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Control of contact resistivity for REBCO NI magnets

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Outline

- Introduction
- REBCO Cu oxidation
- Stainless steel oxidation
  - XPS studies
  - TEM studies
  - Contact resistivity tests.
- Summary

Introduction

- For NI REBCO magnets, contact resistivity between adjacent turns (ρ_c) is a critical parameter. Low ρ_c causes high current and high stress during a quench*, high ramp losses, and significant charging delays.
- The desirable ρ_c varies depending on the details of the coil design, so it is highly desirable to be able to control ρ_c in a wide range.
- Two basic approaches:
  1. Oxidizing REBCO Cu surface.
  2. Oxidizing SS co-wind.
- Our goal is to be able to control ρ_c between 1 – 1000 mΩ-cm^2.

* W Denis Markiewicz et al, 2019 Supercond. Sci. Technol. 32 105010

Reel-to-reel REBCO Cu oxidation

Ebonol C oxidation process

- A surface chemical solution treatment process.
- REBCO tape is treated in solution, rinsed, and dried.

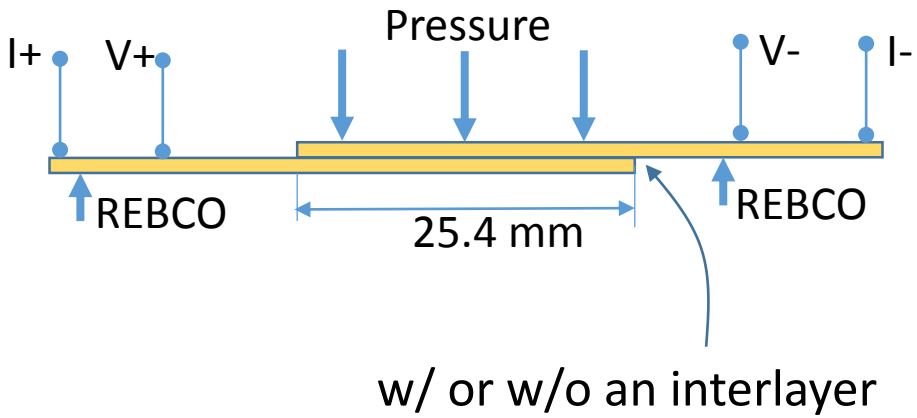
Process parameters:

- Ebonol C special: H_2O = 1:4 at 98 C.
- Reel-to-reel process 0.5 m/min (~40 sec in solution)
- Oxide layer is ~ 0.5 μm thick, controllable by time and temperature

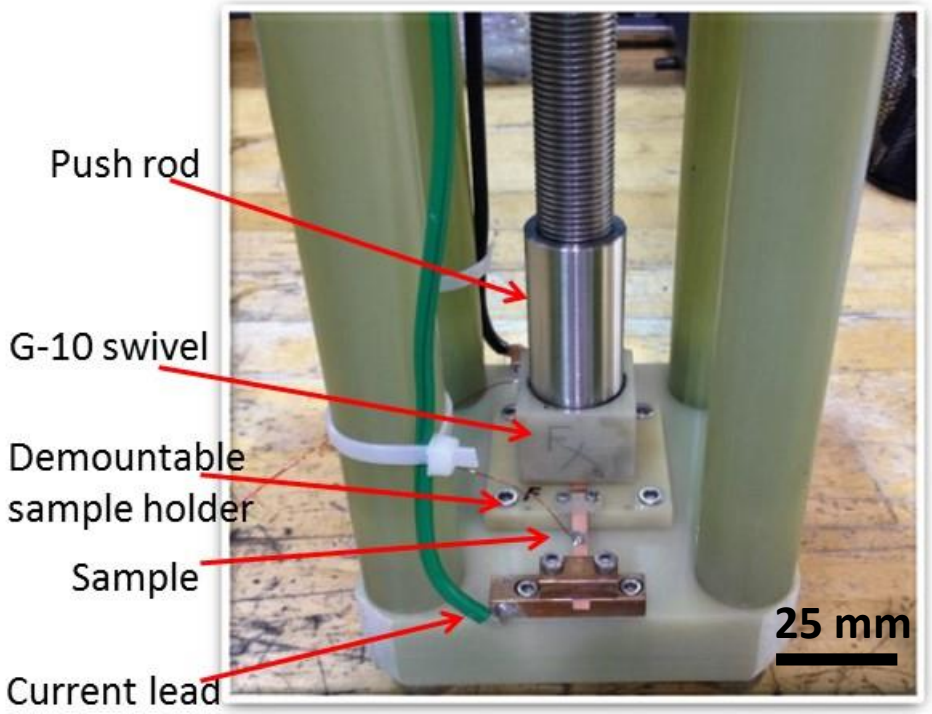
Total of 4 piece lengths of 450 m SuperPower REBCO tapes have been oxidized

Support by Florida State University GAP commercialization fund.

ρ_c measurement



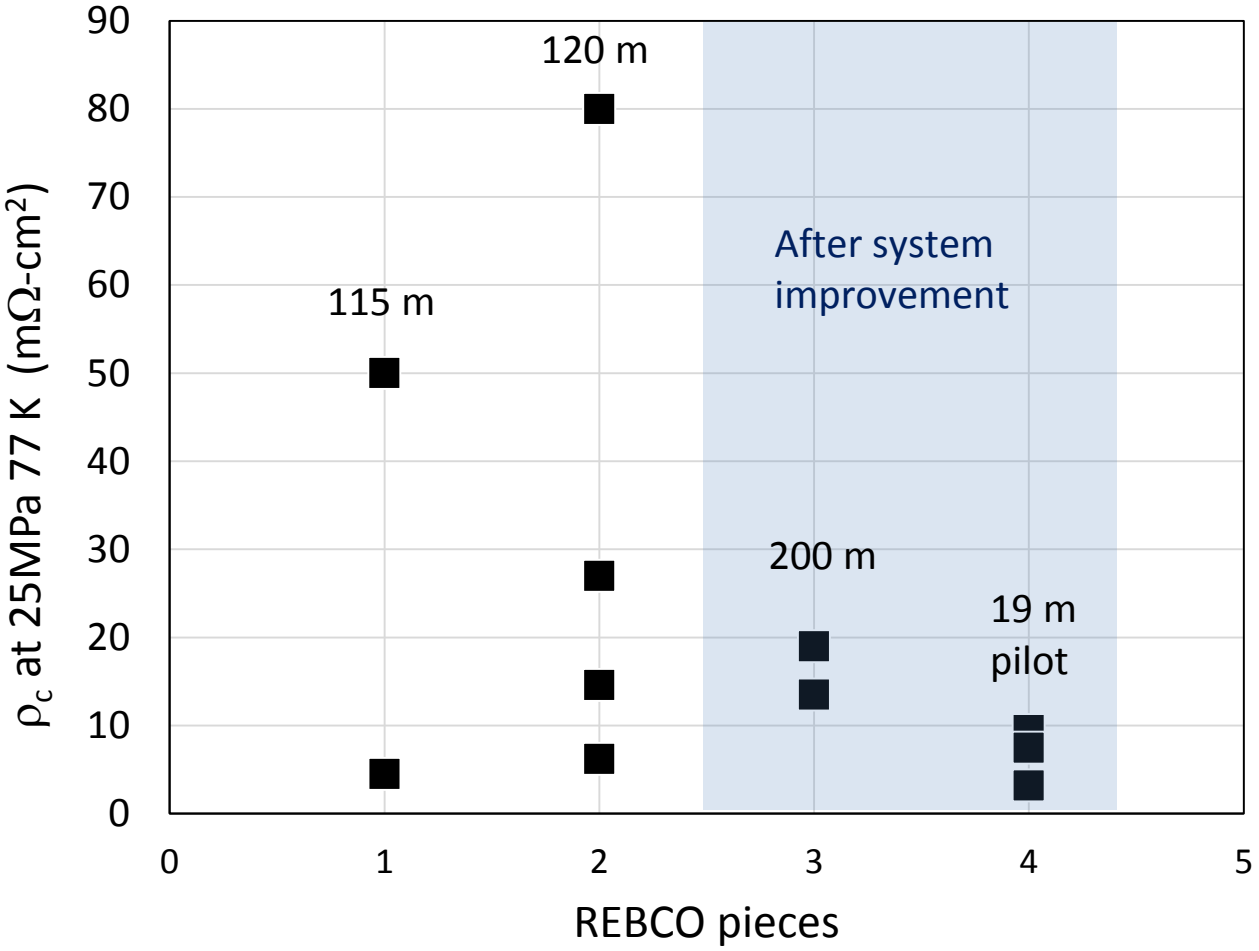
Measurement current 1 A



J. Lu, et al., SUST 2017, 045005

- The device used in either LN_2 or LHe.
- Can be adapted to a MTS machine for fast pressure cycles.

Uniformity of ρ_c from end to end



- Samples cut from the front and back end of each piece were measured at 77 K.
- Large scatter in ρ_c

Modification of the system

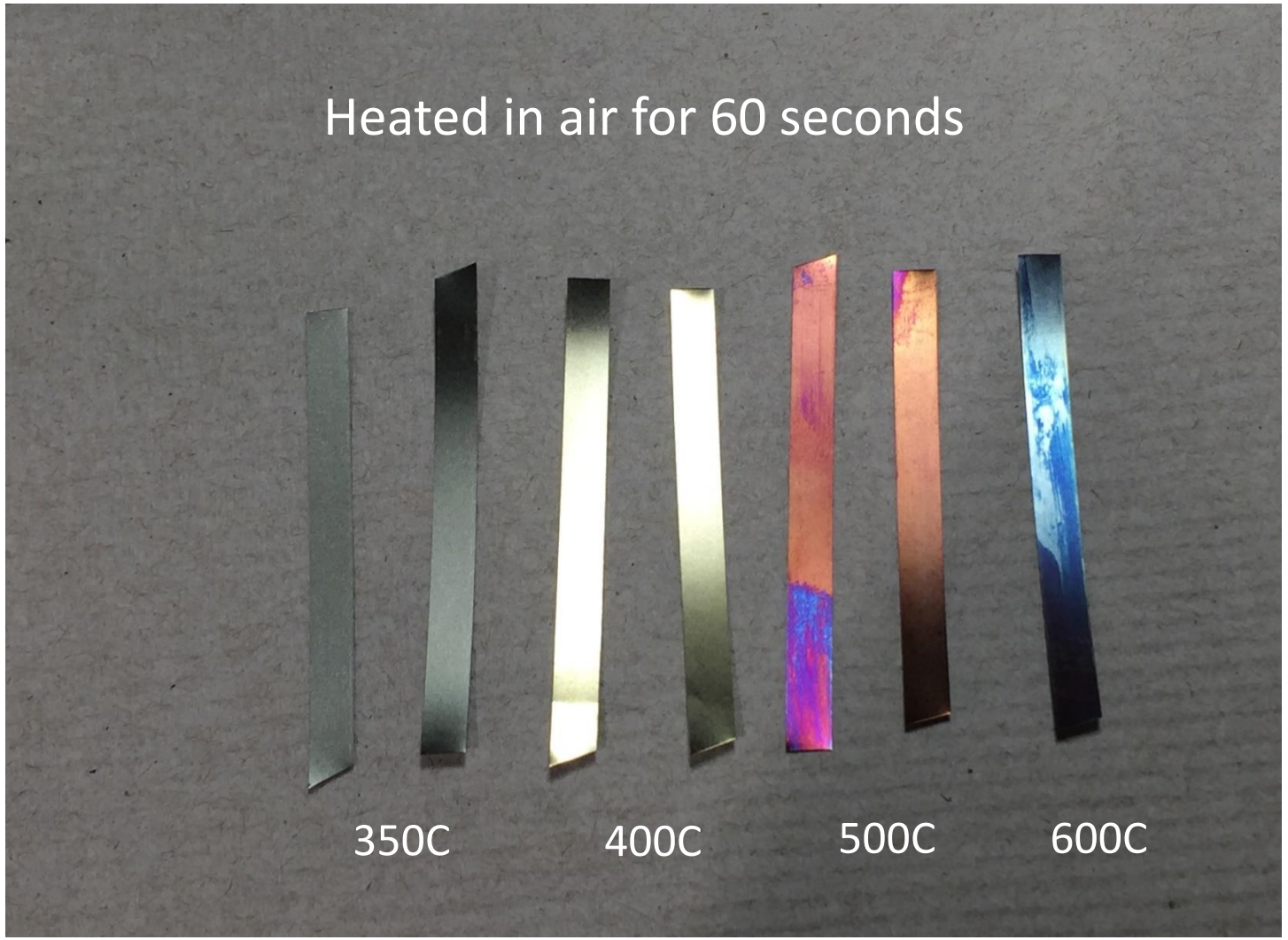
- Better speed control
- Better temperature control

Significantly improved the uniformity.

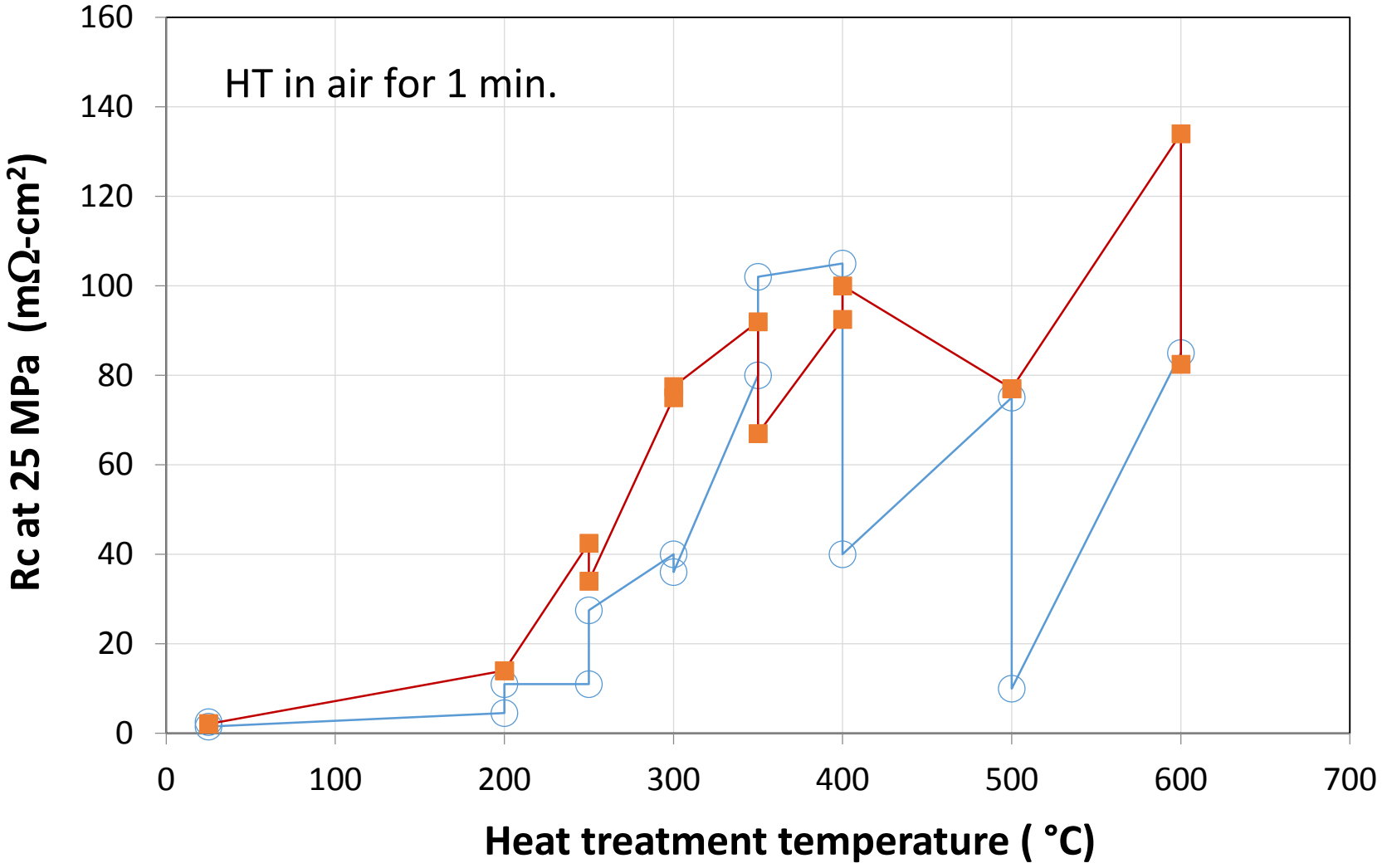
- The scatter was significantly reduced after system modification
- Further improvements are possible.

Oxidizing SS co-wind tape

316 SS tape: full-hard 50 μm, used in the 32 T project

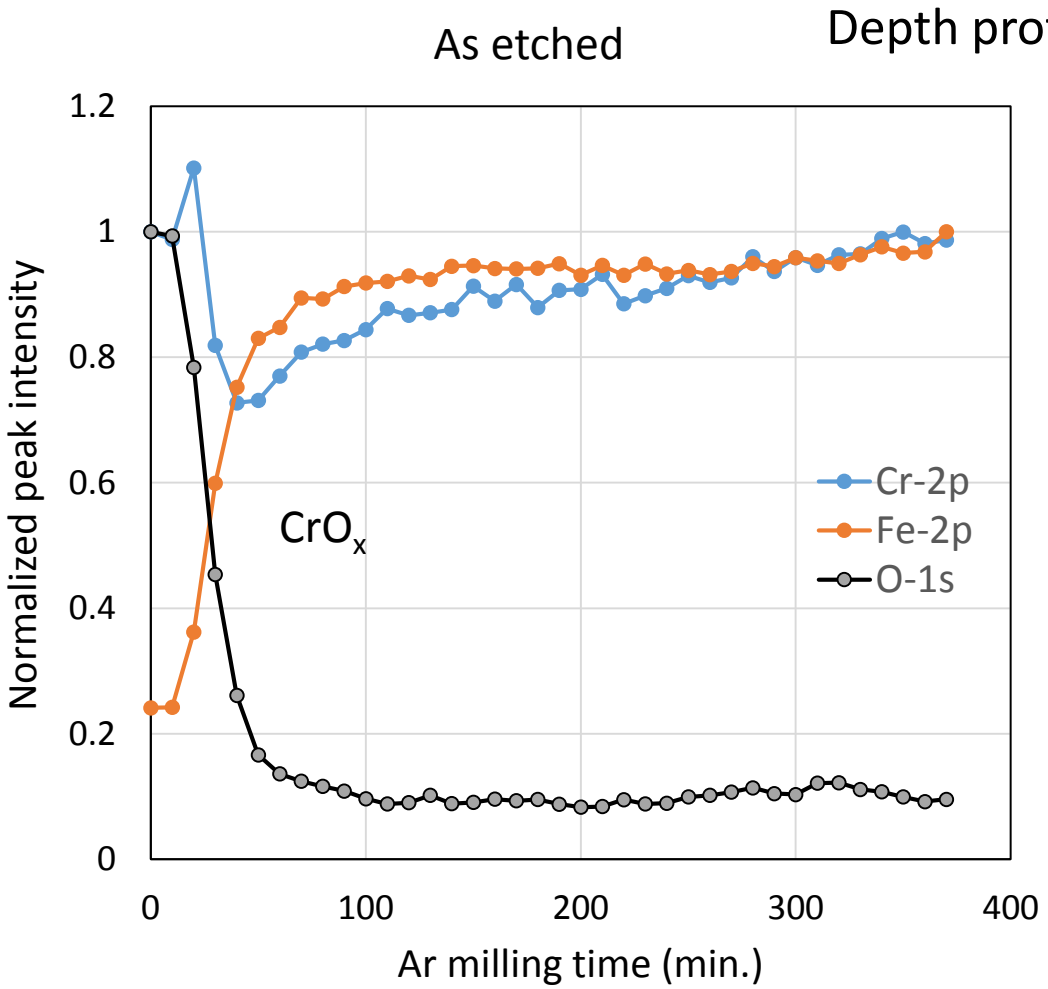


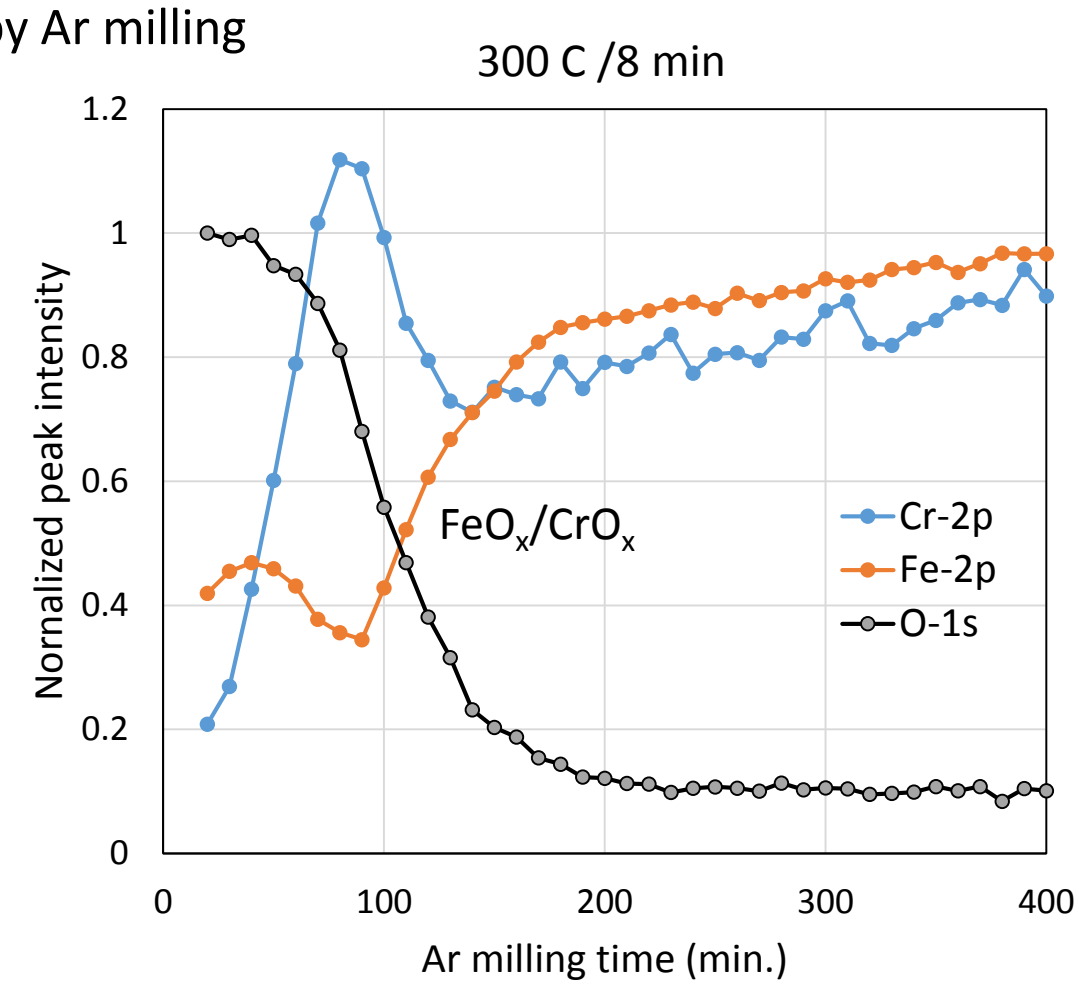
ρ_c of SS at 77 K



Large scatter, but the effect of oxidation is consistent.

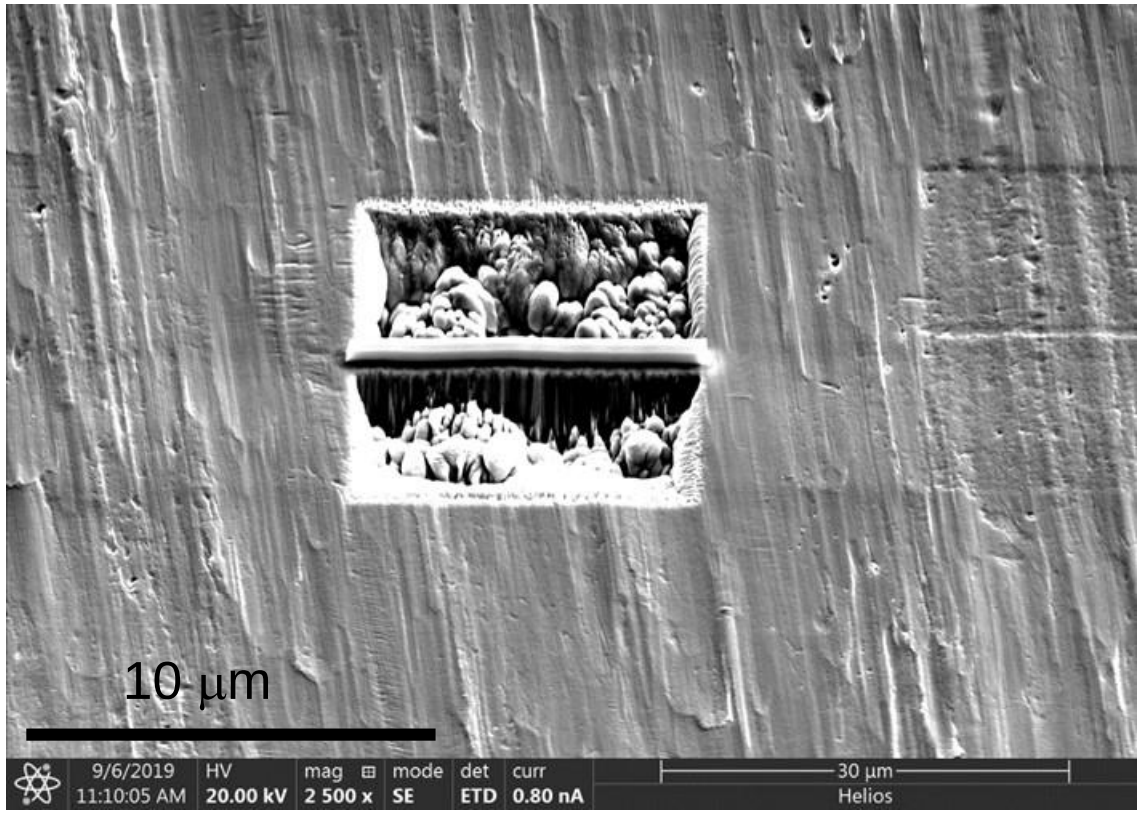
Surface chemistry by x-ray photoelectron spectroscopy (XPS)

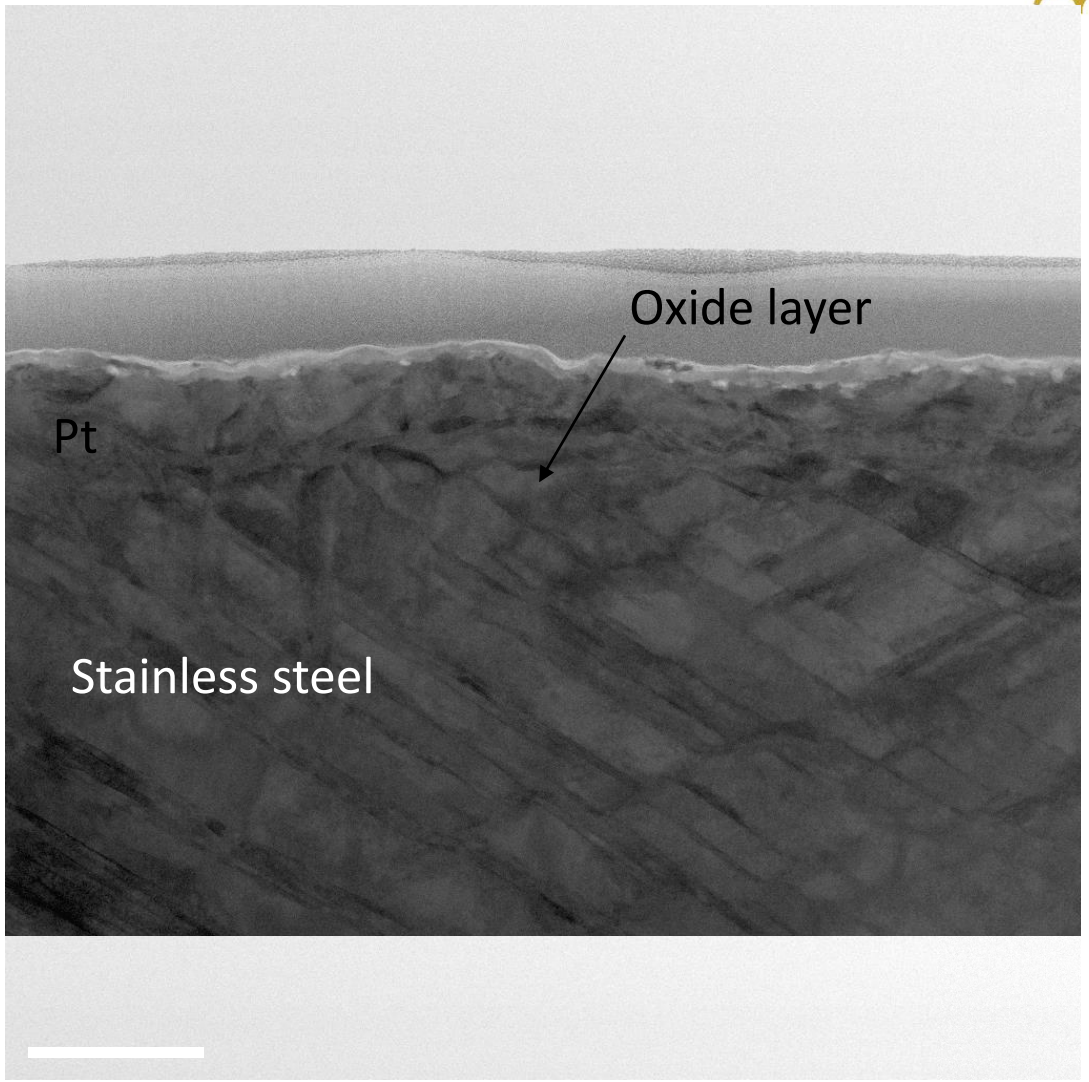




Heat treated SS has much thicker oxide layer, and has FeOx on surface instead of CrOx

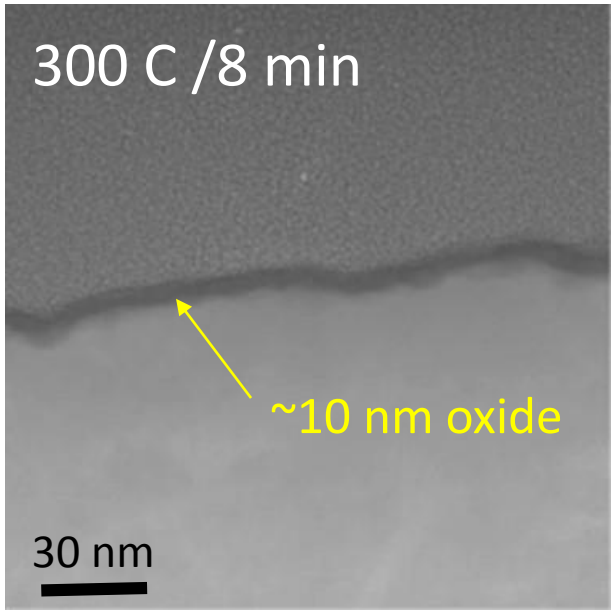
TEM of SS cross-section

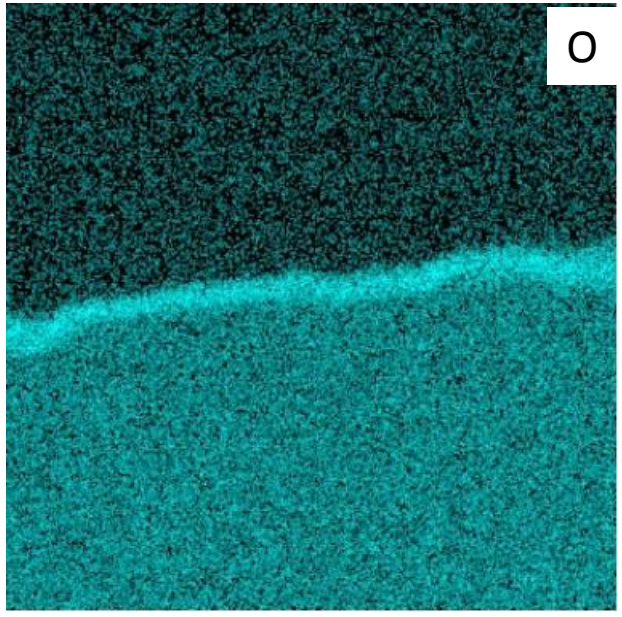


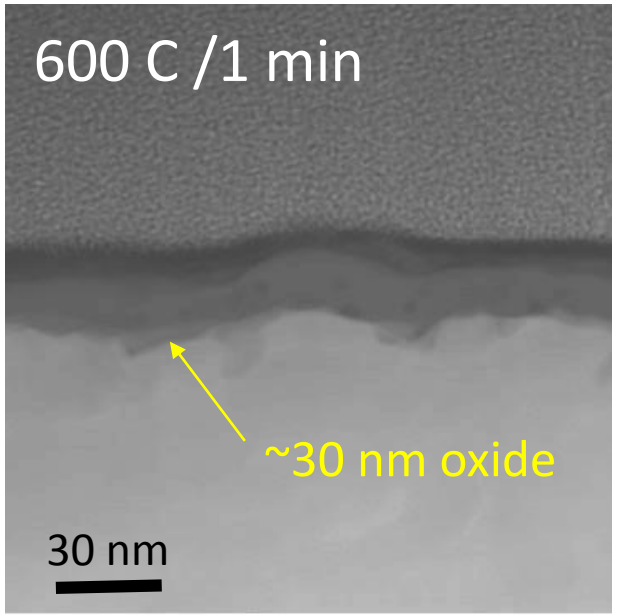


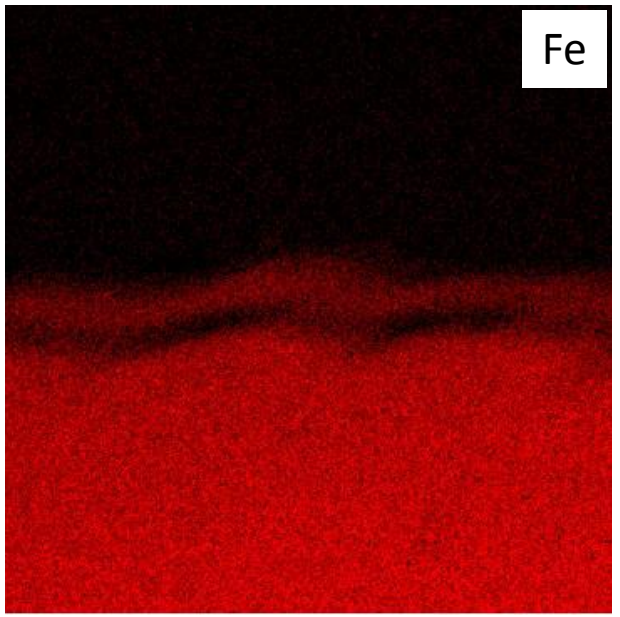
- TEM samples were prepared by FIB.
- A layer of Pt was deposited to protect the thin oxide layer during the ion cutting process.

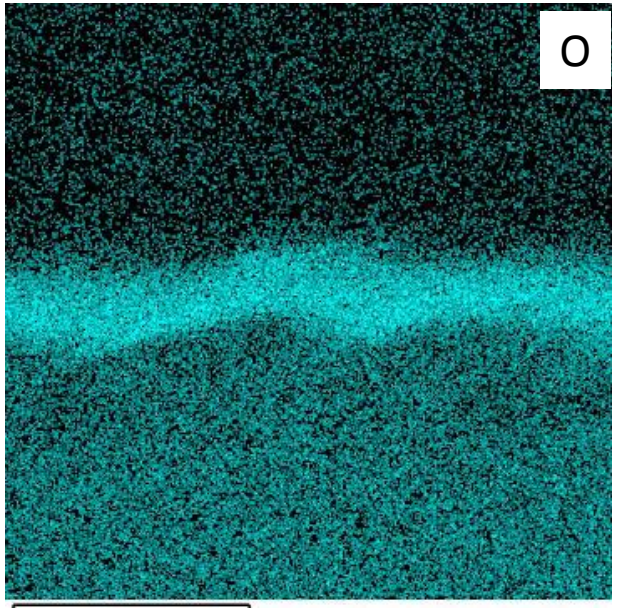
TEM of SS cross-section

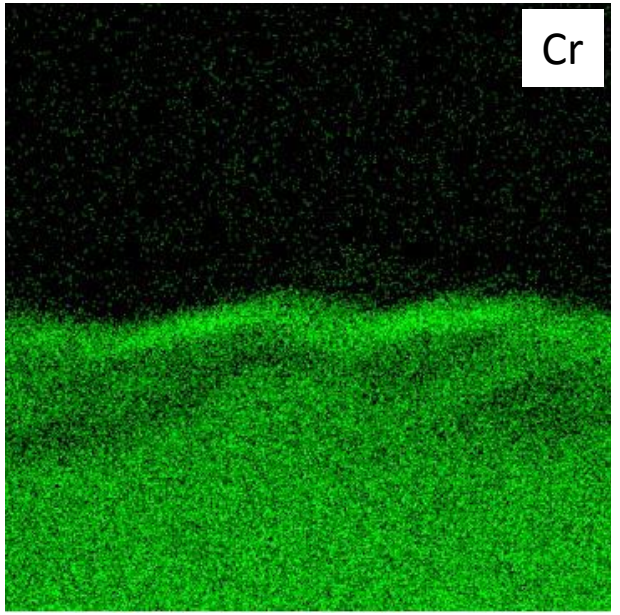




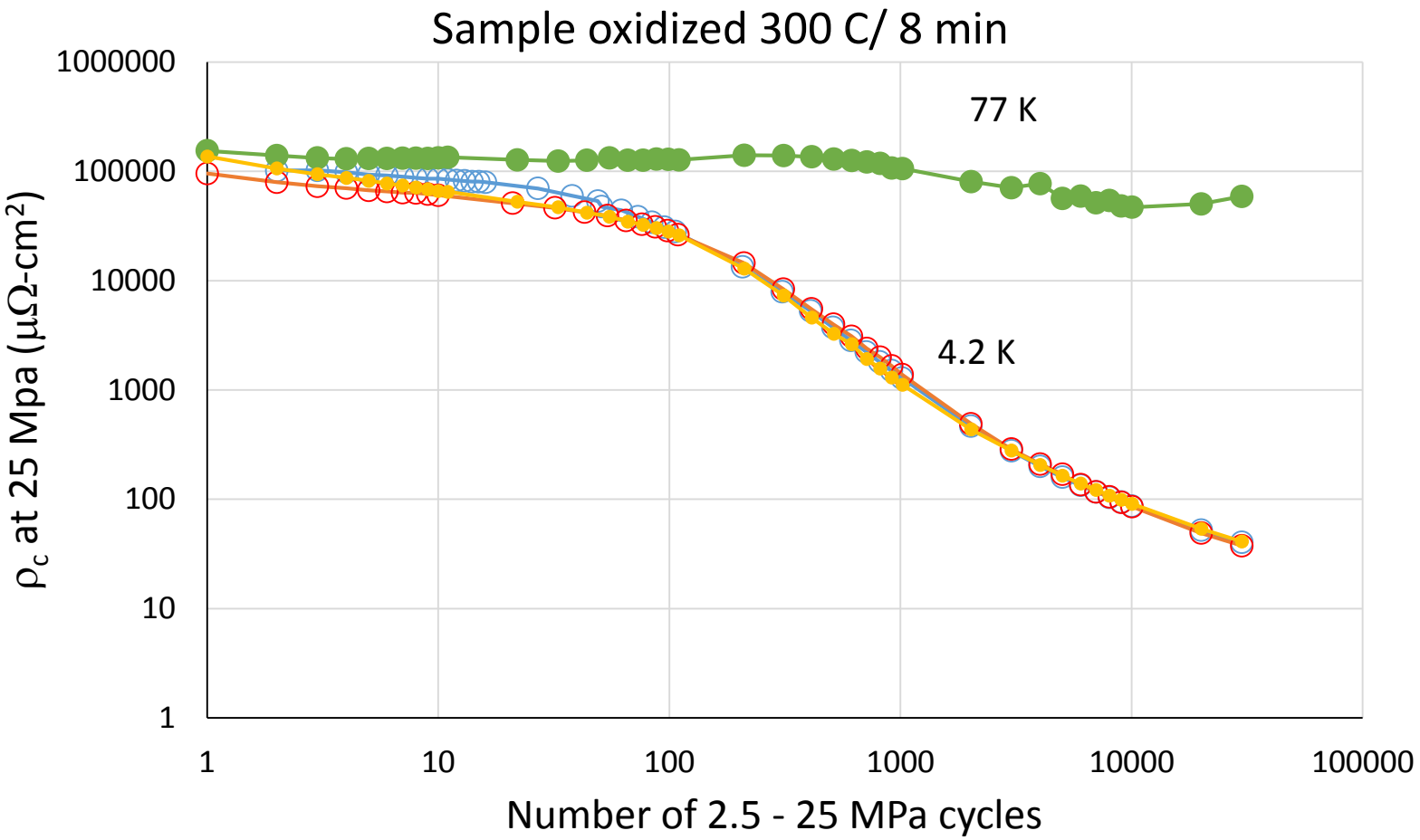






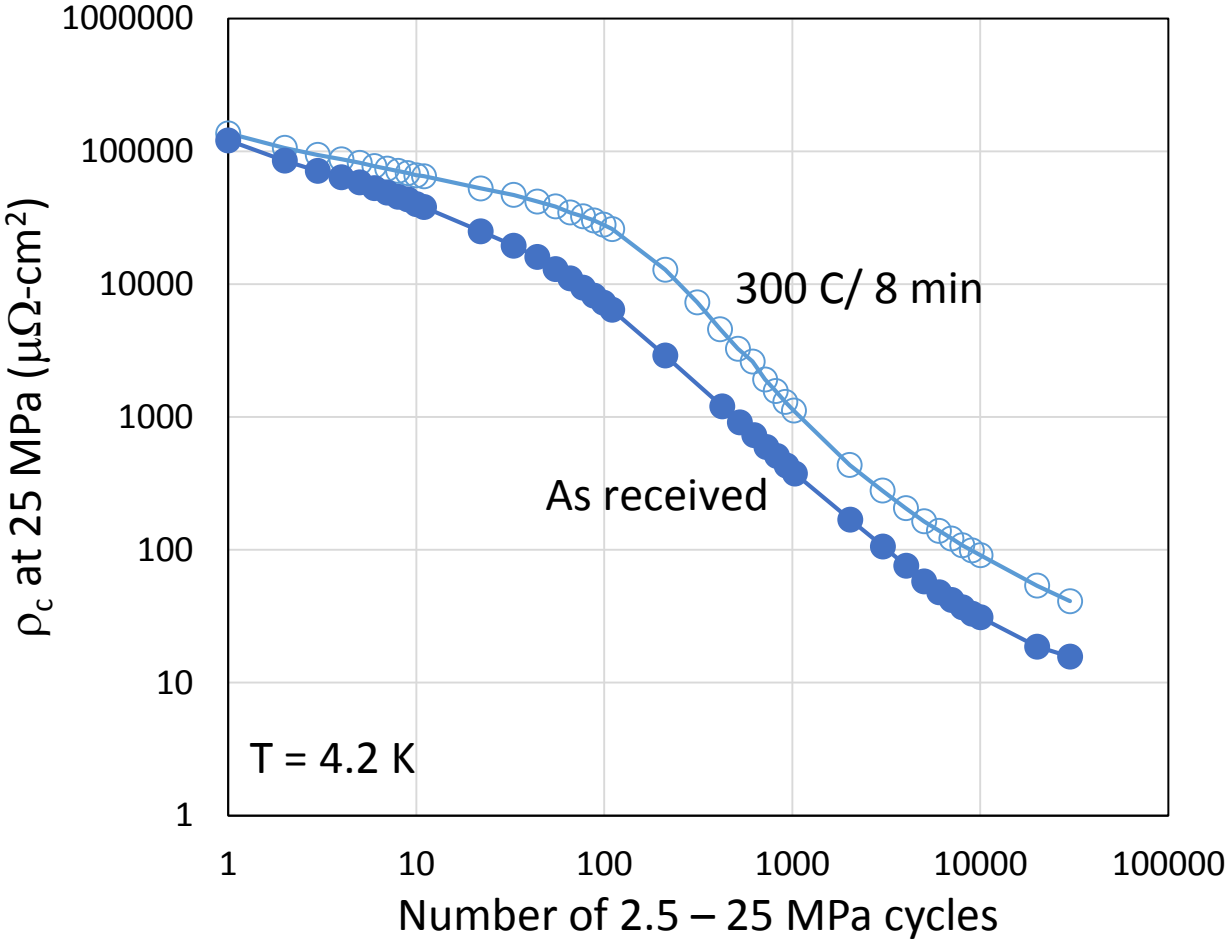


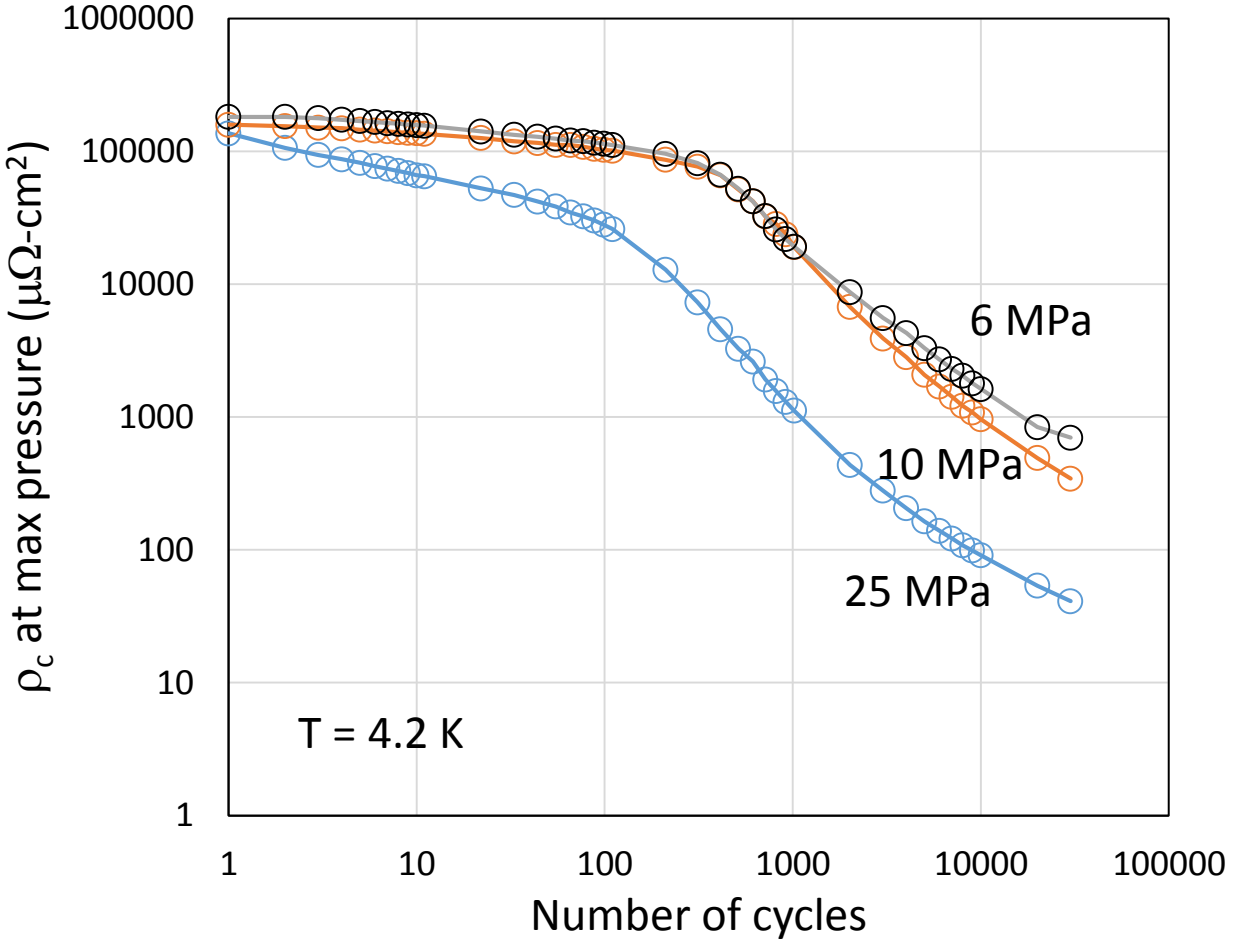
Effect of contact pressure cycling



- Considerable ρ_c decrease after pressure cycle at 4.2 K
- This behavior is consistent with coil test results (Dixon, et al. Tue-Af-Po2.14-10)

Effect of contact pressure cycling

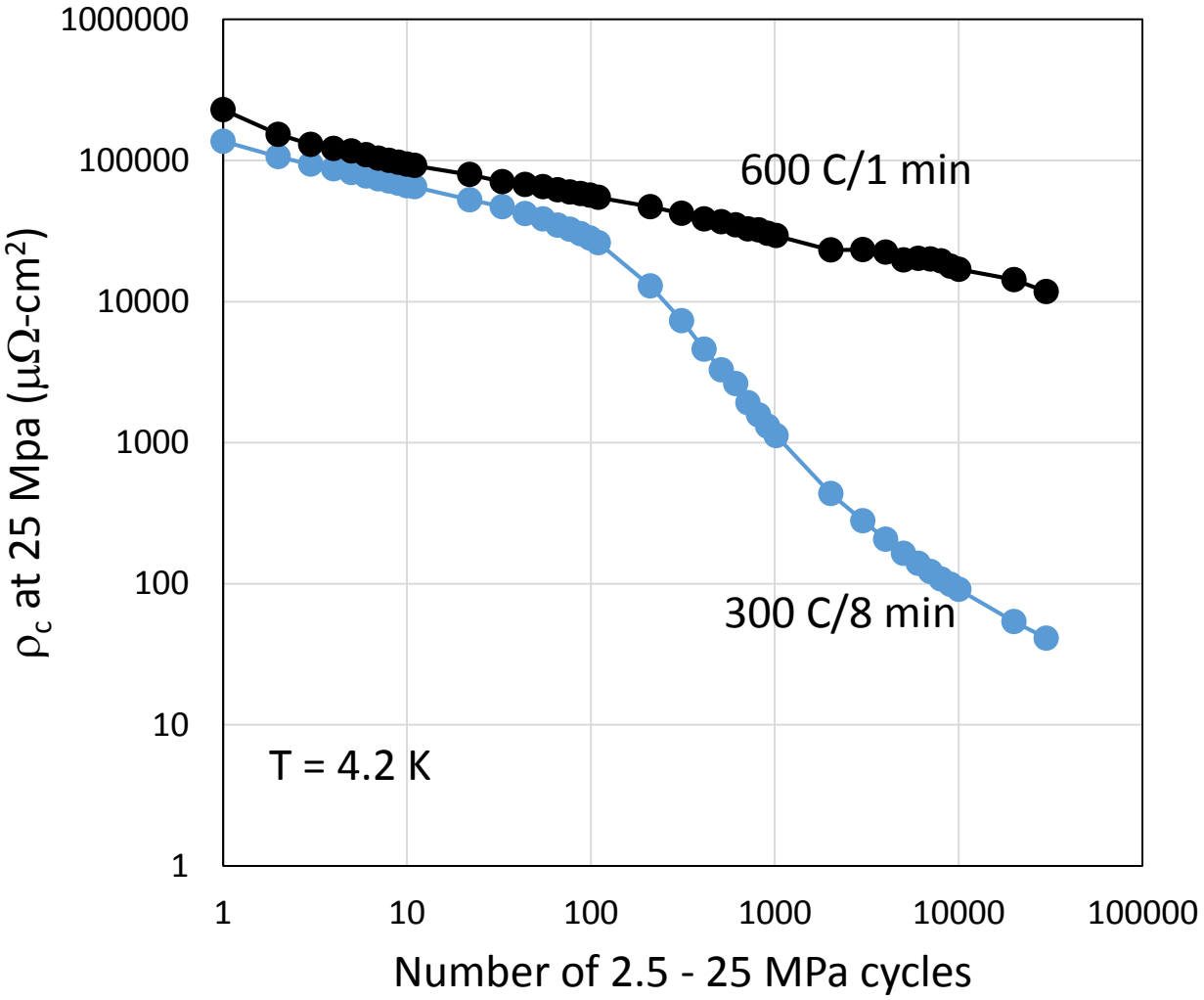




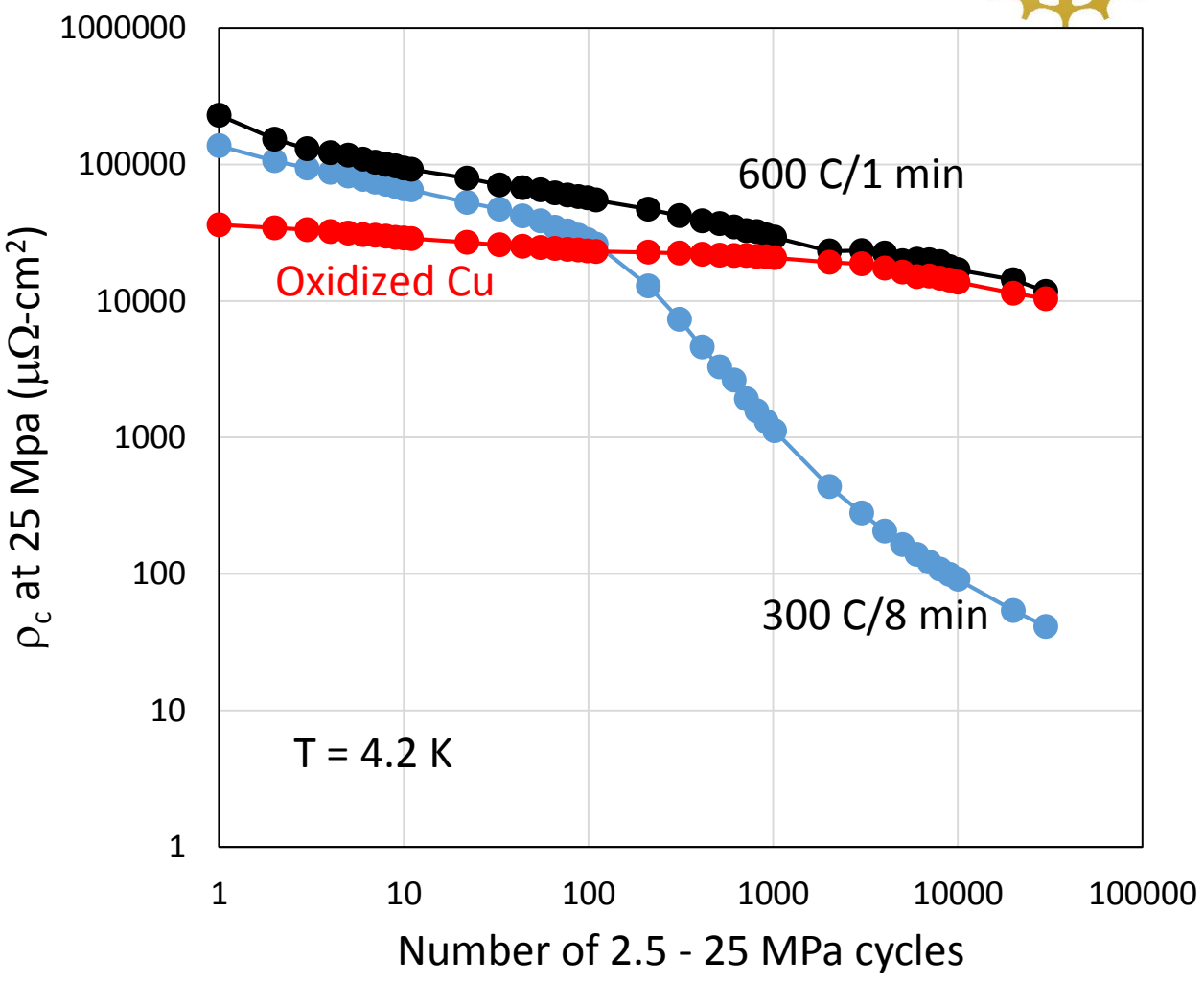
As received SS has greater ρ_c decrease

The effect is less for lower peak pressure.

Influence of different surface treatments



Thicker or/and different surface chemistry seems to make the layer more robust.



REBCO Cu oxidized layer (~0.5 μm) is more robust against cycling.

Summary

- In order to control ρ_c, we experimented with REBCO Cu oxidization and stainless steel co-wind oxidation.
- A reel-to-reel REBCO oxidation capability is developed.
- Stainless steel samples with 10 -30 nm oxide layer are made.
- TEM and XPS were used to analyze the oxide layers.
- Drastic ρ_c decrease in some oxidized SS samples was observed after pressure cycles at 4.2 K.

Development for ρ_c control continues …