Plasma-Enhanced Atomic Layer Deposition of Superconducting NbN Films

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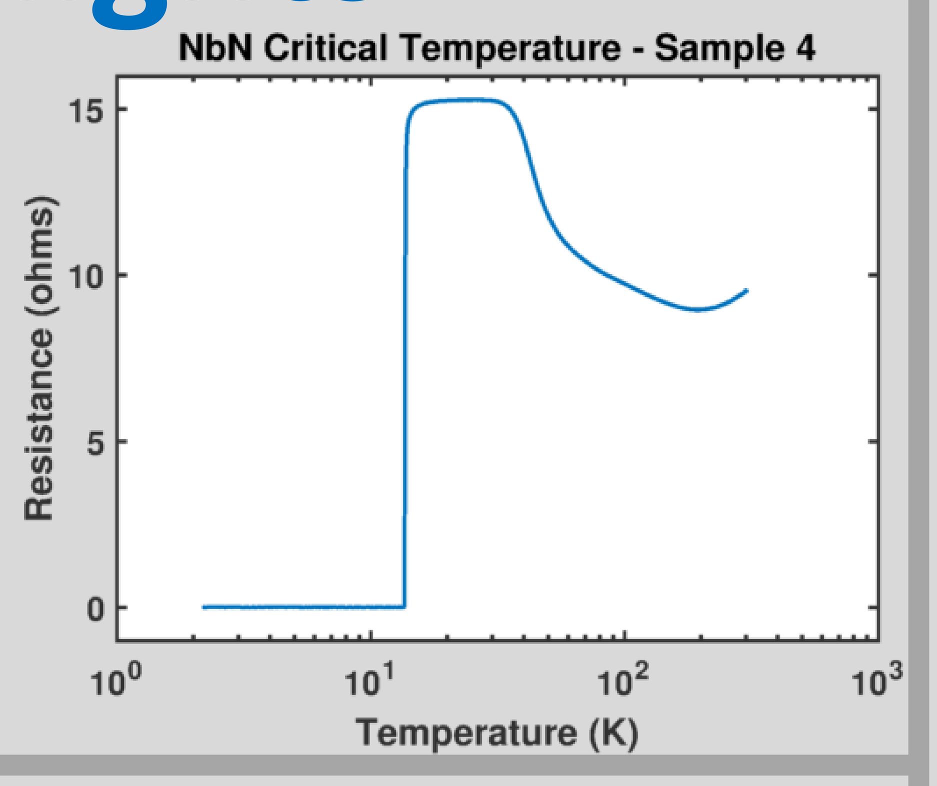
Highlights

- Superconductive PEALD NbN with critical temperature, T_c, values as high as 13.5K
- Room-temperature resistivity values as low as 173$\mu\Omega$-cm



Introduction

- NbN is a Type II superconductor with a T_c of about 16K[1]
- Superconducting NbN has been deposited by Plasma-Enhanced Atomic Layer Deposition (PEALD) previously.[2]
  - T_c = 10.2K, Room T resistivity = 250$\mu\Omega$-cm
- PEALD NbN has been studied for gate electrode applications:
  - $Nb(N\text{-}t\text{-}Bu)(NMeEt)_3$ + H_2 plasma, 715$\mu\Omega$-cm[3]
  - $Nb(N\text{-}t\text{-}Bu)(NMeEt)_3$[4]
- Improvements in PEALD NbN process may lead to higher T_c and lower resistivity values

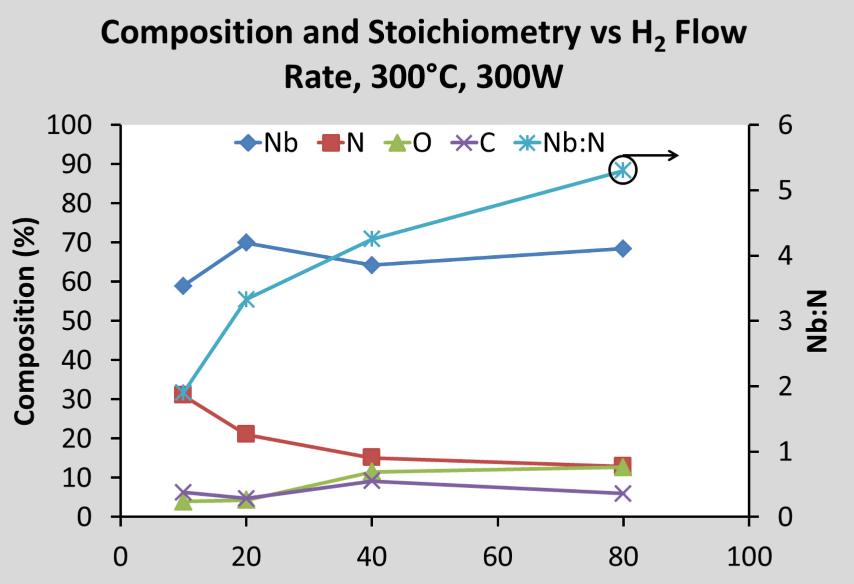
Experimental

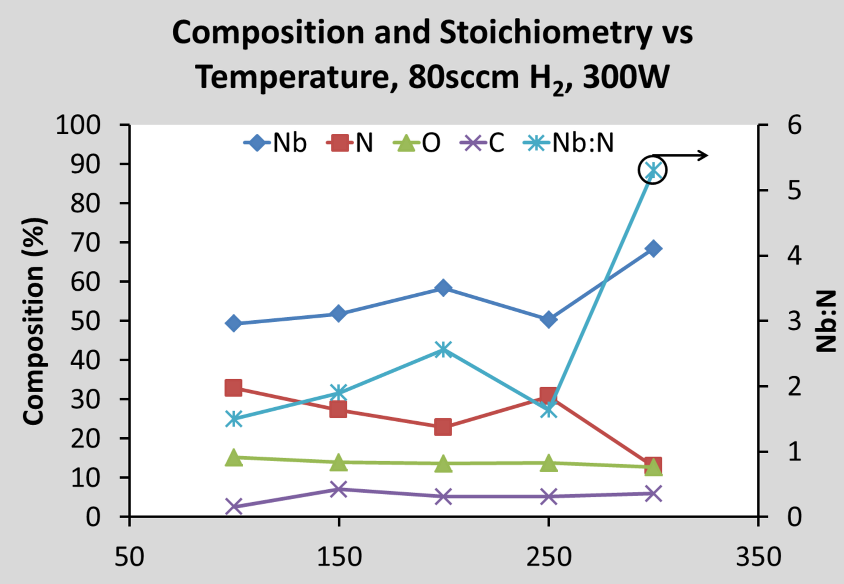
- PEALD of NbN films on an Ultratech/CNT Fiji
- (t-butylimido) tris(diethylamido) niobium(V) (TBTDEN) (100°C)

500 cycles	TBTDEN Pulse	TBTDEN Purge	Plasma	Plasma Purge
Carrier Ar (sccm)	30	30	10	30
Plasma Ar (sccm)	100	100	0	100
Plasma H_2 (sccm)	0	0	0—80	0
Plasma N_2 (sccm)	5	5	5	5
Pump Speed	Low	High	High	Low
Power (W)	0	0	150-300	0
Time (sec)	3x Boost™	8	40	5
Temperature (°C)	100 – 300			

- Spectroscopic ellipsometry for film thickness, *n*, and *k*
- Four point probe technique to assess thin film resistivity
- T_c measured with Quantum Design PPMS through a Stanford Research Systems SR830 lock-in amplifier
- Composition data from PHI Versaprobe XPS

Composition





- Binding energy of the Nb $3d_{5/2}$ peak is ~203.5 eV for all samples consistent with NbN (203.5 - 204 eV) or NbO (202.8 - 204.8 eV) but not Nb metal (201.8 - 202.5 eV)[5]
- C1s peak at ~282.5 eV suggests presence of NbC[5]
- Depositions resulted in Nb-rich films
- H-rich plasmas deplete film of N resulting in higher Nb:N
- Temperature increase increases Nb and decreases N resulting in higher Nb:N

Acknowledgements

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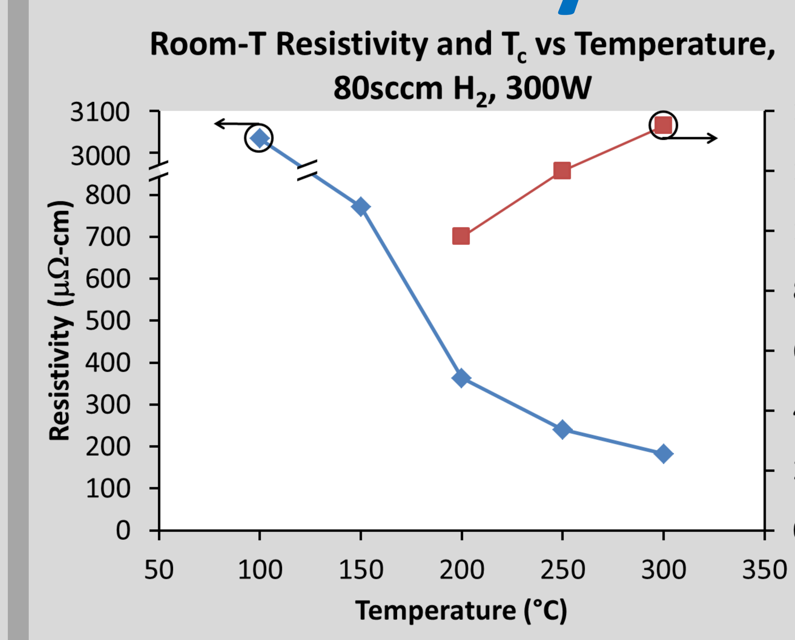
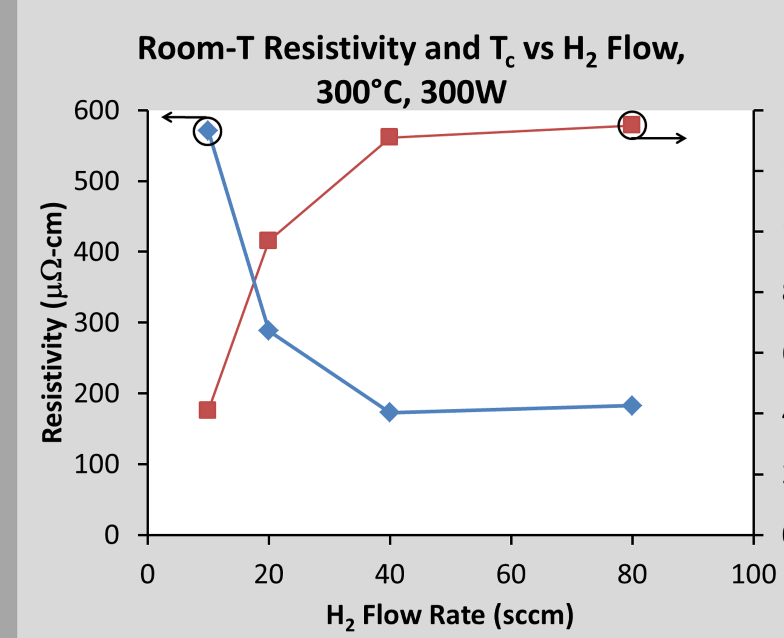
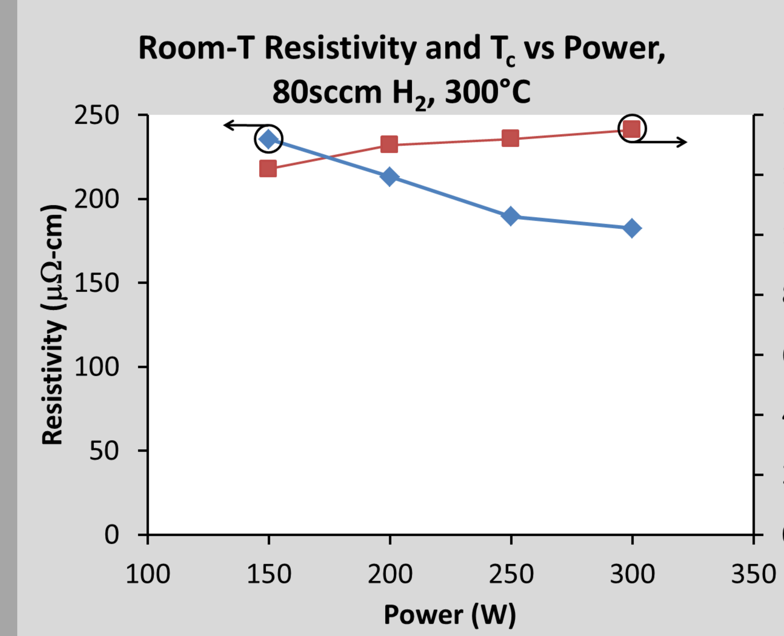
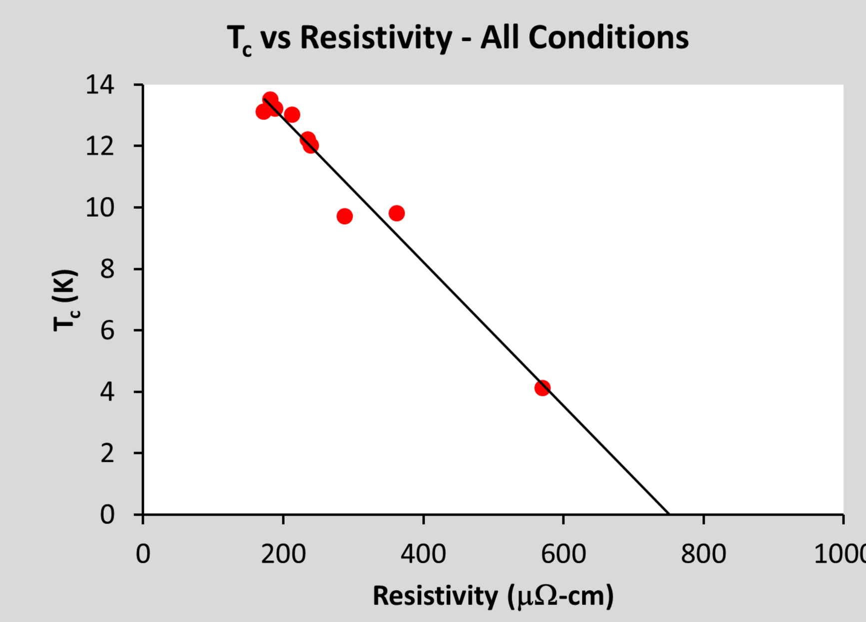
Resistivity and Superconductivity



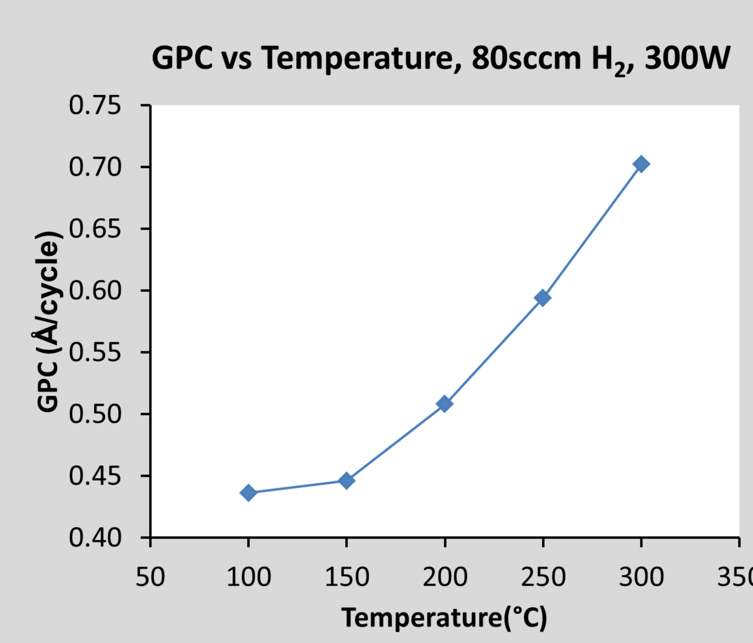


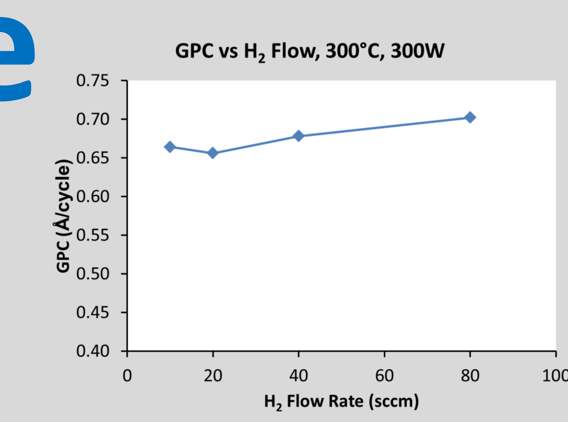


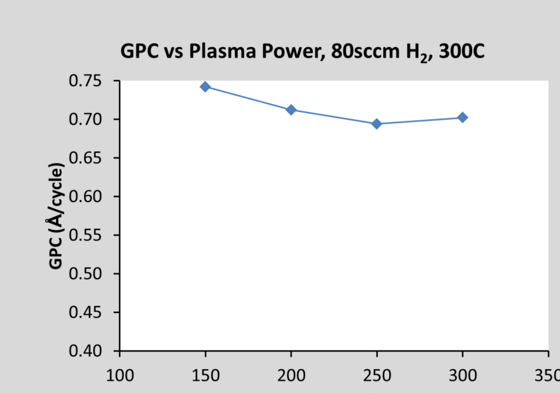
- Resistivity decrease and T_c increase depend primarily on temperature and H_2 flow rate increases
- Plasma power increase is a secondary influence on decreasing resistivity and increasing T_c
- Nb-rich films have lower resistivity and higher T_c
- Negative linear relationship between T_c and resistivity predicts 100C (3035$\mu\Omega$-cm) and 150C (772$\mu\Omega$-cm) films not superconducting



Growth Per Cycle

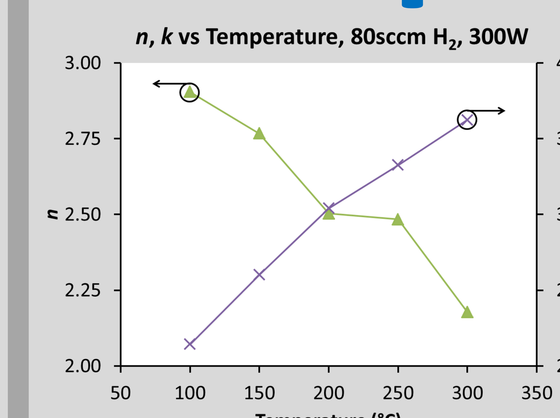


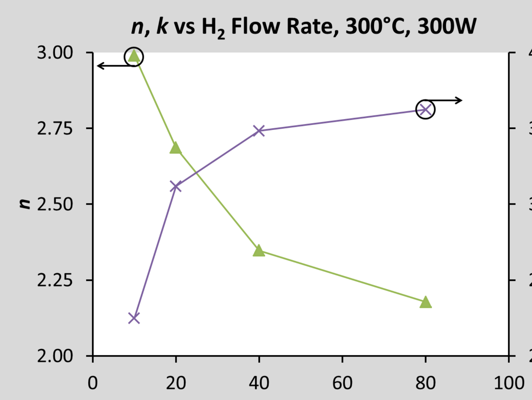


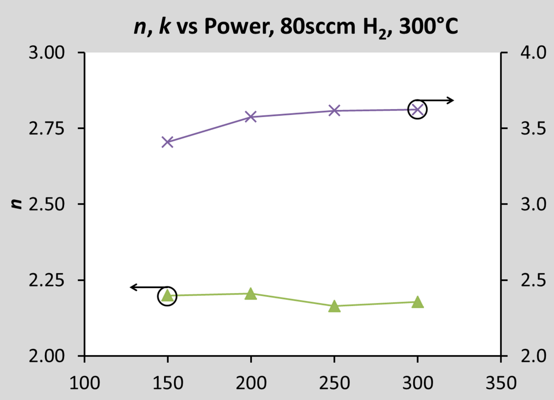


- GPC primarily depends on temperature
- Small GPC increase with H_2 flow at 300°C/300W
- Small GPC decrease over power range at 80sccm H_2/300°C

Optical Properties







- Refractive index decreases and extinction coefficient increases depend primarily on temperature and H_2 flow rate increases
- Plasma power increase is a secondary influence on decreasing *n* and increasing *k*
- Higher *k* and lower *n* in Nb-rich films

Conclusions

- Superconductive PEALD NbN with T_c values as high as 13.5K
- Room-temperature resistivity values as low as 173$\mu\Omega$-cm
- Resistivity and *n* decrease, T_c and *k* increase as NbN films become more Nb-rich at high deposition temperature, high H_2 flow rate, and high plasma power.

References:
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