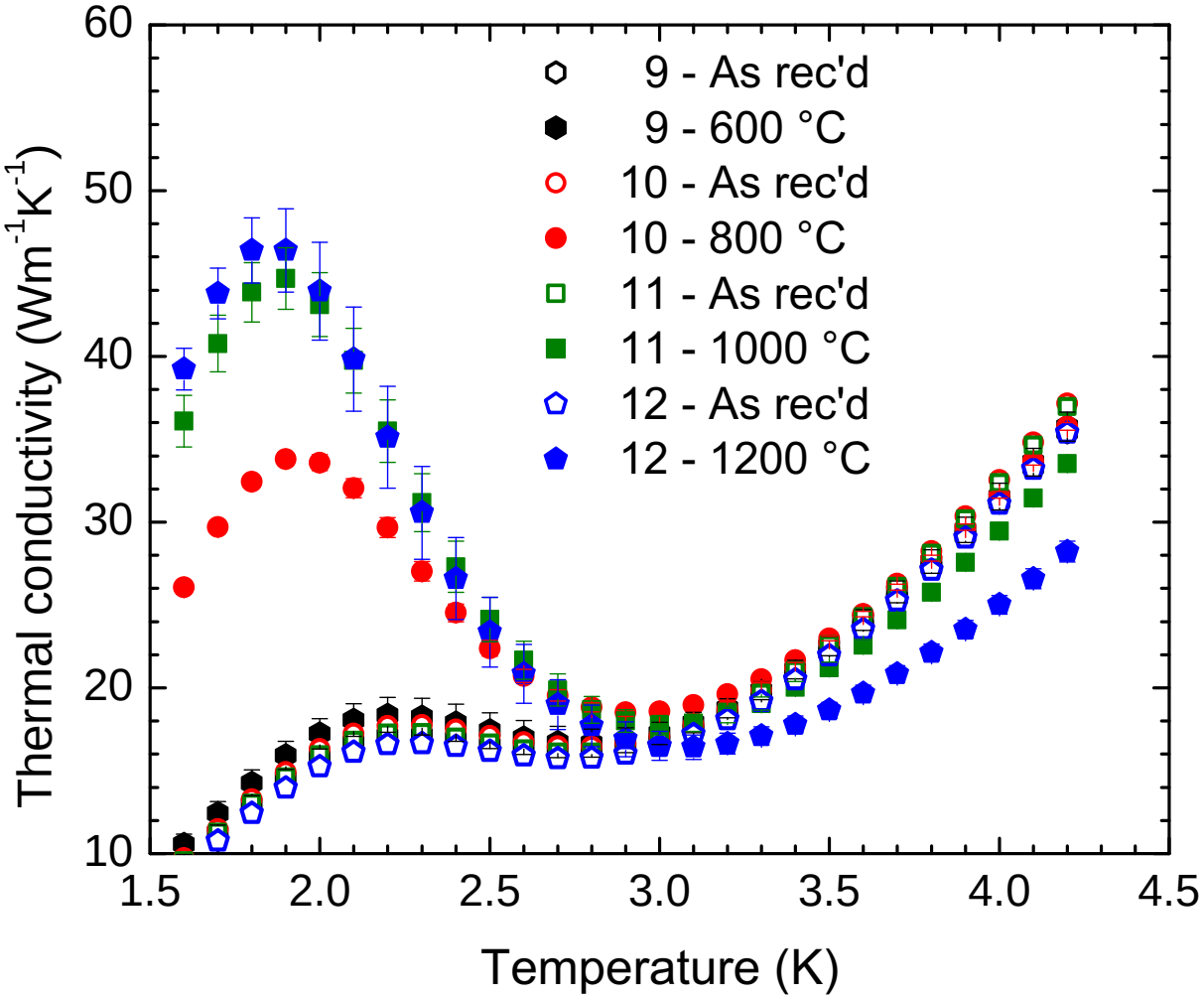
Recovery of Phonon Peak in Annealed Niobium as a Function of Initial Strain and Hydrogen Concentration

S.K. Chandrasekaran,
T.R. Bieler, C.C. Compton, N.T. Wright

Michigan State University

July 16, 2012

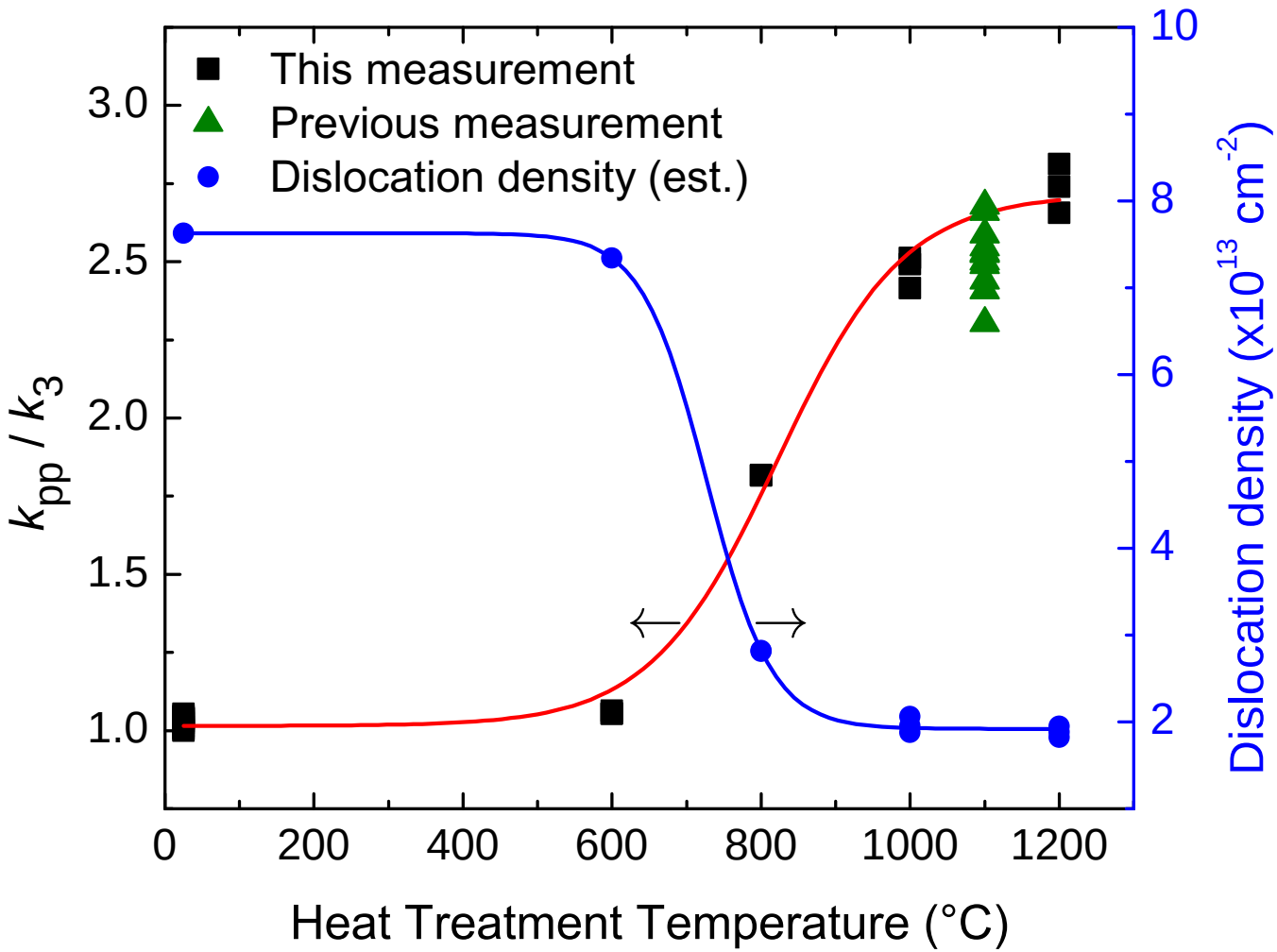
Heat treatment kinetics for 2 h



- k_{pp} an asymptote for $T_h \geq 1000°C$

Ref.: S.K. Chandrasekaran, *et al.*, SRF '11, WEIOA06, 2011

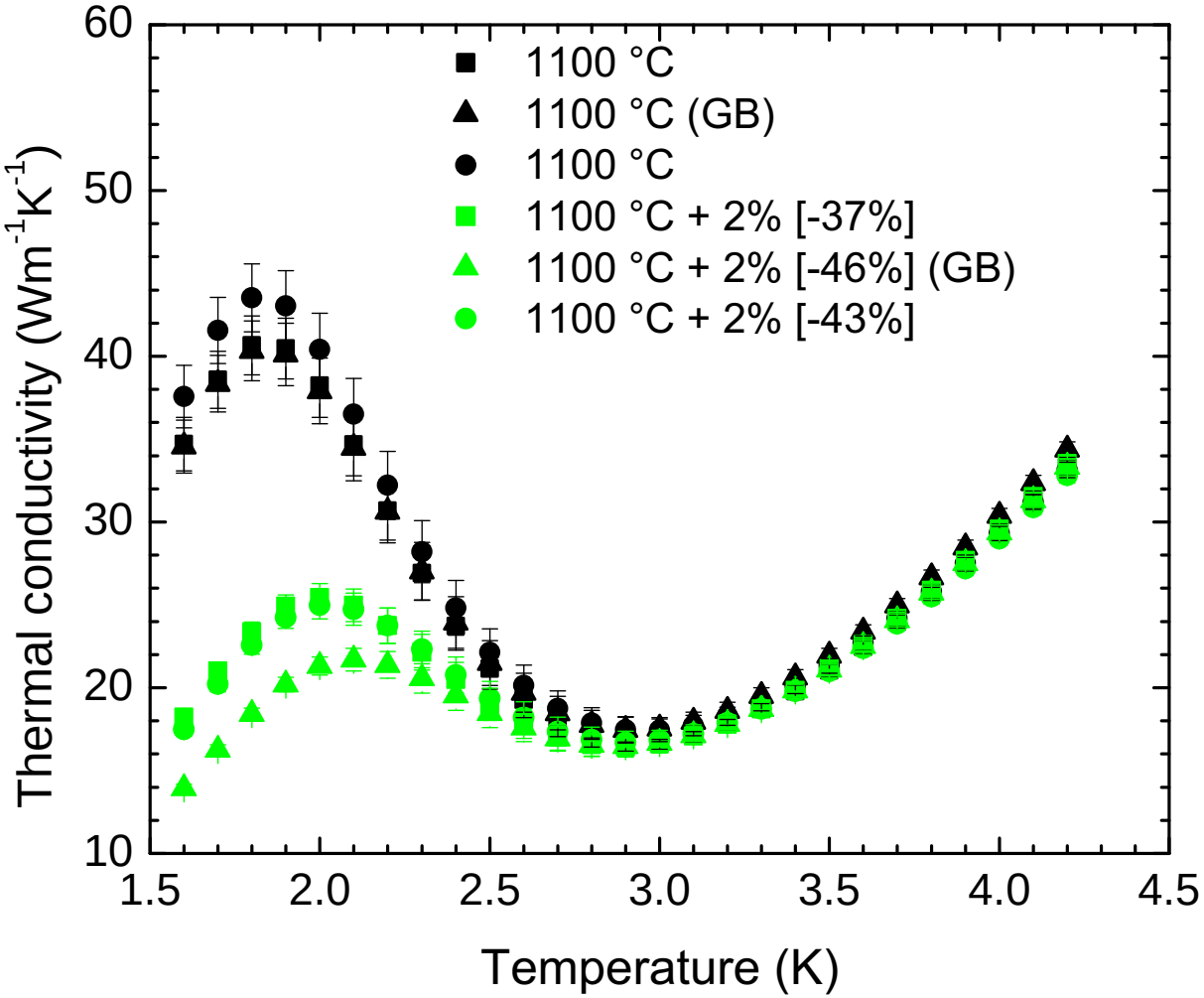
Normalized Phonon Peak vs. T_h for 2 h



- Recovery has sigmoidal dependence on T_h
- k_{pp} inversely proportional to dislocation density

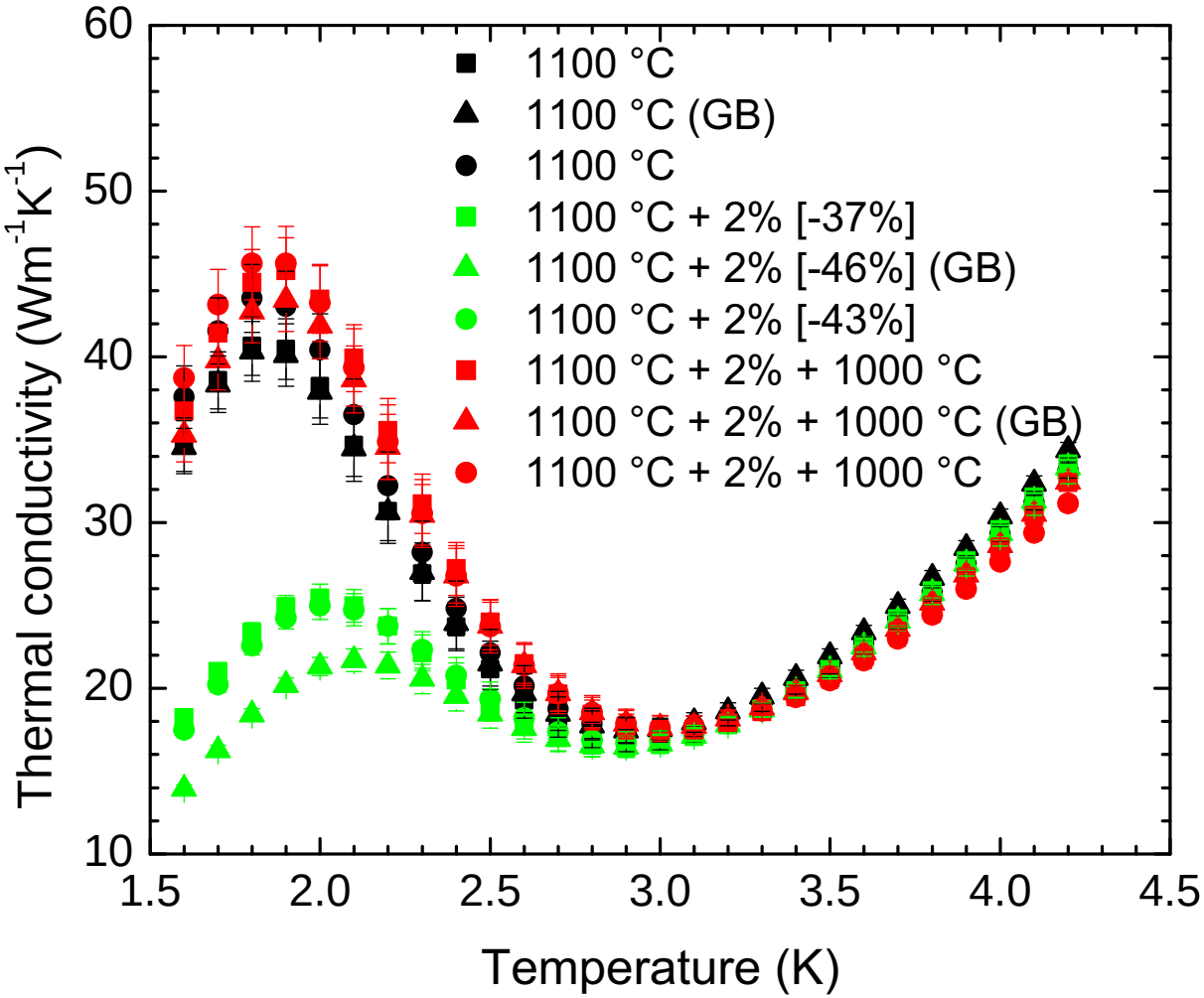
Ref.: S.K. Chandrasekaran, *et al.*, SRF '11, WEIOA06, 2011

2% nominal strain & 1000 °C, 2 h



Grain	Abs. Schmid factor	# active slip sys.	Engg. strain
1 (■)	0.357	1	2%
2 (●)	0.371	1	2%

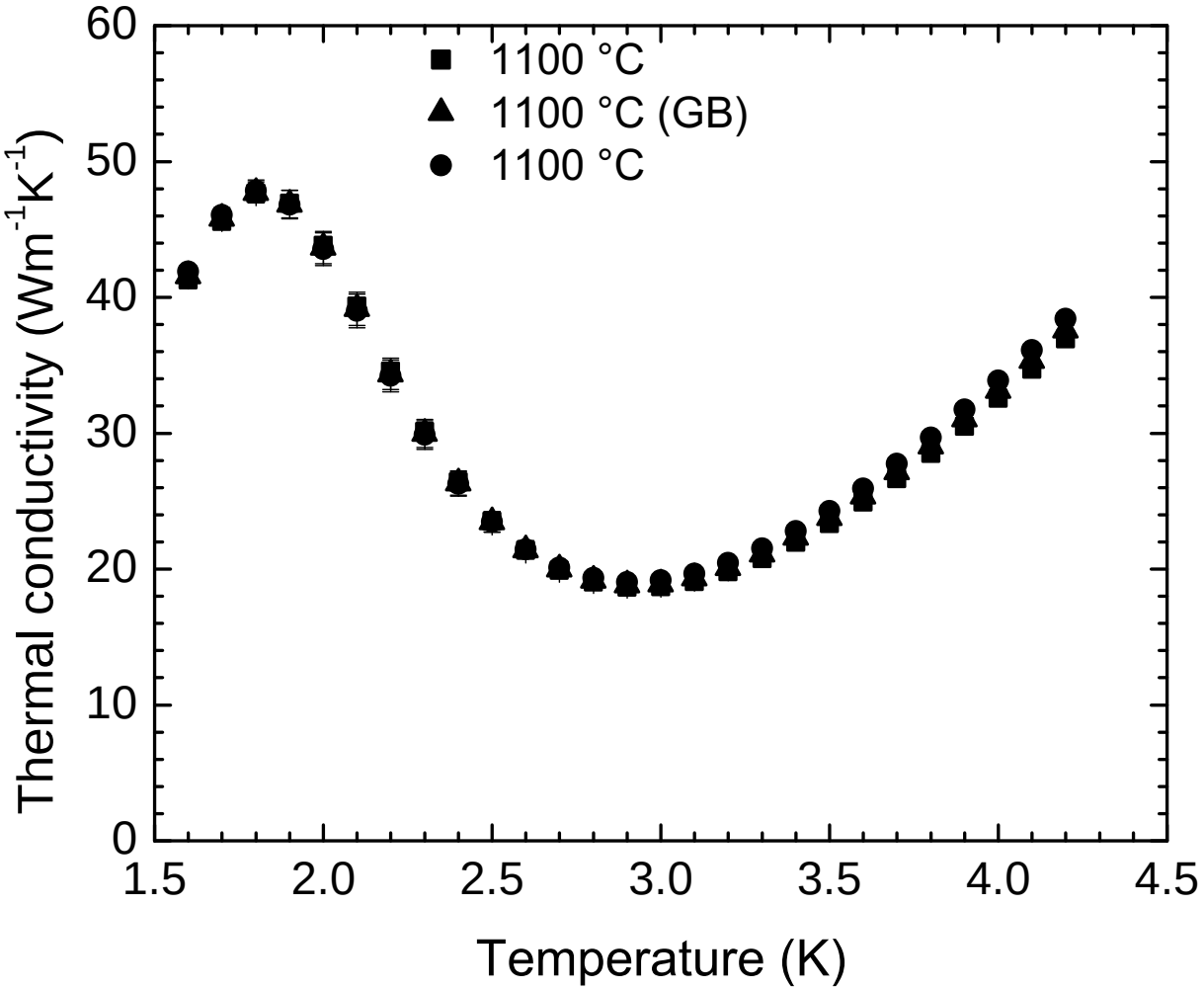
2% nominal strain & 1000 °C, 2 h



Complete recovery for $\epsilon = 2\%$

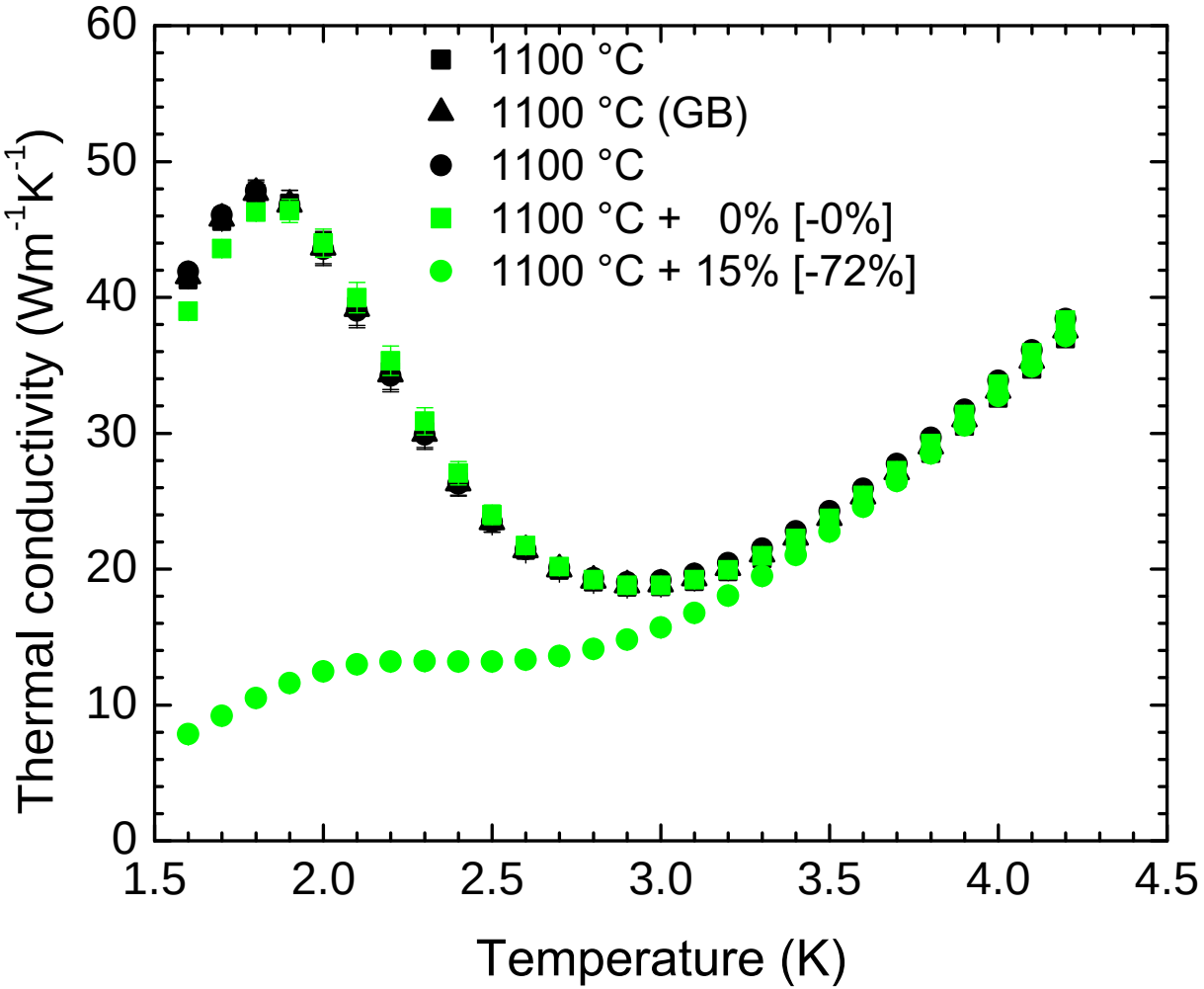
Grain	Abs. Schmid factor	# active slip sys.	Engg. strain
1 (■)	0.357	1	2%
2 (●)	0.371	1	2%

10% nominal strain & 1000 °C, 2 h



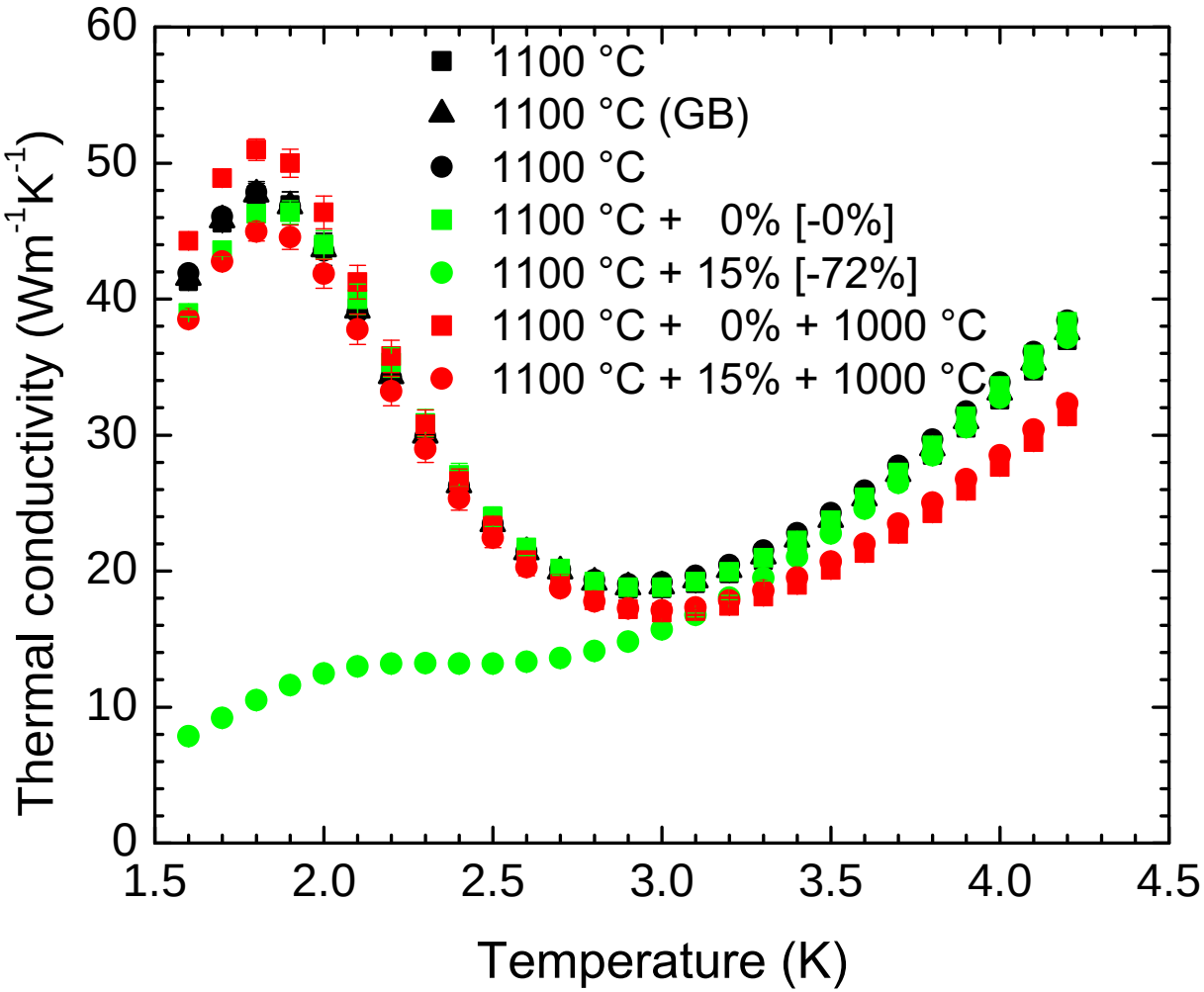
Grain	Abs. Schmid factor	# active slip sys.	Engg. strain
1 (■)	0.359	2	0%
2 (●)	0.481	1	15%

10% nominal strain & 1000 °C, 2 h



Grain	Abs. Schmid factor	# active slip sys.	Engg. strain
1 (■)	0.359	2	0%
2 (●)	0.481	1	15%

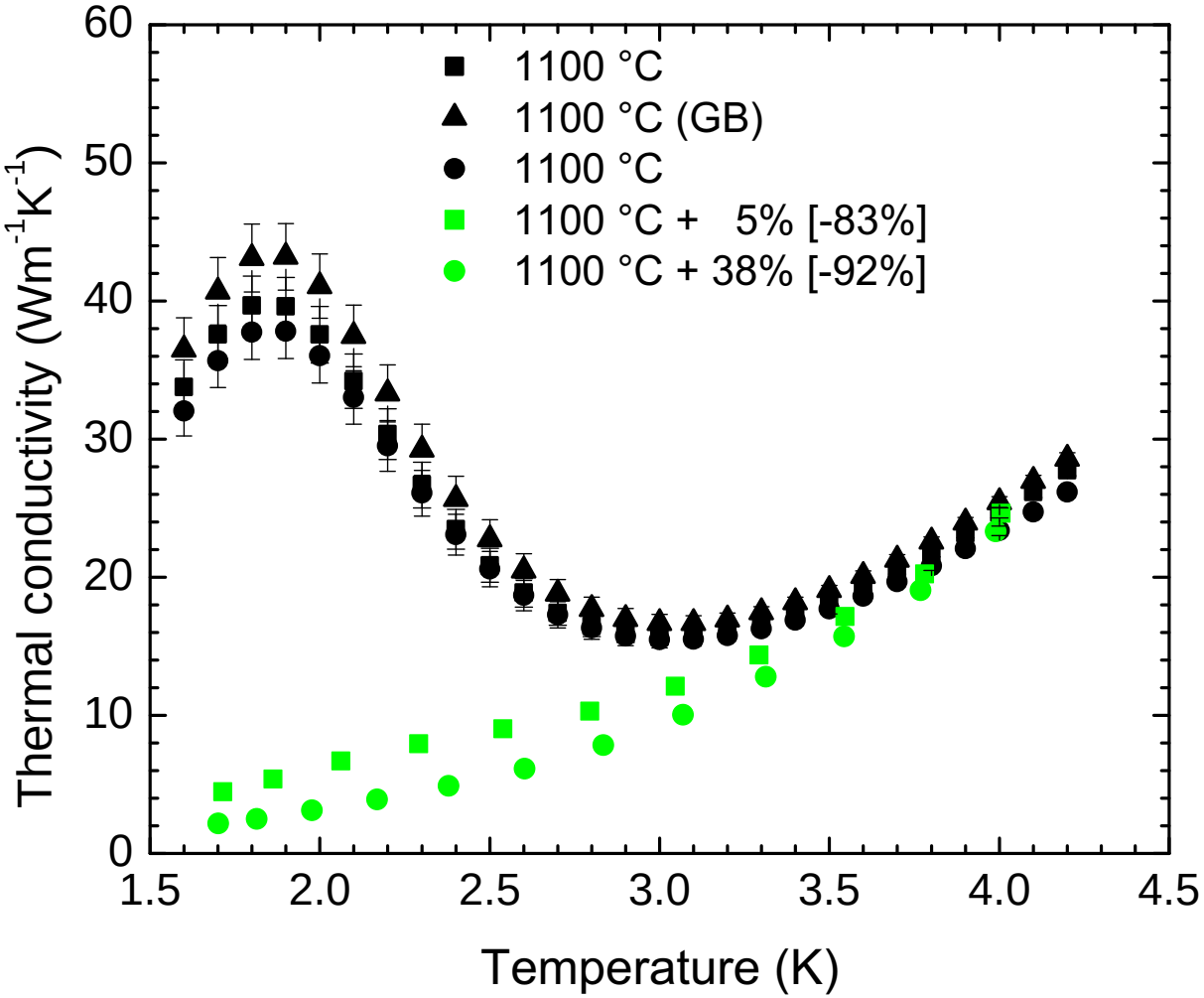
10% nominal strain & 1000 °C, 2 h



Complete recovery for $\epsilon = 15\%$

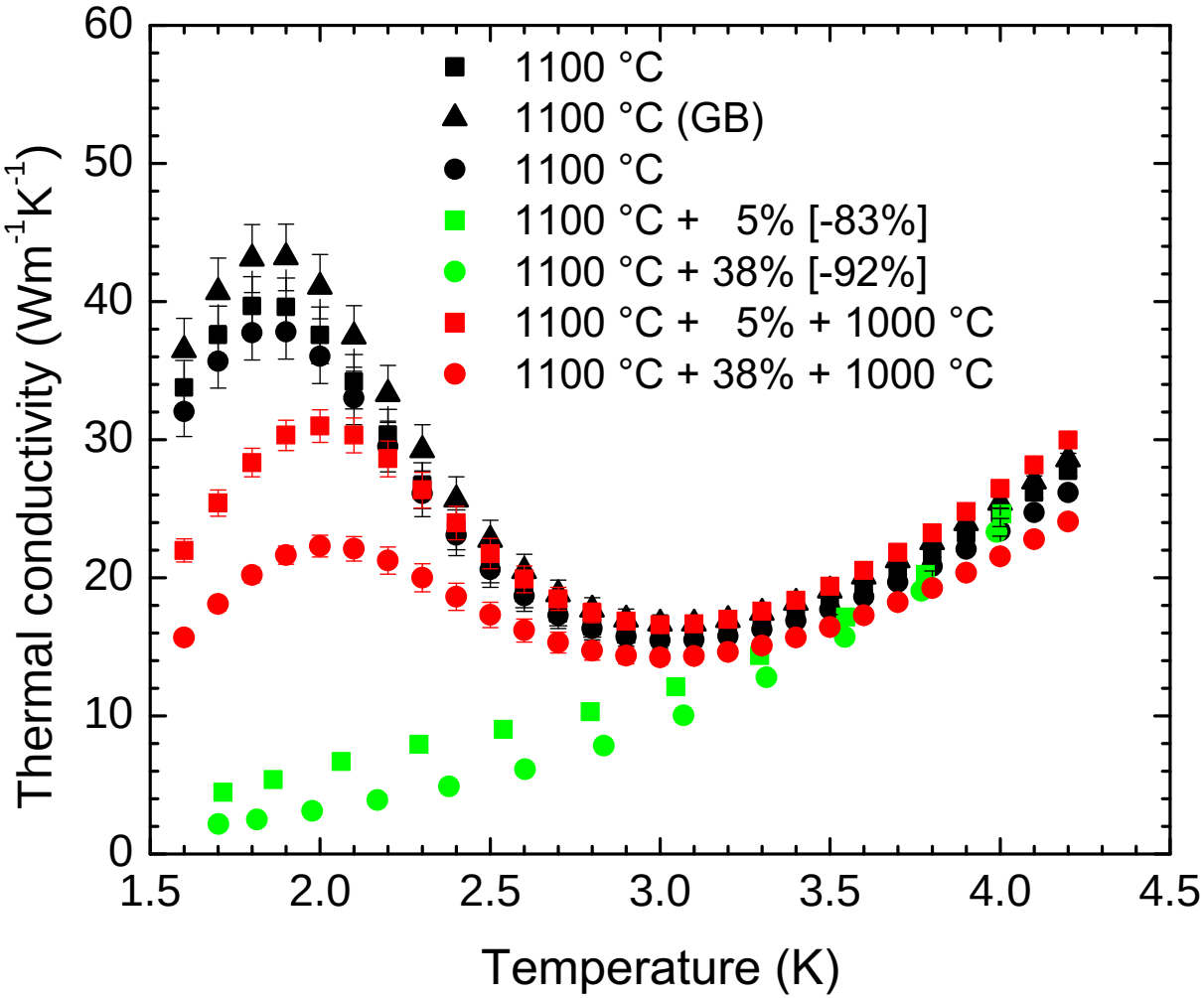
Grain	Abs. Schmid factor	# active slip sys.	Engg. strain
1 (■)	0.359	2	0%
2 (●)	0.481	1	15%

20% nominal strain & 1000 °C, 2 h



Grain	Abs. Schmid factor	# active slip sys.	Engg. strain
1 (■)	0.492	2	5%
2 (●)	0.470	1	38%

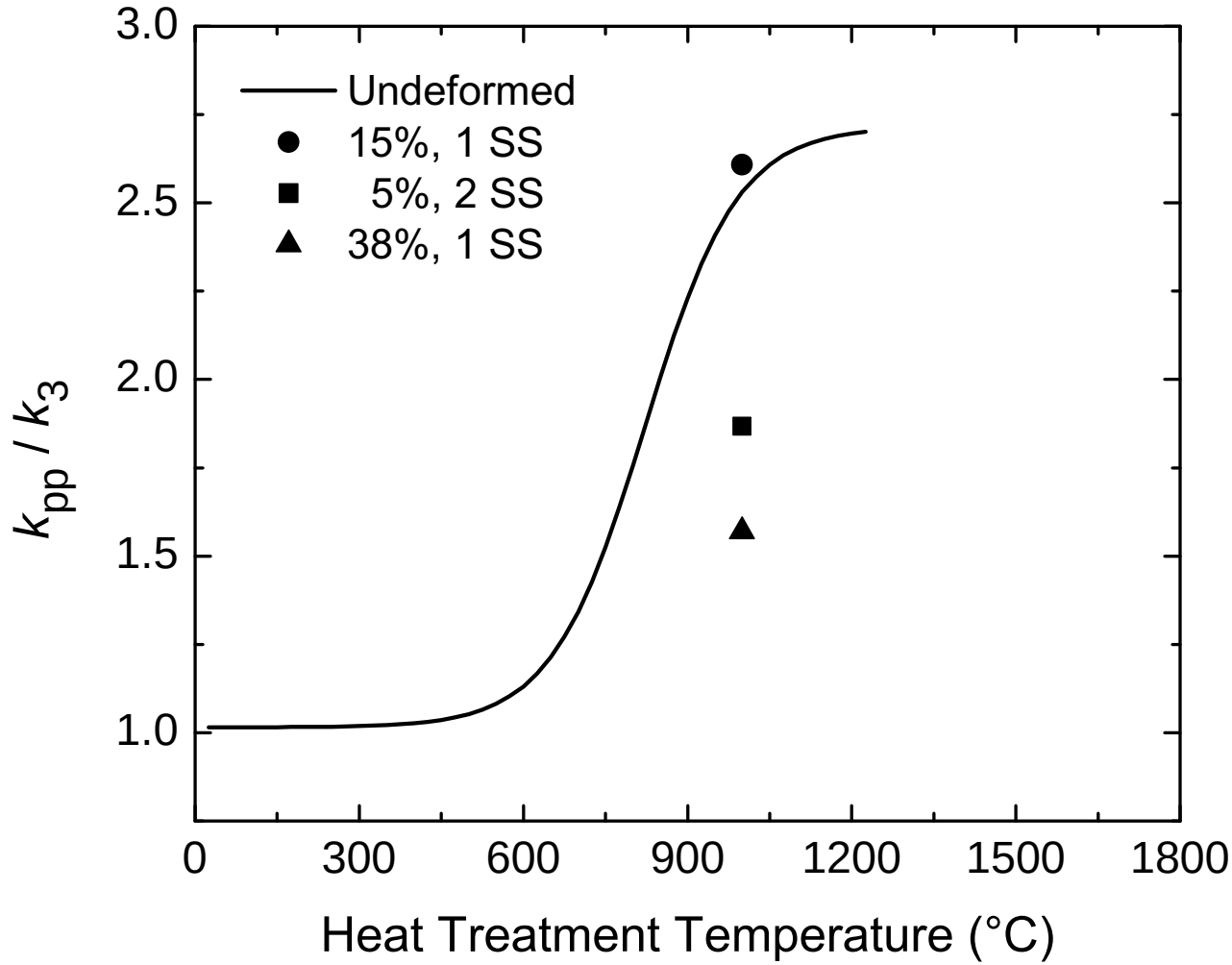
20% nominal strain & 1000 °C, 2 h



Incomplete recovery even for $\epsilon = 5\%$!!

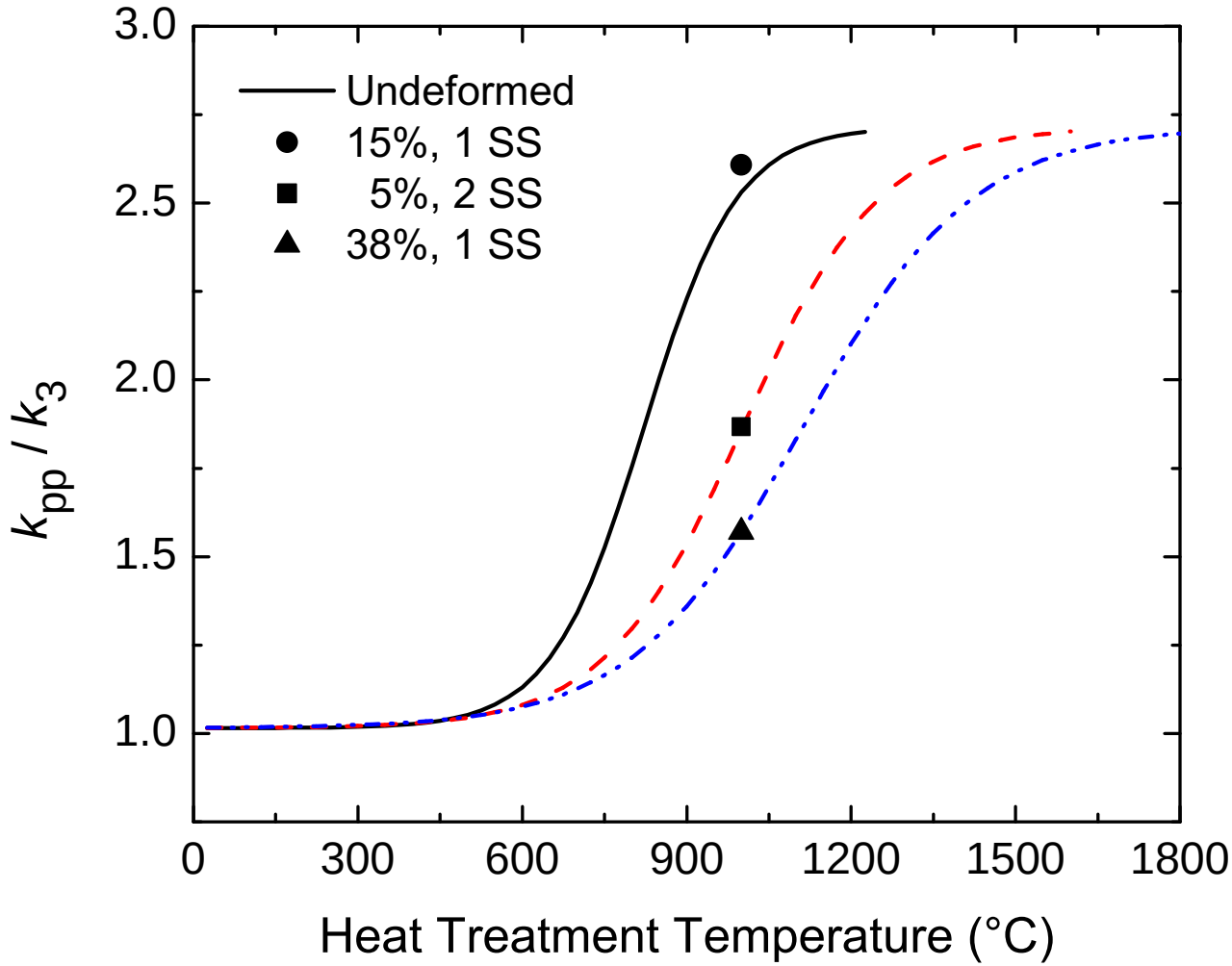
Grain	Abs. Schmid factor	# active slip sys.	Engg. strain
1 (■)	0.492	2	5%
2 (●)	0.470	1	38%

Estimated recovery for 2 h heating in LG Nb



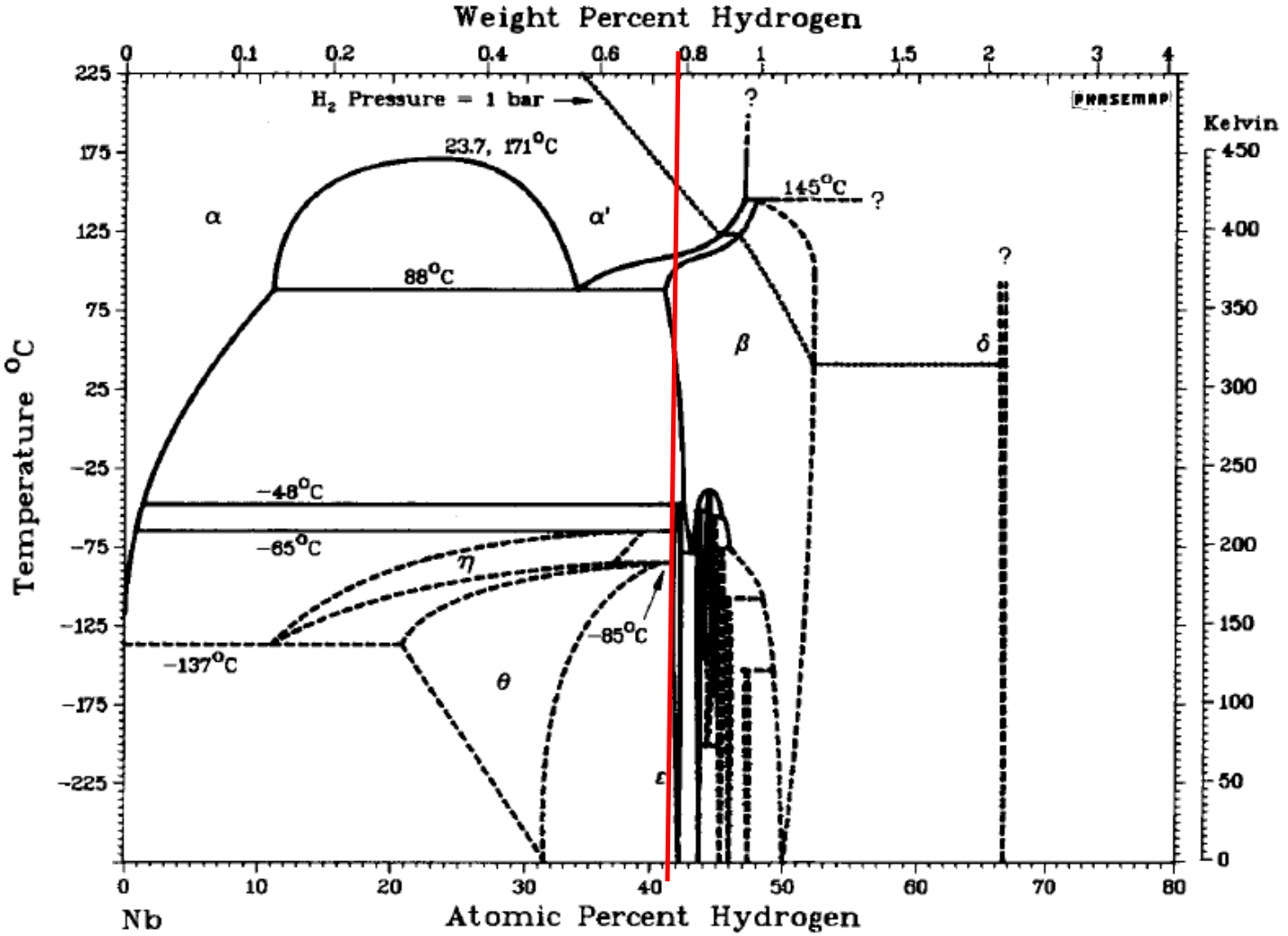
- $T_{HT} \gtrsim 1500$ °C may lead to complete k_{pp} and dislocation recovery

Estimated recovery for 2 h heating in LG Nb



- $T_{HT} \gtrsim 1500$ °C may lead to complete k_{pp} and dislocation recovery

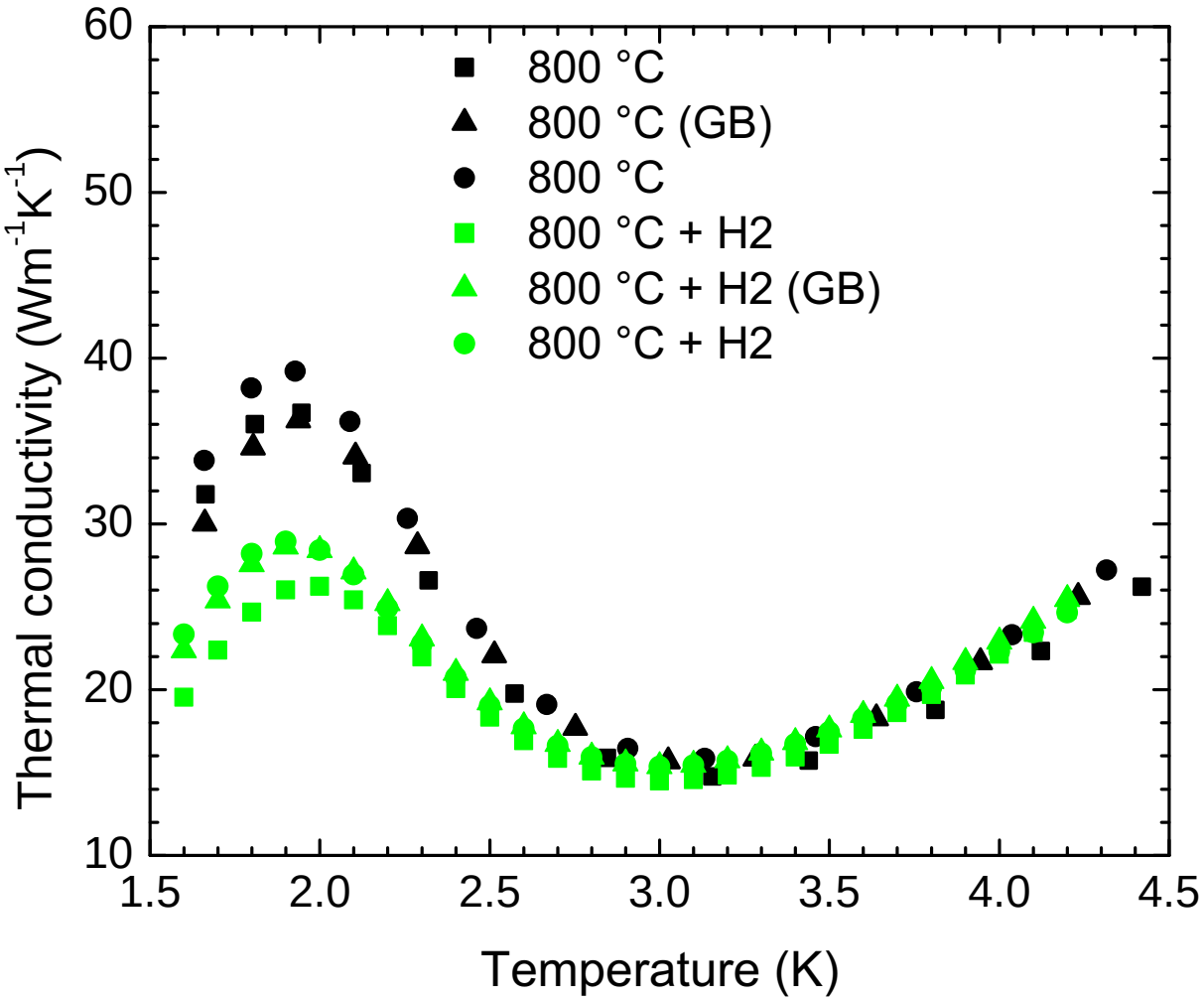
Hydrogen phase estimation



- Nb-H phase borders ($\alpha + \beta$) and β phases at $T = 25$ °C

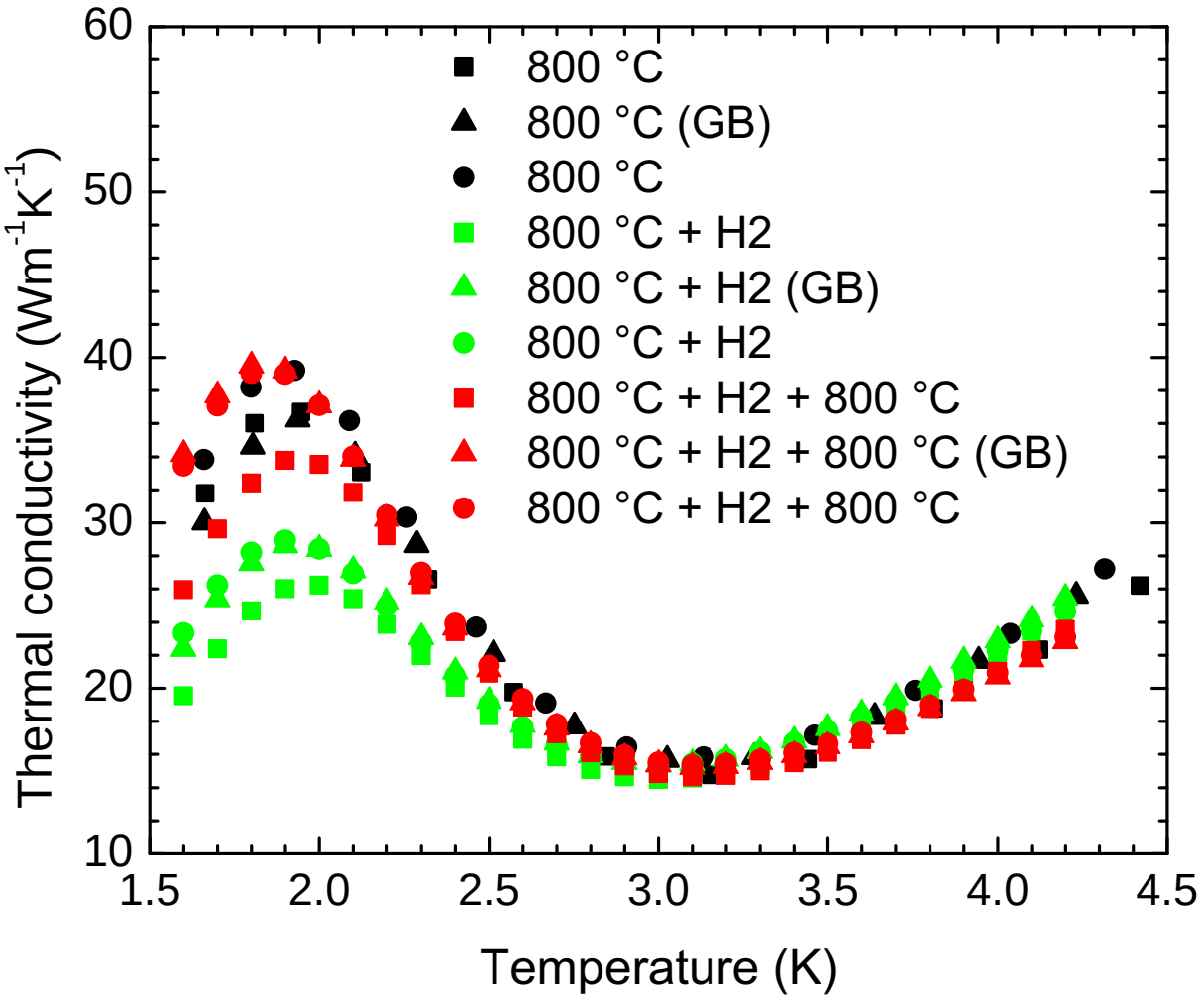
Ref.: J.F. Smith, Bulletin of Alloy Phase Diagrams, vol. 4, pp. 39–46, 1983

Effect of saturated hydrogen on k (RRR=110)



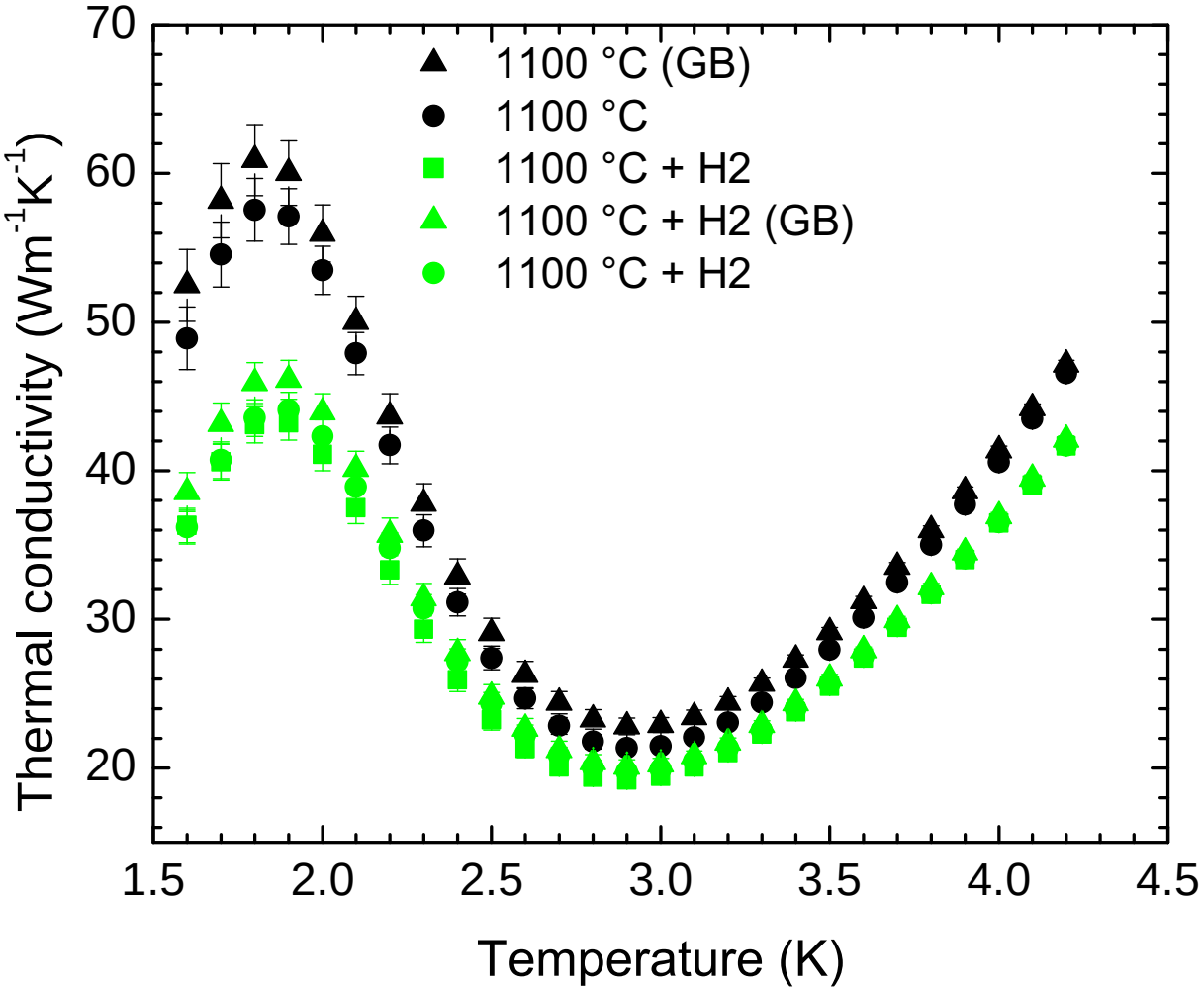
- 25% reduction at phonon peak; no effect for $T > 3$ K
- Complete recovery after 800 °C, 2 h heating

Effect of saturated hydrogen on k (RRR=110)



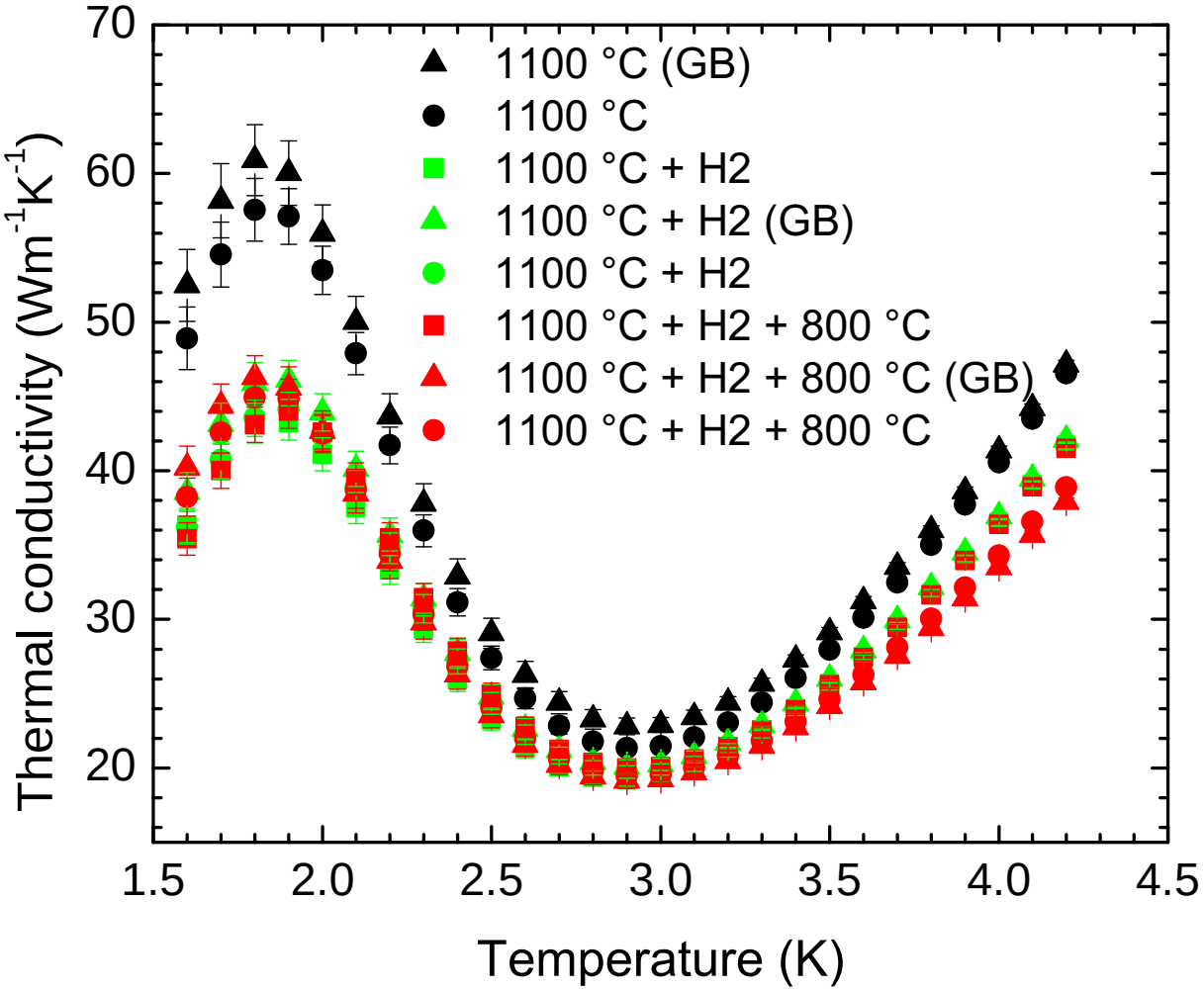
- 25% reduction at phonon peak; no effect for $T > 3$ K
- Complete recovery after 800 °C, 2 h heating

Effect of saturated hydrogen on *k* (RRR=190)



- 25% reduction at phonon peak; 10% reduction at 4.2 K
- NO recovery after 800 °C, 2 h heating: possibly due to greater vacancy saturation at 1100 °C, & H-Nb phase

Effect of saturated hydrogen on *k* (RRR=190)



- 25% reduction at phonon peak; 10% reduction at 4.2 K
- NO recovery after 800 °C, 2 h heating: possibly due to greater vacancy saturation at 1100 °C, & H-Nb phase

Conclusions

Post deformation recovery of k_{pp}

- Dependent on dislocation density
- Strain, Schmid factors & slip systems important
- $T_{HT} \gtrsim 1500$ °C or longer t_{HT} suggested

Hydrogen saturation

- Dependent on vacancy concentration
- Annealing T may increase vacancies

Acknowledgements

Funding

- U.S. Department of Energy, Office of High Energy Physics

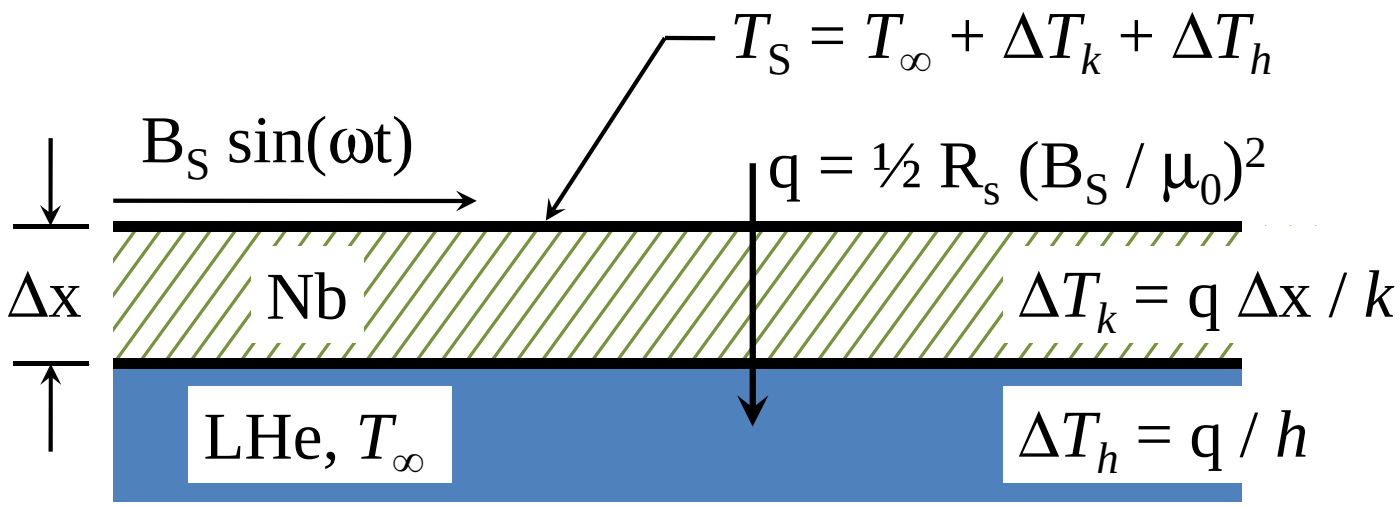
Collaborators

- Di Kang, Michigan State University
- Dr. James V. Beck, Michigan State University (Retired)

Ingot Nb discs

- Dr. G.R. Myneni, Jefferson Laboratory

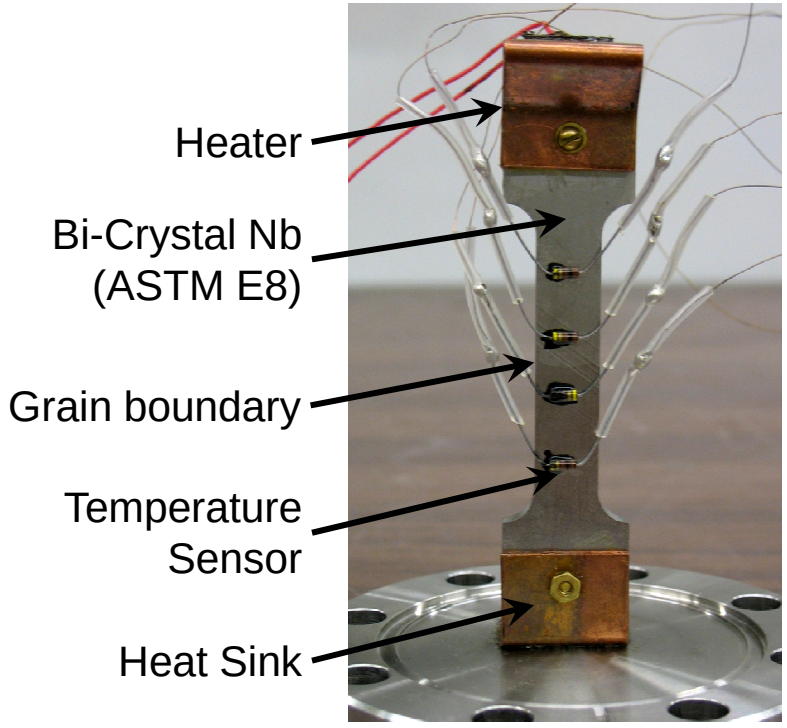
Power dissipation



- Local heating in Nb at surface imperfections
- Points of temperature excess must be cooled to maintain Nb at desired *T*

Measurement Apparatus

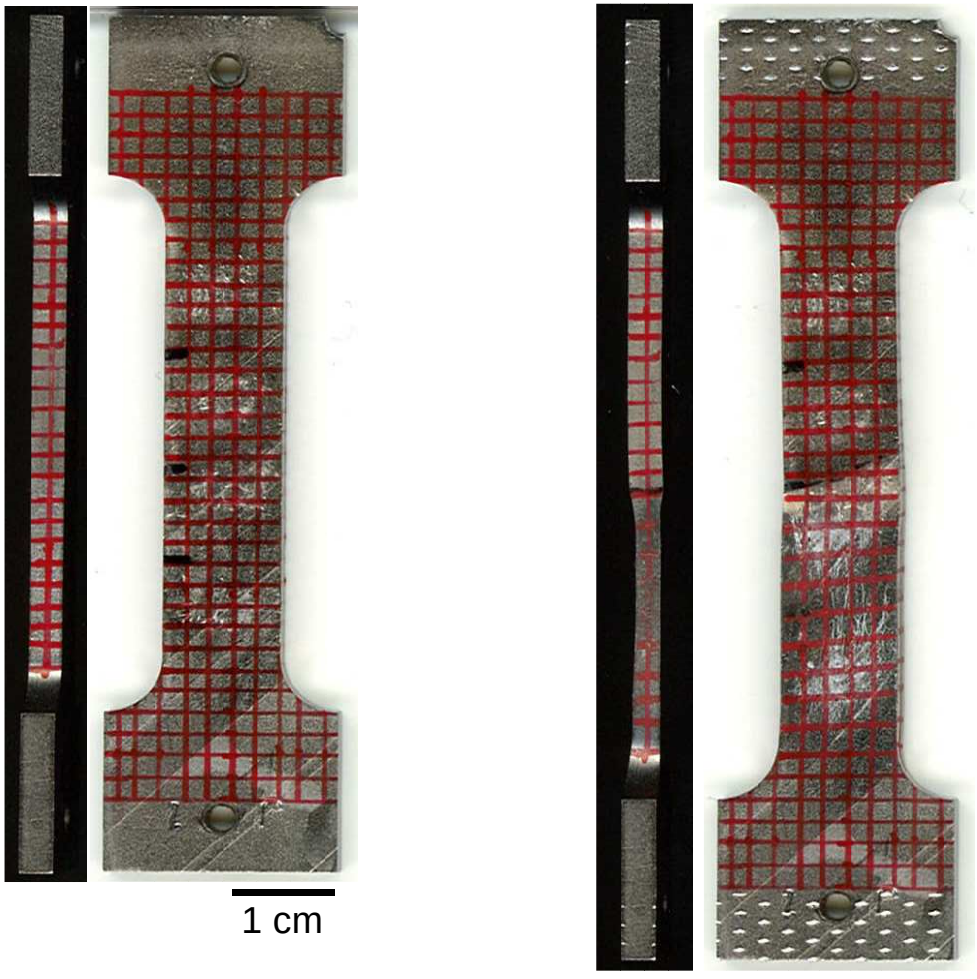
- Specimens conform to ASTM E8
- Up to 4 specimens per test
- Superfluid He at 1.6 K used



Data reduction

- k estimated using model & all T data simultaneously
- Novel estimation algorithm used to obtain parameters within k model
- Method reduces uncertainties in k for $T < 3$ K

20% nominal strain & 1000 °C, 2 h



Grain	Abs. Schmid factor	# active slip sys.	Engg. strain
1 (■)	0.492	2	5%
2 (●)	0.470	1	38%