Nb₃Sn Fabrication and Sample Characterization at Cornell

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Outline

• Motivation
• A little theory
• Wuppertal Method
• Wuppertal Results
• Activities at Cornell

Motivation

• SRF cavity preparation techniques have improved from years of R&D
• Cavity gradient is approaching fundamental limit set by superheating field \( (H_{sh}) \) of niobium
• As beam energy demands continue to rise, accelerators will have to become longer
• ILC calls for tens of km, thousands of cavities
• Higher gradients = $$$$$ savings
• Higher \( Q_0 \)s for CW and at high gradients pulsed = $$$$$ savings
SRF cavity preparation techniques have improved over the years of R&D.

- Cavity gradient is approaching the fundamental limit set by the superheating field $H_{sh}$ of niobium.

As beam energy demands continue to rise, accelerators will have to become longer.

- ILC calls for tens of km, thousands of cavities.

Higher gradients = $\text{$$$$$$ savings}$

- Higher $Q_0$ values for CW and at high gradients
  pulsed = $\text{$$$$$$ savings}$

**Motivation**

$\text{Nb}_3\text{Sn}$ promises to give both!
Theory

- $T_c$ higher so $Q_0$ is higher than for Nb at same $T$
- GL Theory predicts $H_{sh} = 0.75H_c$, $\kappa$ large
- But GL Theory is valid only near $T_c$
- Eilenberger equations give behaviour at lower temperature [Catelani and Sethna, PRB (2008) [2]]

(Assuming large $\kappa$, temp = 2K)
Progress

• Theory indicates gradients of 120 MV/m for perfect Nb$_3$Sn, 200 MV/m for perfect MgB$_2$
• Perfect Nb should give ~55 MV/m
• Years of research has led to reproducible >30 MV/m in accelerator structures
• After much R&D, new materials may outperform Nb
• Some research has already gone into Nb$_3$Sn
• Best performance from vapor diffusion technique at Wuppertal U. in 1990s (G. Mueller, M. Peiniger, et al. – see references)
Wuppertal Method

• A crucible of tin is heated in an evacuated chamber
• Evaporated tin coats the connected cavity
• The temperatures of the tin and the cavity are controlled independent of each other
• \( \text{SnCl}_2 \) is used to nucleate growth sites early on

Adapted from Dasbach et al. (1989) [3]
Wuppertal Method - Details

• (1) Initial heating at 200°C and degassing
• (2) Nucleation at 500°C and heating for 5 hrs
• (3) Growth at 1100°C (cavity) and 1200°C (tin source) for 3 hrs
• (4) Tin heating off but cavity still hot for 30 mins (avoid surplus Sn)

• Best CW result shown – High $Q_0$!! Great potential
• However, $Q$-slope at ~5 MV/m typical for Wuppertal tests
• Max field then: $E_{acc}$ ~15 MV/m (600 Oe) – need higher $Q_0$’s at medium field level CW, and higher fields pulsed
• EP, baking may help to mitigate problems
• Thermometry and surface studies can also help find any weak spots in coating
Wuppertal Results – 1997

- Pulsed measurements done at Cornell with Wuppertal cavity
- Maybe cavity coating not perfect everywhere
New Materials at Cornell

• Restarting Nb$_3$Sn work at Cornell – older work gives hope for promising results
• 2010 pulsed high power test of Wuppertal Nb$_3$Sn cavity
• Fabrication of Nb$_3$Sn coatings on samples
• Planned fabrication of Nb$_3$Sn coatings on cavities
• Pillbox TE cavity
• Mushroom TE cavity
2010 Test of Wuppertal Nb$_3$Sn Cavity

LDP1-3  29Apr10
1.93K Q-Curve

Retested after 20 years on shelf and unknown history

Cornell Data (N. Valles) with Wuppertal cavity
2010 Test of Wuppertal Nb$_3$Sn Cavity

$H_{\text{max}} = -1304.3 (T/T_c)^2 + 1044.9$

Cornell Data (N. Valles) with Wuppertal cavity
Cornell Nb₃Sn Furnace Insert

• Compatible with existing single cell UHV furnace
• Start with samples
• Tin in crucible at bottom of insert
• Heater brings tin to higher temp than sample
• Thermocouples for temp measurement
Sample Furnace

- Manufacturing almost complete
- Almost all parts in hand
- Hoping for first coating by end of month
Cavity Furnace

- Plan to weld full cavities into furnace insert
- EP cavities after weld
- Cut cavities out after coating, HPR, and test
- Use thermometry and Cornell OST quench detection to locate any weak areas
- Dissect cavities so that surface studies can be performed on weak areas
- Use this feedback to improve coating technique
Pillbox TE Cavity

- Takes sample plates OR small samples
- In commissioning phase
- Plans exist to test MgB$_2$ from X. Xi (Temple)

Demountable sample bottom plate

TE011, $f = 6$ GHz \[ \frac{H_{\text{max, sample}}}{H_{\text{max, cavity}}} \approx 0.8 \]

Sample radius = 3.5 cm
Pillbox TE Cavity – Small Samples

TE011, f = 6 GHz

$H_{\text{max, sample}} / H_{\text{max, cavity}} \sim 0.64$

Sample radius = 0.25 cm

Additional port to keep symmetry

Small round sample plate
Mushroom TE Cavity

TE012, $f = 4.78$ GHz

$H_{\text{max, sample}} / H_{\text{max, cavity}} \sim 1.24$

sample radius = 5 cm

TE013, $f = 6.16$ GHz

$H_{\text{max, sample}} / H_{\text{max, cavity}} \sim 1.57$

sample radius = 5 cm
Current status and future plans

• Current status:
  – Fabrication of small sample pillbox TE cavity done
  – EP, 800C & 120C bake, HRP of pillbox TE cavity done
  – No multipacting from TRACK3P simulation for mushroom TE cavity coupler design

• Test plans and schedule:
  – Pillbox TE cavity commissioning
  – New mushroom-type high gradient TE cavities ready for first tests in early next year
  – Collaboration: Send us your samples!
Summary

• Nb3Sn is good candidate for reaching gradients >50 MV/m
• Wuppertal method for coating cavities using vapor diffusion is being attempted at Cornell
• Furnace insert for coating samples is almost ready
• Pillbox TE cavity commissioning
• Mushroom TE cavity being built
• Call for samples!
Call for Samples!

- If you have any samples you would like to try in an RF test
- 3.5 cm or 0.25 cm radius for the pillbox TE cavity;
- 5 cm radius for the mushroom TE cavity;
- Email Matthias Liepe, mul2 at cornell.edu
References

Wuppertal Papers

- G Müller et al. “Nb3Sn layers on high purity Nb cavities with very high quality factors and accelerating gradients,” *Proc. EPAC96*, Barcelona, Spain, pp. 2085-2087, 1996.