## Hot Topic Session: Speaker’s List

<table>
<thead>
<tr>
<th>Category</th>
<th>Name</th>
<th>Institute</th>
<th>Speaker confirmed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
<td>Gianluigi Ciocmani</td>
<td>JLab</td>
<td>yes</td>
</tr>
<tr>
<td>1. Choice of cryocoolers</td>
<td>Tomohiro Yamada</td>
<td>KEK</td>
<td>yes</td>
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<tr>
<td>1b) Ram Dhuley</td>
<td></td>
<td>FNAL</td>
<td>yes</td>
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<tr>
<td>1c) Roman Kostin</td>
<td>Euclid Tech.</td>
<td></td>
<td>yes</td>
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<tr>
<td>1d) Ziqin Yang</td>
<td>IMP</td>
<td>J. Hao</td>
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<tr>
<td>2. Thermal Link design</td>
<td>Neil Stilin</td>
<td>Cornell U.</td>
<td>yes</td>
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<tr>
<td>2b) Tomohiro Yamada</td>
<td>KEK</td>
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<td>2c) Ram Dhuley</td>
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<tr>
<td>2d) Roman Kostin</td>
<td>Euclid</td>
<td></td>
<td>yes</td>
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<tr>
<td>2e) Thomas Proslier</td>
<td>CEA-Saclay</td>
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<tr>
<td>3a. Nb3Sn on Cu thin-film performance</td>
<td>Cristian Pira</td>
<td>INFN</td>
<td>yes</td>
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<tr>
<td>3b) Shawn McNeal</td>
<td>Ultramet</td>
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<tr>
<td>3b. Nb3Sn on Nb thin-film performance</td>
<td>Uttar Pudasaini</td>
<td>JLab</td>
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<tr>
<td>3bb) Jiankui Hao</td>
<td>PKU</td>
<td></td>
<td>yes</td>
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<tr>
<td>3bc) Liana Shpani</td>
<td>Cornell</td>
<td>N. Stilin</td>
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<td>4. Tunability / robustness of Nb3Sn</td>
<td>Grigory Ereminov</td>
<td>FNAL</td>
<td>yes</td>
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</table>
3aa
**Nb$_3$Sn on Cu:**

**Motivations for Cu substrate**
- **Cheaper** than Nb
- Higher **thermal conductivity**
- Higher **mechanical stability**
- **PVD technology** (Nb on Cu) already used for: LEP, LHC, HIE-ISOLDE @ CERN, ALPI @ INFN LNL

**Different technologies under study:**
- **PVD**
  - Magnetron Sputtering
    - Single Target
    - Double Target
  - HiPIMS
- **CVD**
- **Electroplating**
- **Bronze Route**
**Nb₃Sn on Cu by PVD**

- **R&D is Focused on Coating Parameter Optimization to get the right phase at lowest Working T possible**
- **No RF test yet on cavities available**
- **Only a couple of preliminary tests on QPR @CERN**

**Multiple Challenges**

- A15 are Brittle materials
- Complicated Phase Diagram
- Substrate preparation
- Low melting point substrate
- Interface diffusion
- Target Production

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**Strategies**

- Single Target configuration easier to scale into cavities
  - @ CERN and JLab HiPIMS to densify coating
  - @ STFC DCMS-HiPIMS comparison
  - @ INFN thick Nb buffer layer (barrier and accommodation effect) improve dramatically Tc

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**Signal Amplitude**

**Temperature (K)**

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**Nb Buffer Layer Thickness (μm)**

**Tc > 17 K @600 C**

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**Challenges for conduction-cooled SRF cavity technology**
3ab
CVD $\text{Nb}_3\text{Sn}$ Thin Film Performance

Shawn R. McNeal, Victor M. Arrieta*
Ultramet | Pacoima, California

VESNA Technology Collaboration Meeting (TTC 2023)
Fermilab | Batavia, Illinois | December 5–8, 2023

**CVD $\text{Nb}_3\text{Sn}$ coating on copper substrate:** excellent adhesion

**CVD $\text{Nb}_3\text{Sn}$ coating on copper cavity substrate**

**CVD $\text{Nb}_3\text{Sn}$ on welded copper cavity**

**Q vs. E for first-of-kind CVD $\text{Nb}_3\text{Sn}$ welded copper cavity SN38-39 and seamless copper cavity SN-4 with CVD $\text{Nb}_3\text{Sn}$ coating on CVD niobium interlayer at 4.2 K**

**SN-4A, seamless copper cavity substrate (BTM, Inc.)**

* Shawn.McNeal@ultramet.com  Victor.Arietta@ultramet.com
What Is Needed for CVD-based Nb₃Sn/Cu Cavities

Non-Trivial Factors Impeding CVD-based Cavity Technology Growth

❖ Cavity Design Define cavity design early to enable focused, efficient, relevant process R&D for all involved

❖ CVD Nb₃Sn-on-Copper Process Development & Scaling
  ➢ CVD reactor customization and optimization
  ➢ CTE mismatch, thermostructural analysis, and interlayers
  ➢ ID surface conditioning methods for bare copper and Nb₃Sn coatings
  ➢ OD strengthening methods: AM, electrochemical, thermal spray?

❖ Precursor Process Development & Scaling
  ➢ Fundamental R&D: Precursor process development leading to reliable supplier for high-quality precursors

❖ Copper Cavities Expanded domestic infrastructure & capabilities
  ➢ Fundamental R&D Copper cavity substrate process R&D for high-quality cavity substrates necessary for efficient, relevant R&D leading to reliable supplier(s) (with inventory!)

❖ Testing Ready access to material and cavity testing
  ➢ Ideas? Quick-check/in-process cavity test methods?

❖ CVD Nb₃Sn-on-Copper Cavity Production
  ➢ Build-test-repeat to TRL-9
Performance of vapor-diffused Nb$_3$Sn grown on Nb
Performance of vapor-diffused Nb$_3$Sn grown on Nb

**R&D 1.3/1.5 GHz single-cell cavity performance**

- 1.3/1.5 GHz single-cell cavities attain accelerating gradient in excess of 20 MV/m with $Q \sim 10^{10}$.
- Cavities of various frequencies (650 MHz, 952 MHz, 2.6 GHz, 3.6 GHz) coated at different facilities show comparable performance.
- 952 MHz and 650 MHz cavities successfully operated with cryocoolers.

**Multi-cell cavity performance**

- 1.5 GHz five-cell and 1.3 GHz 9-cell cavities were demonstrated to reach $Q \sim 10^{10}$ at 10 MV/m at 4.4 K.
- Maximum gradients achieved up to ~20 MV/m.
- Several projects are underway to build cryomodules with coated cavities aiming for 4 K operation with conduction cooling.

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TTC-2022
Vapor-diffused Nb$_3$Sn grown on Nb: current issues

- Why is the attainable gradient limited?
  - Several approaches are being explored to push the gradient.
    - Roughness/Topography Management: Parameter optimization post-coating treatment and deposition of Sn before thermal diffusion……
    - Film thickness reduction: correlates with surface roughness reduction and improved gradient limit
    - What are the other limiting factors?

- What causes the frequent Q-slope?
  - Studies are focused on correlating material properties and RF performance
    - Grain boundary structure and compositions
    - Limitations due to local defects
    - Facility and procedure dependent: performance sensitivity to Sn residue condensation, Ti evaporation from NbTi flanges….?

- Feasibility for practical applications – how to preserve thin-film performance?
  - The coating process is adopted for larger/longer cavities with multiple Sn sources and coating parameter modifications.
  - How to deposit a high-quality coating on any arbitrary shape/sized cavities?
  - NbTi flanges are more practical – avoid Ti contaminations
    - Hardware to contain Ti and/or altering coating parameters?

- Reproducibility is challenging!??
Nb$_3$Sn Cavities Coated by Tin Vapor Diffusion (Jiankui Hao, PKU)

Coating: 1250°C, 120 min, Annealing: 1150 °C, 60 min
$Q_0 \sim 1.1 \times 10^{10}$ @4.2K @ low field, max. $E_{\text{acc}} \sim 17.3$MV/m

Vertical Tests (2023)

<table>
<thead>
<tr>
<th>Test ID</th>
<th>$T_{\text{grad.}}$</th>
<th>$Q_0$ @ 1.0 MV/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS03(1$^{\text{st}}$, Oct. 17)</td>
<td>15.7 K/m, ~6 min/K</td>
<td>3.3E9</td>
</tr>
<tr>
<td>NS06(1$^{\text{st}}$, Oct. 17)</td>
<td>15.7 K/m</td>
<td>3.0E9</td>
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<td>NS03(2$^{\text{nd}}$, Oct. 18)</td>
<td>110</td>
<td>1.1E9</td>
</tr>
<tr>
<td>NS03(3$^{\text{rd}}$, Oct. 23)</td>
<td>2.7 K/m, ~10 min/K</td>
<td>4.9E9</td>
</tr>
<tr>
<td>NS06(3$^{\text{rd}}$, Oct. 23)</td>
<td>2.7</td>
<td>4.7E9</td>
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Vertical tests at different cooling rate
Conduction cooling of Nb$_3$Sn cavity

**Next step**

- Choose the best Nb$_3$Sn cavity NS04
- Cold spray with copper
- Slower cooling controlled with heater

**Question/Discussion**

- What’s the best cooling rate for vertical test and conduction cooling?

**Nb$_3$Sn cavity**

Conduction cooling

$Q_0 \sim 7 \times 10^8$

@ $E_{\text{acc}} = 1.75$ MV/m

$P_c = 0.57$ W

Cryocooler on and off, 17-18 K, $\Delta T < 2$ K
T<16 K, cryocooler on, cooling down to 4 K
3bc
**Goal for conduction-cooled SRF cavity technology:** Reach higher $Q_0$ at 4.2K

**Main challenge:** achieve a smooth Nb₃Sn film with uniform thickness and stoichiometry.

→ **Improving vapor diffusion:**
  
  Sample studies have shown that pre-nucleation chemical treatments affect tin coverage on Nb substrate.

→ **Alternative growth method:** electrochemical synthesis.

Anneal > 900°C to thermally convert to stoichiometric, smooth Nb₃Sn.

Lower surface roughness

Minimize tin depleted regions (↓$T_C$)

DOI 10.1088/1361-6668/acf5ab

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**nb3sn thin film performance on nb | liana shpani (ls936@cornell.edu)**

TTT 2023
This alternative growth method provides uniform tin nucleation and sufficient Sn supply in critical times

⇒ smoother Nb$_3$Sn films with little variation in Sn concentration with depth.

⇒ First ever alternative growth method to vapor diffusion to achieve **quality factors >10$^{10}$** at 4.2K

⇒ Very low BCS low resistance