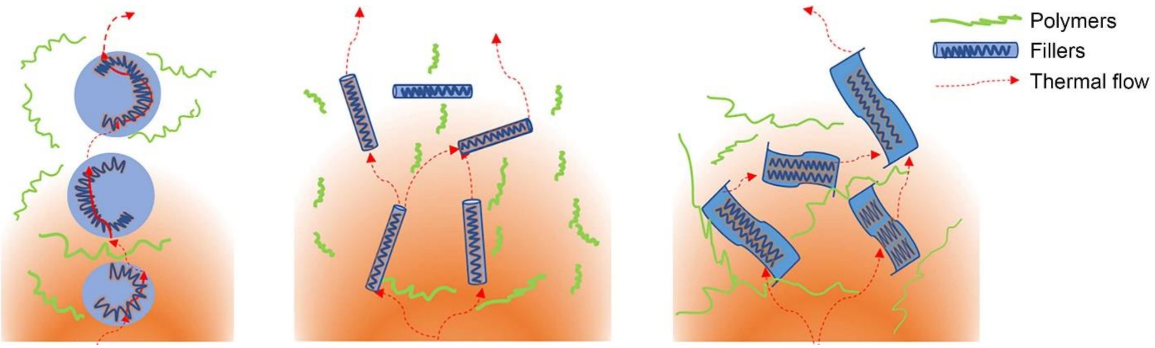
Electrical insulation fillers with high thermoconductivity at low temperature[1-3]



Epoxy resin: CTD 528

- Low Toxicity
- Long Pot-Life
- Low Viscosity, <1000 cP @ 25 ˚C
- **Excellent adhesion to fibers and fillers**

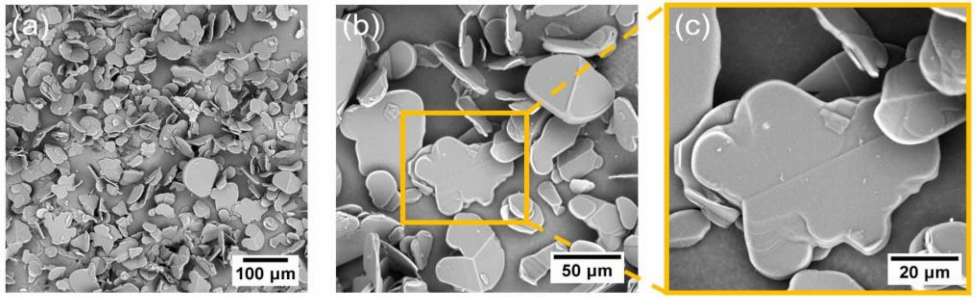
Filler shapes can make a big difference.



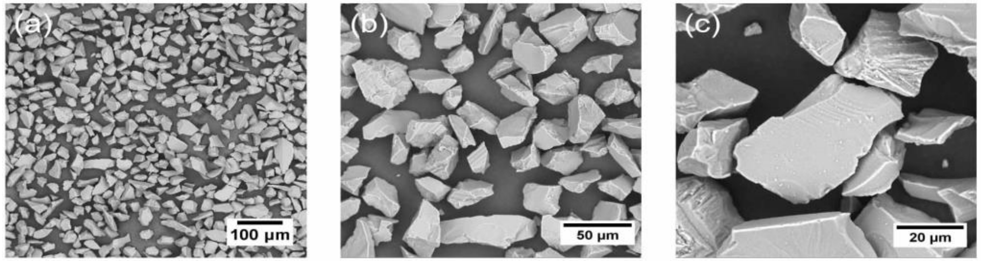
[1] Bagrets N., Otten S., Weiss K. P., et al. Thermal and mechanical properties of advanced impregnation materials for HTS cables and coils[C]. IOP Conference Series: Materials Science and Engineering IOP Publishing, 2015.
[2] Lake Shore Cryotronics Inc. Appendix I: Cryogenic reference tables[EB/OL]. https://www.lakeshore.com/docs/default-source/product-downloads/literature/lstc_appendixi_l.pdf
[3] Sichel E. K., Miller R. E., Abrahams M. S., et al. Heat capacity and thermal conductivity of hexagonal pyrolytic boron nitride[J]. Physical Review B, 1976,13(10):4607-4611.

Filler shapes can make a big difference.
We have tried several fillers.

BNmp



Sapphire

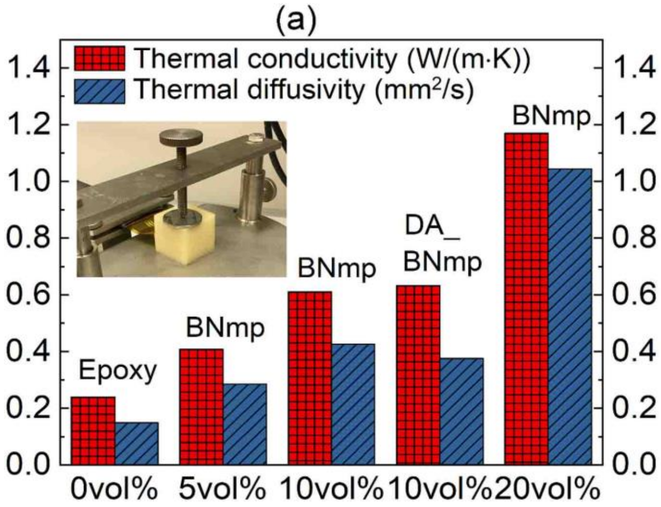


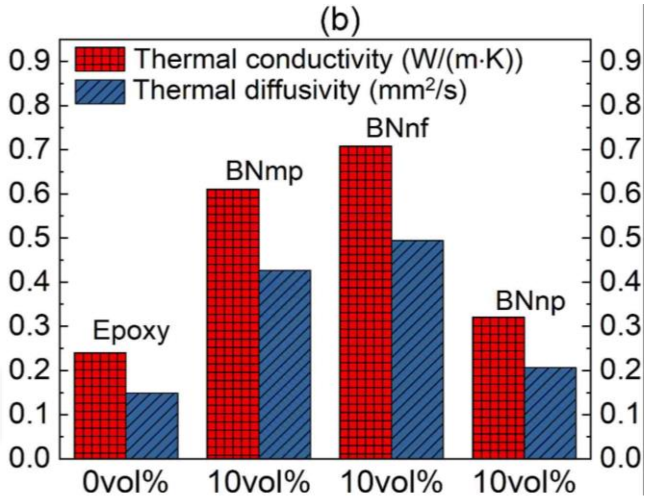
Fillers we tried

BNmp
(Boron nitride micro particle)
- Single-crystal filler
- Plate shape
- Mean particle size 45μm

BNnp
(Boron nitride nanoparticle)
- Diameter 70-80nm

BNnf
(Boron nitride nanoflake)
- Lateral size 500-600nm

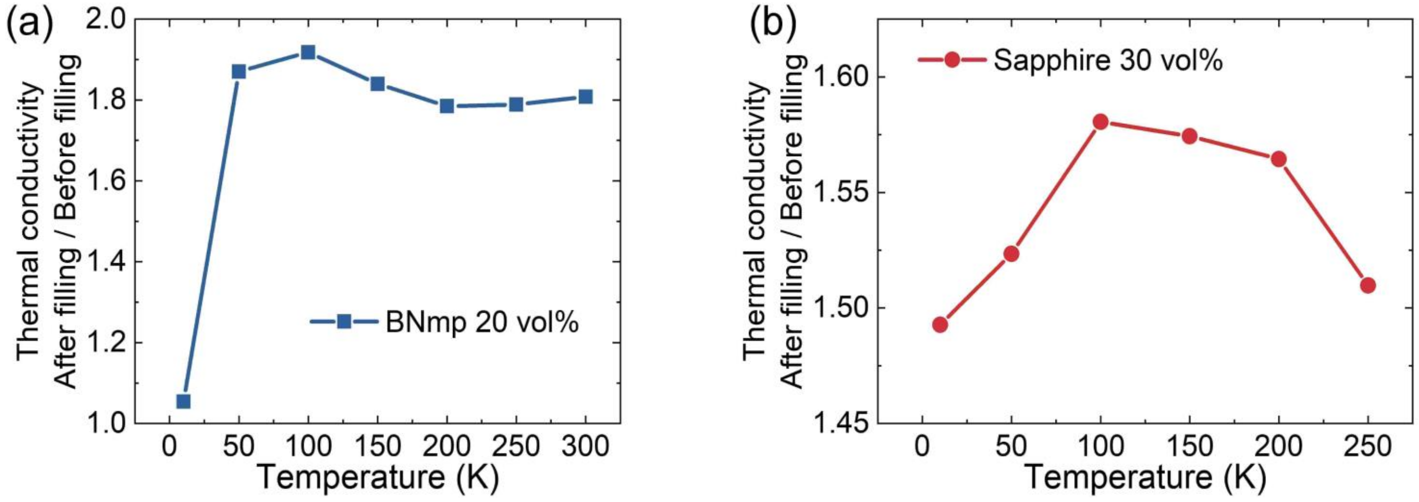


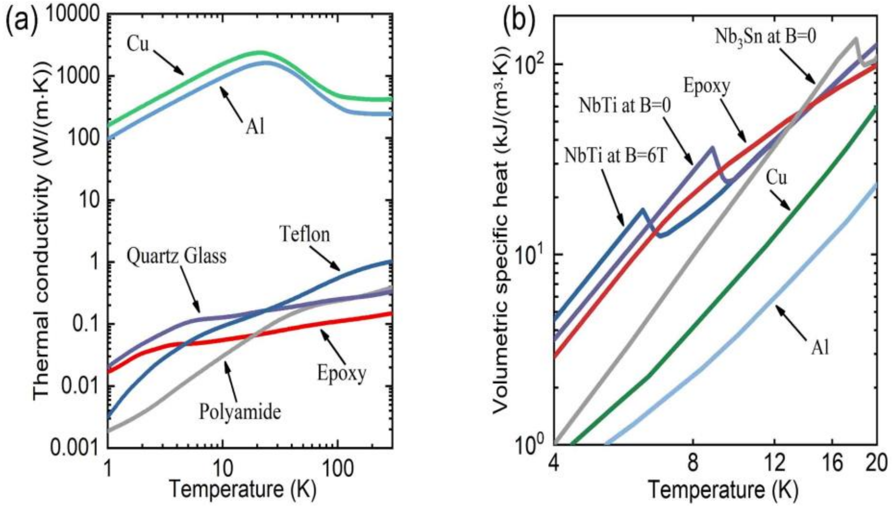


Enhancement of thermoconductivity 10vol% BNnf > BNmp > BNnp

RT thermoconductivity measurement conducted at LBNL molecular foundry.

Thermoconductivity of epoxy improves at low temperatures, even at <20 K

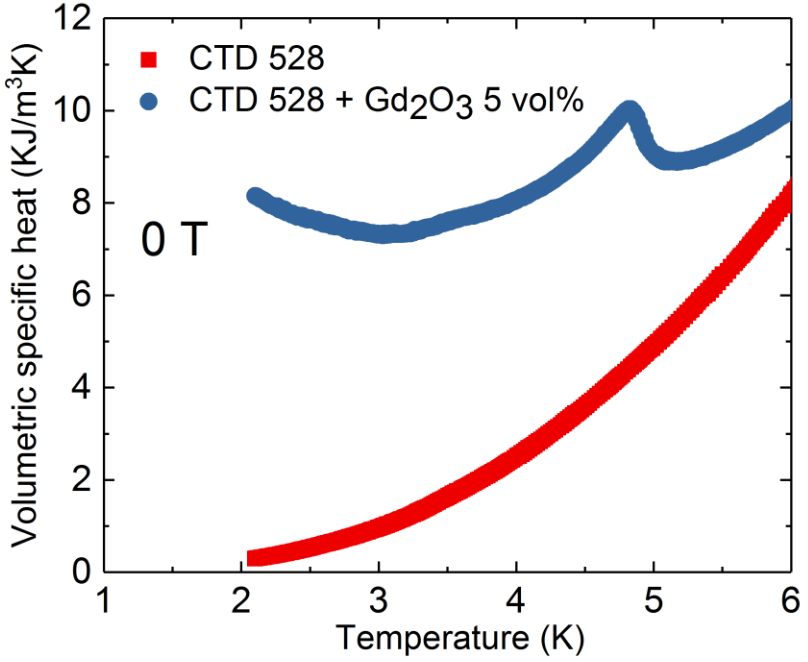


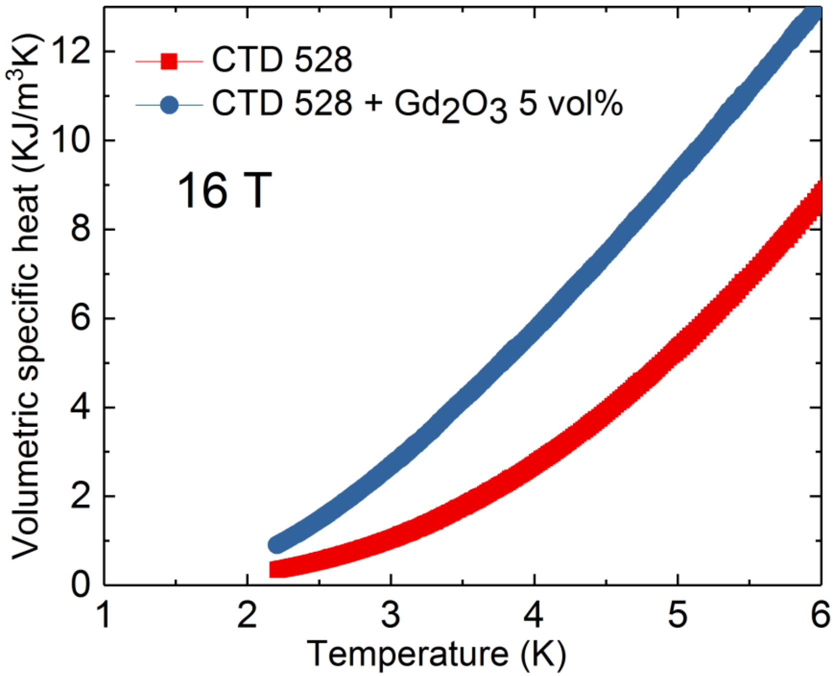


- **Low temperature data was measured by Xingchen Xu (Fermilab) using PPMS.**

- For LTS, high thermoconductivity aspect of epoxy is only an additional benefit. **Controlling CTE and strain energy of epoxy is the primary benefit of a loaded epoxy.**

High specific heat, Gd_2O_3 filled epoxy





Work conducted in collaboration with C. Tarantini (FSU), and with inputs from X. Xu (Fermilab)

Concluding remarks

- CTD701x will be the first new resin to get into the LBNL's CTD subscale magnet (Diego Arbelaez).

- We have been running three independent studies at LBNL:
    - Developing approach of preparing epoxy/filler suitable for superconducting magnets, especially epoxy nanocomposite.
    - Explore the possibility of high toughness, or high thermoconductivity (more for HTS), and high specific heat epoxy, and processing parameters.

Yet to make into magnets. Interesting academic excise overall.

- Method for interfacial control.