Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

CVD Thick Nb Film and Cavity Coating

Zeming Sun, Mingqi Ge, Katrina Howard, Matthias Liepe, James Maniscalco, Thomas Oseroff, Ryan Porter (CLASSE)

Victor Arrieta, Shawn McNeal (Ultramet)

TESLA Technology Collaboration
02/2020

Introduction

- Bulk Nb vs. Nb films
  - ➢ Improved thermal conductance
    - ✓ Cu: >300 W/(m·K) vs. Nb:75 W/(m·K)
  - ➢ Low cost

- Chemical vapor deposition (CVD)

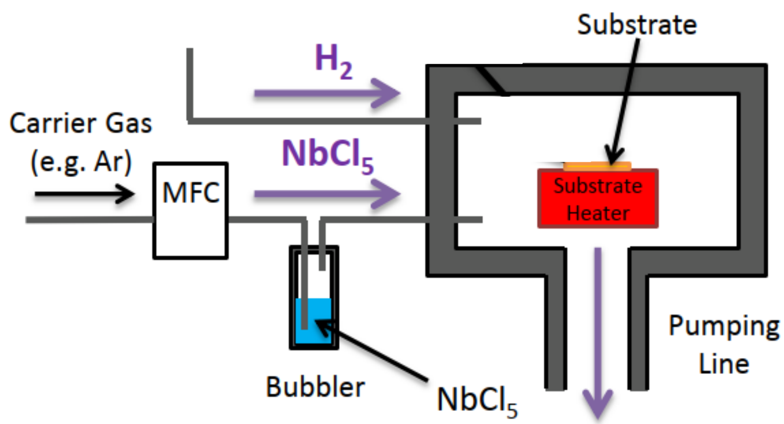
Gas precursors

↓

Reaction and decomposition

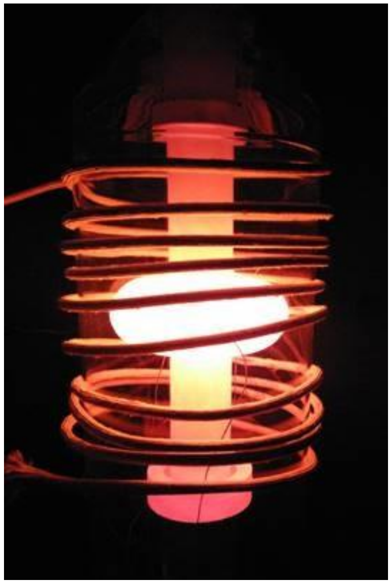
↓

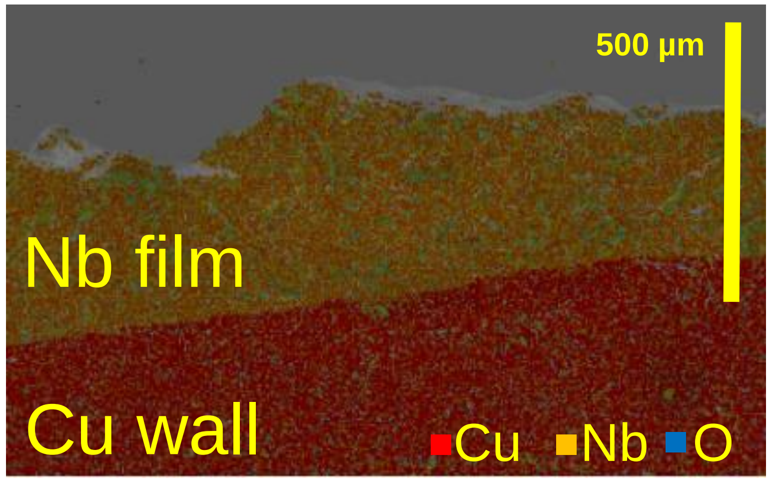
High quality films

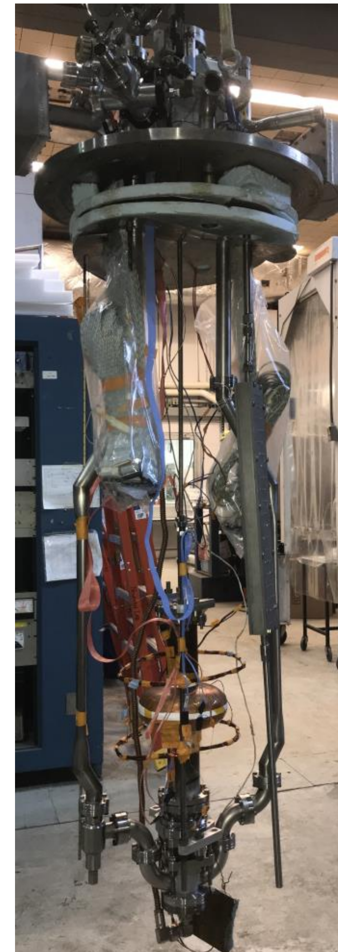


Reference: P. Pizzol et al., IPAC (2016)

CVD→Characterization→RF test

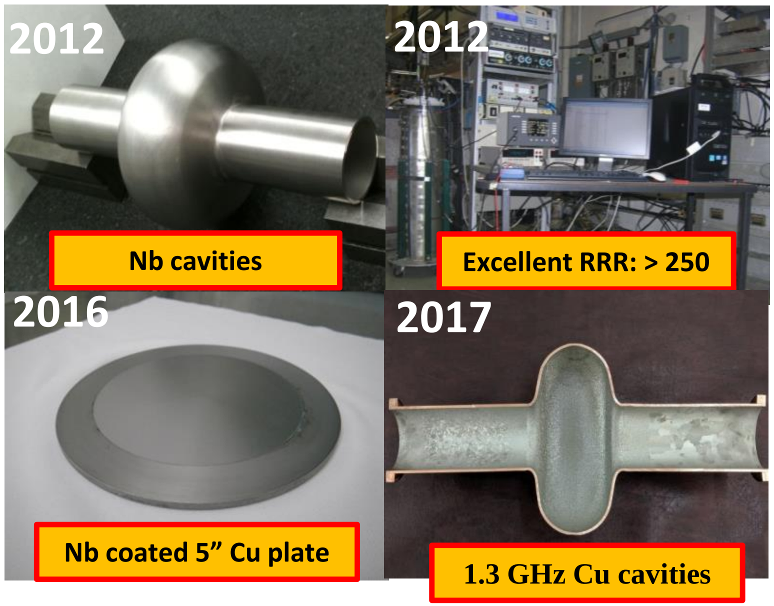


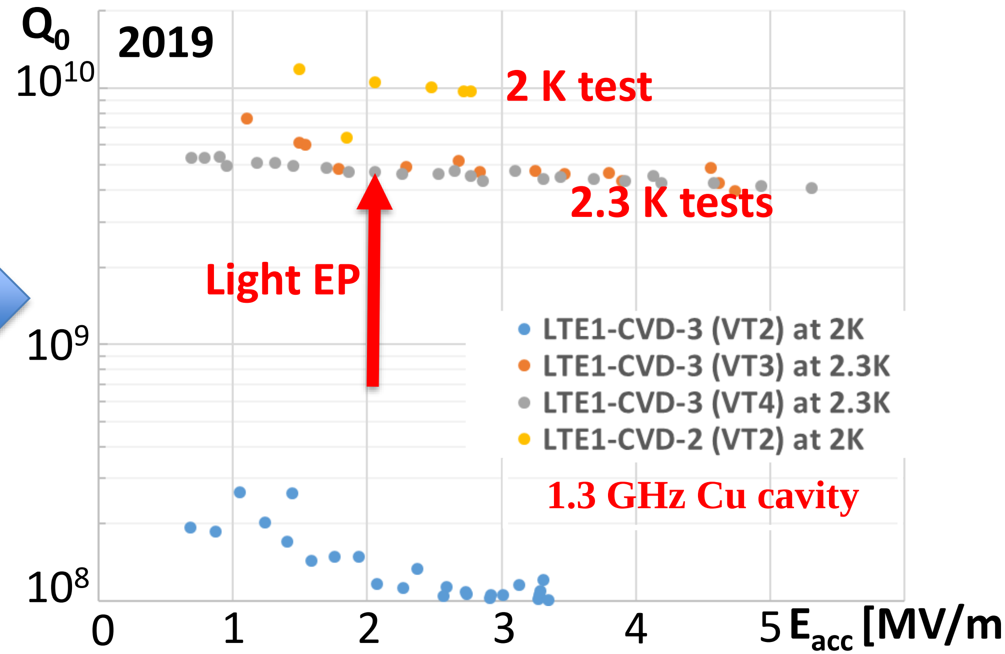




- CVD advantages
  - Coats intricate cavity structures
  - Low temperature processing
  - High deposition rate
  - Thick film deposition
  - Allows post electropolishing (EP)

Progress at Cornell/Ultramet

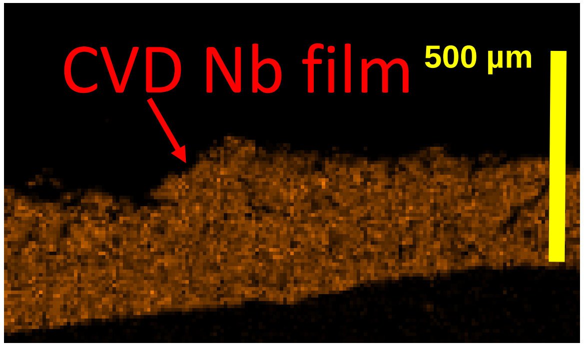




- Film optimization & process scale-up
  - ➢ High purity (high RRR)
  - ➢ Excellent adhesion
  - ➢ Full size cavity
- Post process optimization & electropolishing (EP)
  - ➢ Low residual resistance ($R_0 < 10$ nΩ)
  - ➢ No severe Q-slope up to 5 MV/m

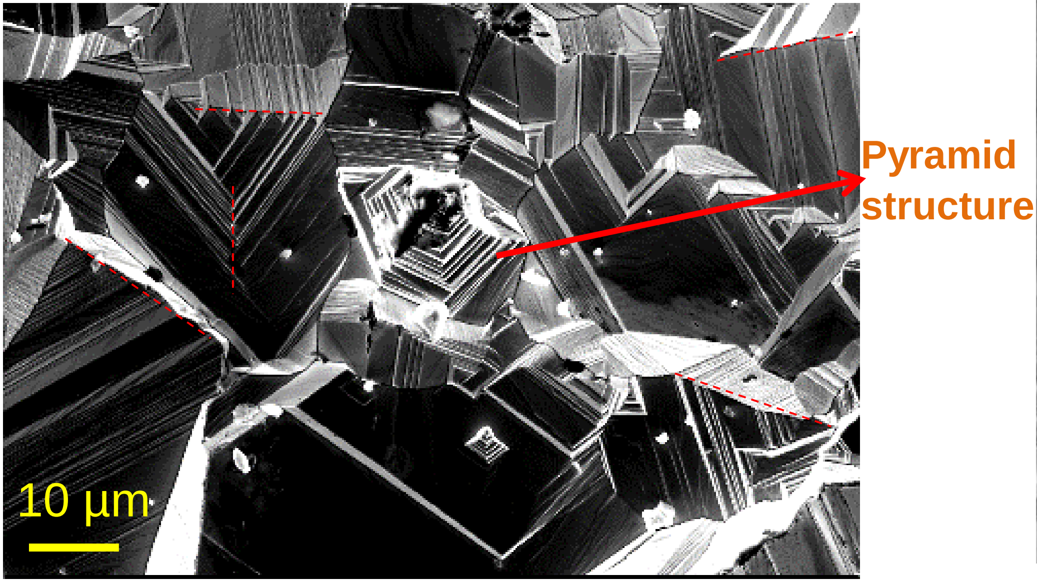
Challenge, solution, & motivation

- Challenge: Very large surface roughness (> 100 um) in CVD films
  - Locally enhance magnetic fields
  - Quench before reaching high E_{acc}

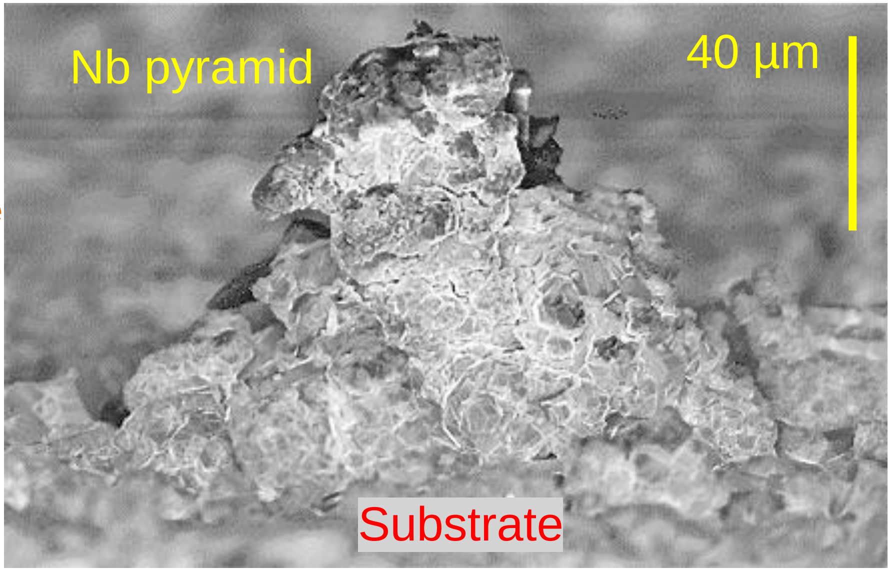


- Solution: Post EP
  - Widely adopted in SRF community
  - New features during polishing CVD Nb thick films
- Motivation:
  - Analyze the distinctive surface profile & structural properties of CVD films
  - Improve the understanding of EP treatment on these films

Distinctive surface features of CVD films



Surface imaging

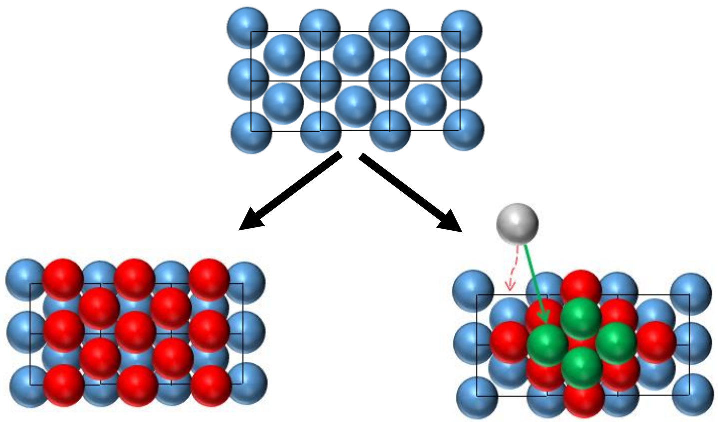


Cross-section

- Facets and steps
- Large *pyramid* regions
- Twin structures
- (110) preferred together with (100), (211) planes

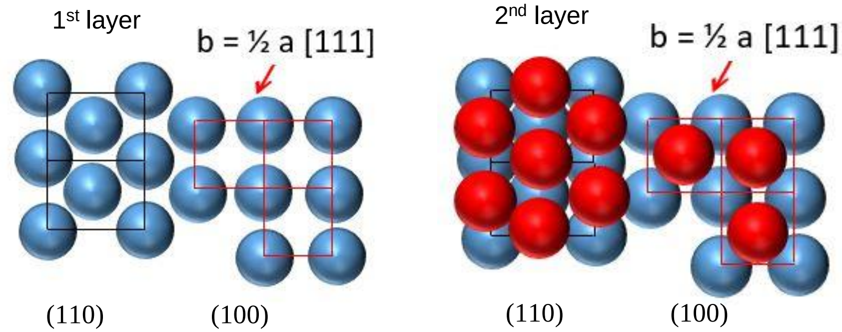
CVD formation mechanisms

- Facet formation

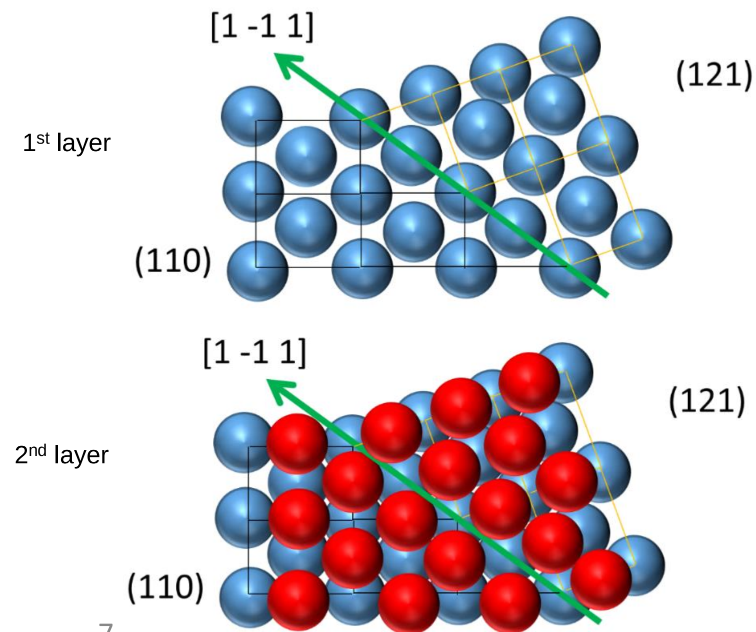


Normal stack | Terrace-step-kink formation

- Dislocations at (110)/(100) planes



- Twin structures at (110)/(211) planes

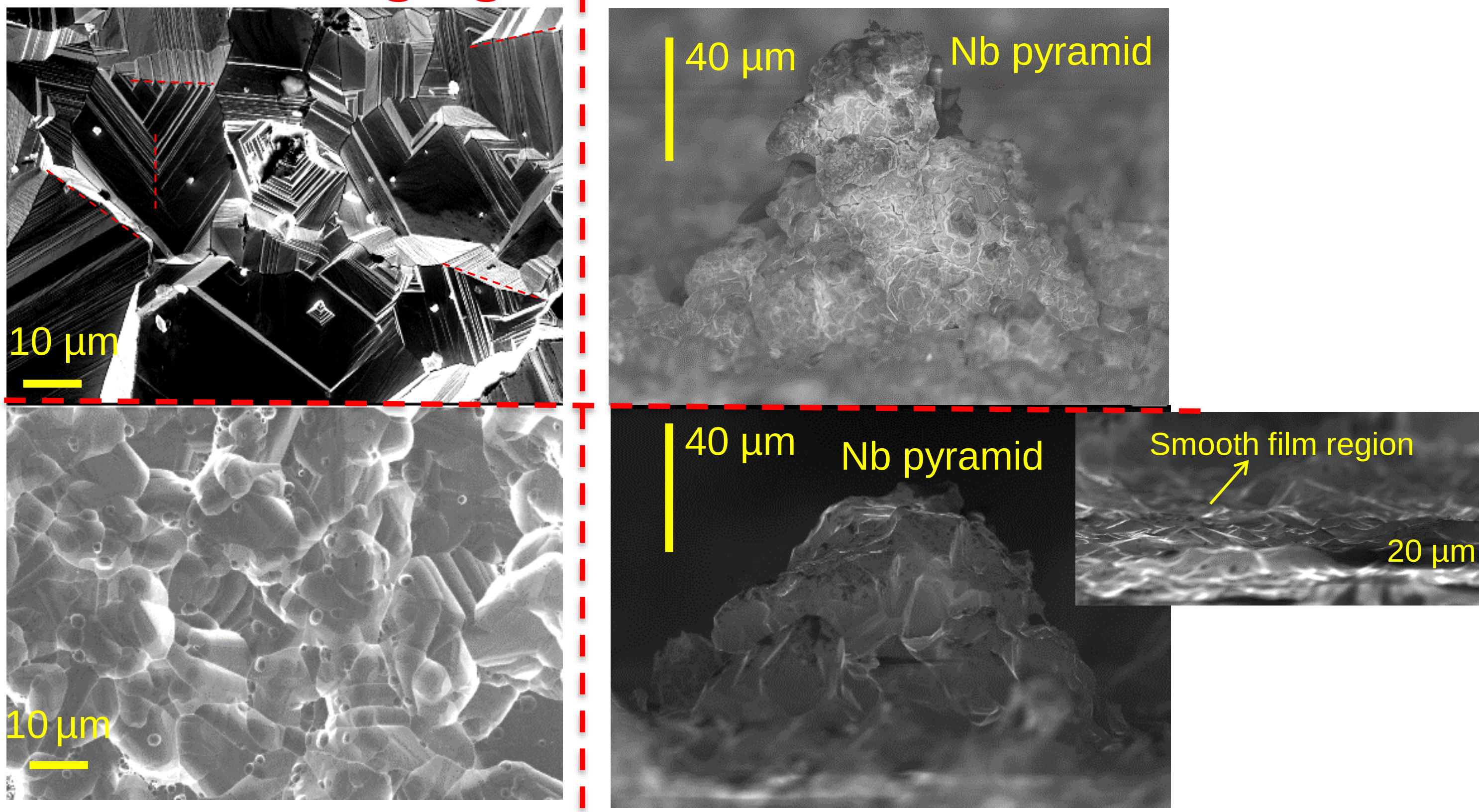


Effect of EP: SEM imaging

Surface imaging | Cross-section

As-deposited CVD films

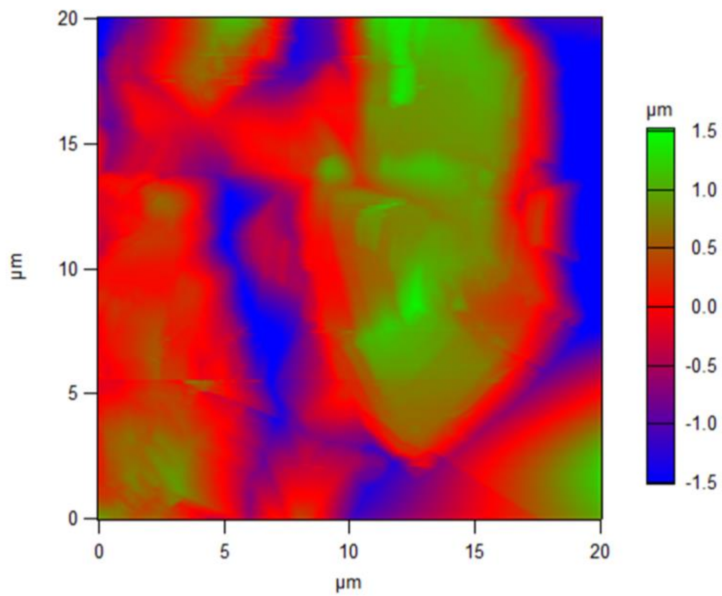
After EP



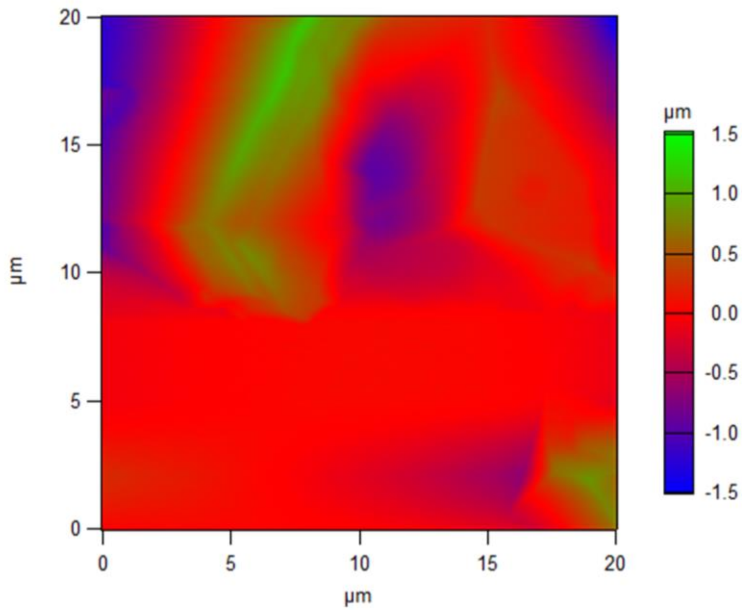
- Smoothing edges & sharps
- Reducing the height of pyramids

Effect of EP: quantification on the flat region

As deposited



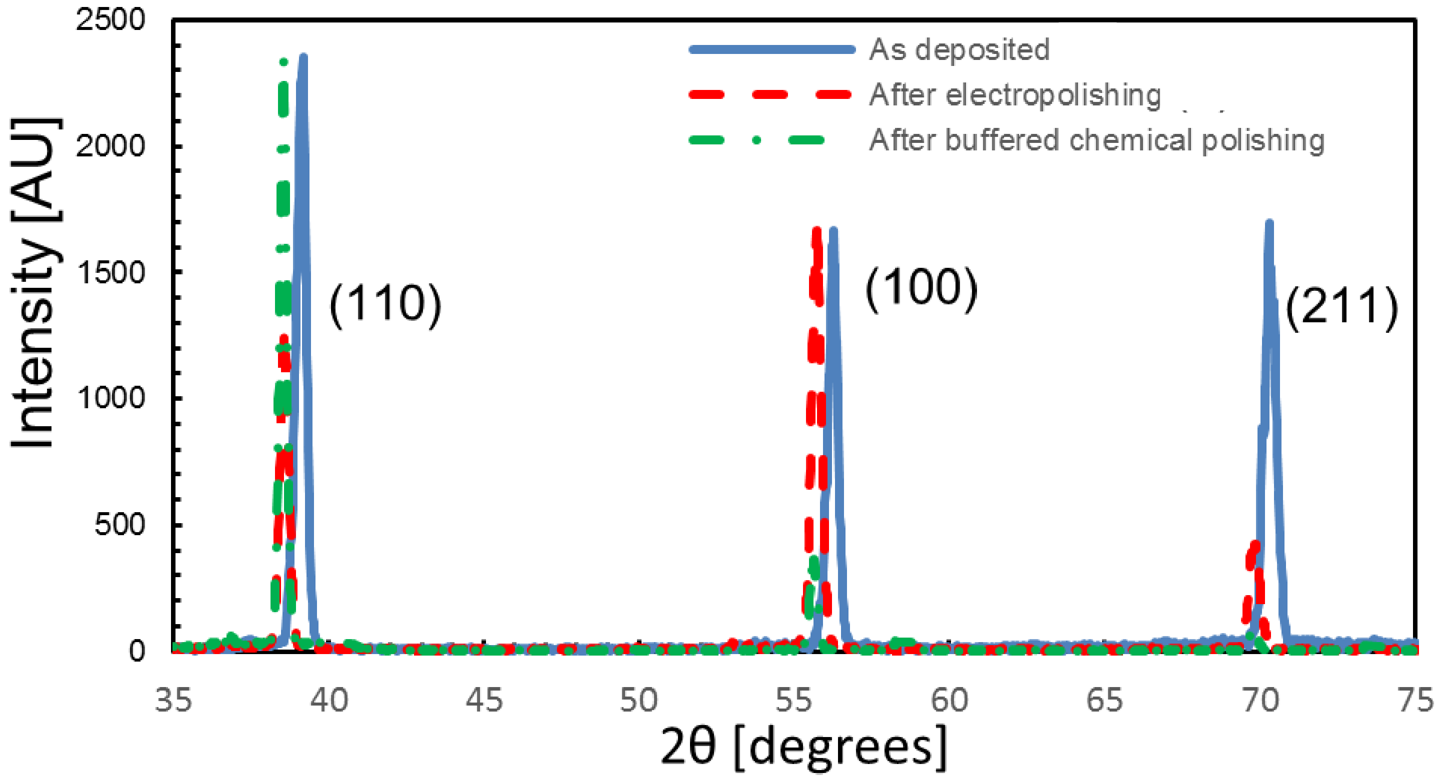
After EP



	Ra (nm)	Rq (nm)	Rz (µm)
As deposited	594	737	4.2
After EP	271	387	2.6

- Achieving large area of flat regions
- Overall smoothing effect by half

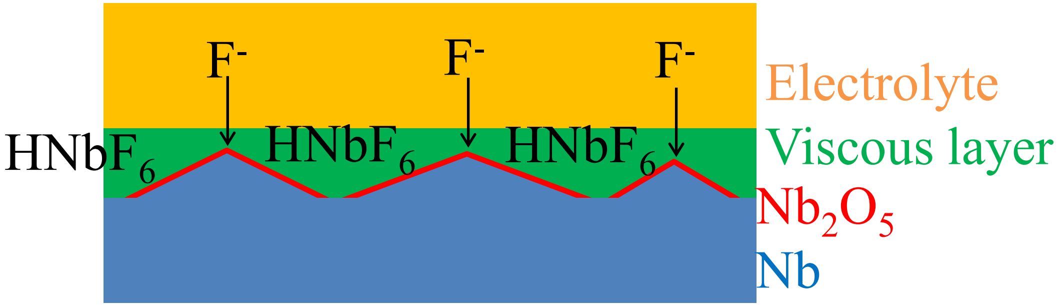
Effect of EP: possible orientation dependence



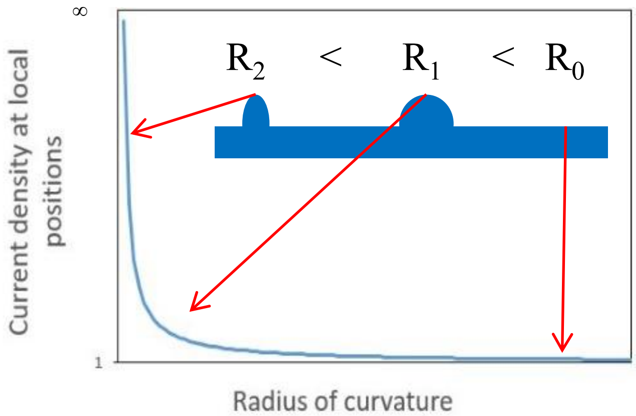
- **Polishing rate comparison:**
  - Electropolishing: (110) and (211) faster than (100)
  - Buffered chemical polishing: (100) and (211) faster than (110)

Effect of EP: question & possible explanations

- **Question to the conventional understanding (H. Tian, et al., J. Electrochem. Soc. 2008)**



Micropolishing



Macropolishing

- **Two possible explanations:**
  - Different feature sizes (>100 um and <1 um) involve both micropolishing and macropolishing
  - Oxidation formation is orientation dependent

Conclusions & future work

- CVD/EP-combined technology is promising.
  - High Q_0
  - Low residual resistance
  - Did NOT observe Q-slopes
- CVD Nb films observed unique surface features and their formation mechanisms are analyzed.
- EP is an effective and important approach to smooth the film surface and, especially, reduce the pyramid heights.
- Ultramet is submitting a Phase I proposal to work with Cornell to further investigate the Post EP Treatment for the Ultramet CVD Nb-on-Copper cavities.

Acknowledgements

This work is supported by

- U.S. DOE SBIR phase-II award
  (under Grant DE-SC0015727)
- Center of Bright Beams
  (from the National Science Foundation under Grant
  No. PHY-1549132)

Also, this work made use of

- Cornell Center for Materials Research Shared Facilities which are supported through the NSF MRSEC program (DMR-1719875)
- Cornell NanoScale Science and Technology Facility supported by the National Science Foundation under Grant No. NNCI-1542081

Thank you for your attention!