Effect of Heat Treatment Temperature on the Thermal Conductivity of Large Grain Superconducting Niobium

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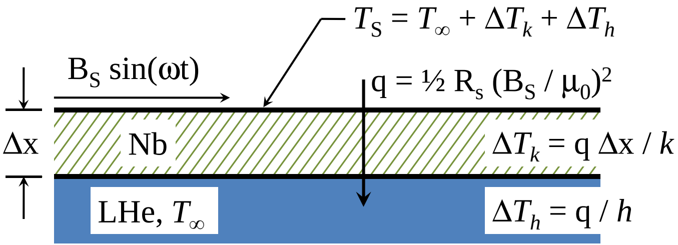
Powe

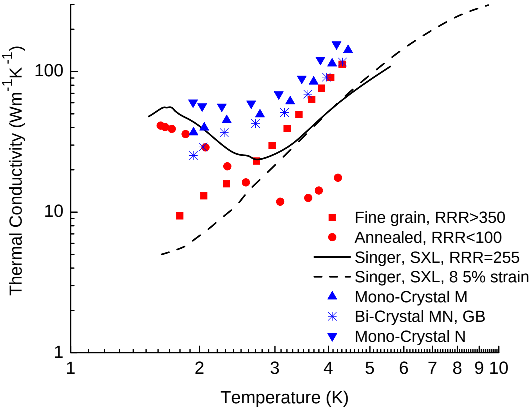


- The heat needs to be dissipated into surrounding liquid helium to maintain the bulk temperature below T_c
- Imperfections in the Nb surface result in local heating

Thermal Conductivity of Superconducting Nb

Conduction in Nb at 2 – 4.2 K is a function of

- purity
- imperfection density
- grain size
- grain orientation?



Motivation for this study

- Need to relate thermal conductivity *k* with
  - metallurgy
    - e.g., grain size, grain orientation, purity
  - processing history
    - e.g., deformation, heat treatments
- Doing so
  - Allows prediction of thermal response of final device
  - *k* can be used as a diagnostic tool
    - e.g., imperfection density, purity

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Model for k

$$k(T) = R(y)\left[\frac{\rho_{295}}{L\mathrm{RRR}\,T} + aT^2\right]^{-1} + \left[\frac{1}{D\mathrm{e}^{-y}T^2} + \frac{1}{B\lambda T^3}\right]^{-1}$$

- ρ_{295} – electrical resistivity at 295 K
- L – Lorentz constant
- RRR – ratio of electrical resistivity at 295 K to that at 4 K
- a – coefficient of momentum exchange with lattice
- D – quantifies phonon scattering by electrons
- B – value from Casimir for scattering at crystal boundaries
- λ – phonon mean free length
- $y \approx \alpha T_c/T$

Ref.: F. Koechlin and B. Bonin, Supercond. Sci. Technol. **9** (1996)

Parameters to be estimated

$$k(T) = R(y)\left[\frac{\rho_{295}}{LRRR\,T} + aT^2\right]^{-1} + \left[\frac{1}{D\mathrm{e}^{-y}T^2} + \frac{1}{B\lambda T^3}\right]^{-1}$$

$$\Downarrow$$

$$k(T) = R(y)\left[\frac{\beta_1}{T} + \beta_2 T^2\right]^{-1} + \left[\frac{\beta_3}{\mathrm{e}^{-y}T^2} + \frac{\beta_4}{T^3}\right]^{-1}$$

and

$$y \approx \alpha\frac{T_c}{T}$$

$$\Downarrow$$

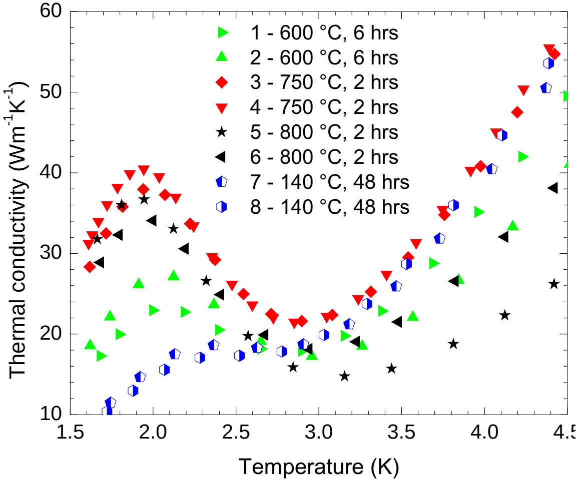
$$y \approx \beta_5\frac{T_c}{T}$$

Specimen History: Set 1 – Different ingots

- Large grain specimens
- Unstrained specimens

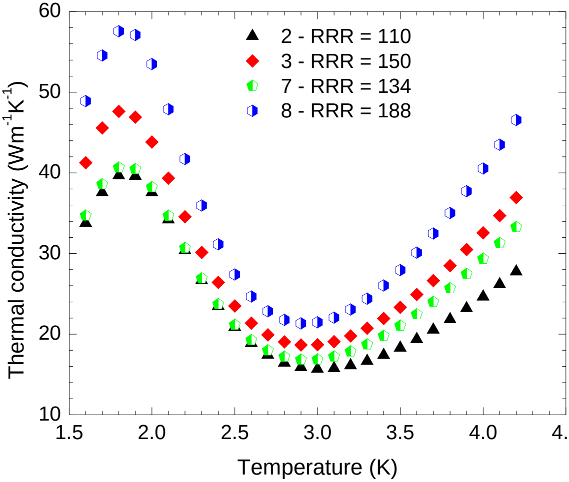
Specimen	Est. RRR	Ta content (ppm)	Heat Treatment: First heating T_h (°C)	First heating t (hrs.)	Second heating T_h (°C)	Second heating t (hrs.)
1	191	1275	600	6	-	-
2	131	668	600	6	1100	4
3	190	756	750	2	1100	4
4	196	756	750	2	-	-
5	104	1322	800	2	-	-
6	143	523	800	2	-	-
7	174	1375	140	48	1100	4
8	200	704	140	48	1100	4

Thermal conductivity: $T_h = 140\ °C – 800\ °C$



- k_{pp} dependent on heat treatment temperature
- 140 °C, 48 hrs.: no change in bulk

Thermal conductivity: $T_h = 1100\ ^\circ C$



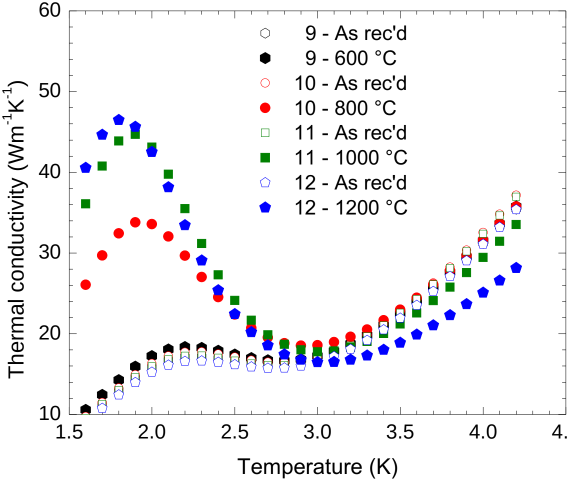
- k_{pp} shows dependence on RRR
- k for all specimens: too many variables

Specimen History: Set 2 – Same ingot disc

- Reduce extraneous factors affecting *k*
- Specimens cut from one grain, same orientation w.r.t. heat flow
- Unstrained specimens

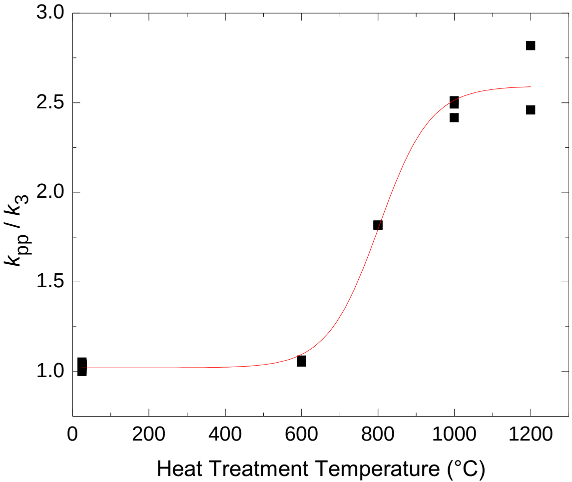
			Heat Treatment			
	Est.	**Ta content**	**First heating**		**Second heating**	
Specimen	**RRR**	**(ppm)**	T_h (°C)	t (hrs.)	T_h (°C)	t (hrs.)
9	146	1357	600	2	-	-
10	143	1357	800	2	-	-
11	151	1357	1000	2	-	-
12	141	1357	1200	2	-	-

k for 2 hrs. heating



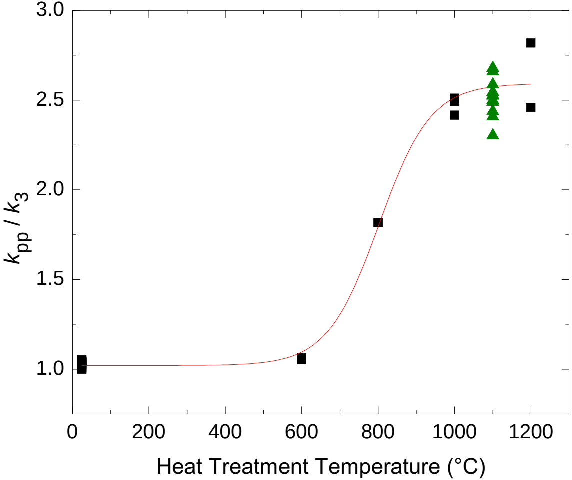
- No change in *k* after 600 °C, 2 hrs.
- Similar k_{pp} for 1000 °C & 1200 °C

Normalized phonon peak vs. T_h



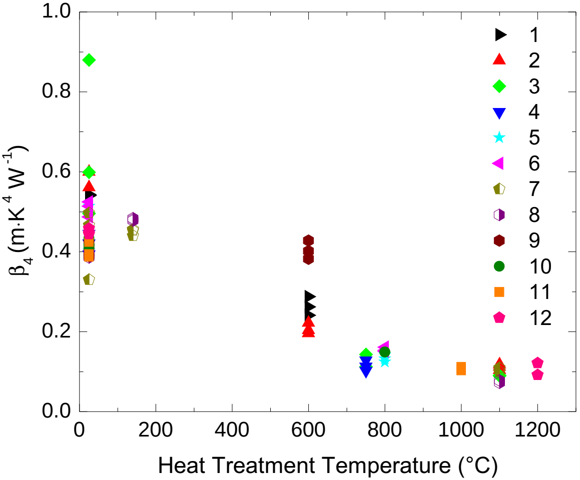
- Sigmoidal dependence on temperature
- Plateau above 1000 °C?

Normalized phonon peak vs. T_h



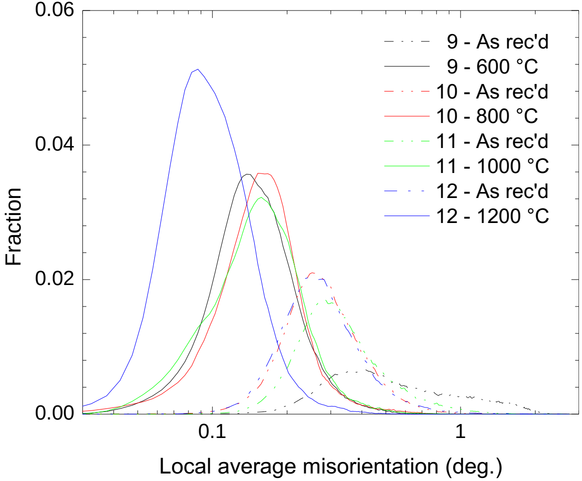
- 1100 °C, 4 hrs. data supports plateau
- All data from unstrained LG Nb

β_4: phonon scatt. by dislocations and boundaries



- Lower β_4 with increasing heat treatment temperature
- Asymptotic convergence

Local average misorientation



- Dislocation recovery at the surface
- 0.005° bins used

Conclusions

- 140 °C, 48 hrs.; 600 °C, 2 hrs.: no change in k
- k_{pp} shows dependence on RRR
- k_{pp}/k_3 shows sigmoidal dependence on T_h
- Possible plateau in k_{pp}/k_3 for $T > 1000$ °C
  - For unstrained LG Nb
- Rate constants may be estimated from Set 2
- $T < 1000$ °C, longer t could reproduce max. k_{pp}/k_3
  - Economically beneficial

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Ingot Nb discs

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