Virtual International Workshop on Nb3Sn SRF Science, Technology, and Applications (Nb3SnSRF'20)

Report of Contributions

https://indico.classe.cornell.edu/e/1806

Contribution ID: **1** Type: **Oral presentation**

Field Emission Cathodes on Niobium Conduction-Cooled SRF Cavity

Friday, 13 November 2020 10:20 (20 minutes)

A high-current electron source capable of generating high charge electron bunches at MHz repetition rates is currently being prototyped. The source is based on a 650-MHz single-cell superconducting cavity modify to include a reentrant cathode holder optimized to significantly enhance the electric field on the cathode surface. The electrons are produced via field emission from a field-emitter-array cathode. The system is cooled using a cryogen-free conduction cooling system to ~5K. Electromagnetic simulations indicate the SRF-cavity configuration supports an average accelerating field of 1.4MV/m with the peak field at the cathode around 8.5MV/m. The average electron beam current is limited to 10 microamps by the RF-power source and the field-emitters enhancement factor. We will discuss the design strategy and planned improvements, along with the status of the experiment.

Primary author: MIHALCEA, Daniel (Northern Illinois University)

Co-authors: DHULEY, Ram (Fermilab); GEELHOED, Michael (Fermilab); MOHSEN, Osama (Northern Illinois University); Prof. PIOT, Philippe (Northern Illinois University & Argonne); Dr THANGARAJ, Charles Tobin (Fermilab)

Presenter: MIHALCEA, Daniel (Northern Illinois University)

Session Classification: Applications

Track Classification: Applications

Contribution ID: **2** Type: **Oral presentation**

Ultra-Low Cost Approach to Superconducting Nb3Sn RF Cavities Using Melt Casted Bronze Structures

Thursday, 12 November 2020 09:20 (20 minutes)

Energy to Power Solutions (e2P) in collaboration with the Thomas Jefferson National Accelerator Facility (JLAB) have investigated a novel approach to fabricating Nb3Sn SRF cavities using an ultra-low cost melt casting fabrication process. e2P's simple melt casting techniques can be used to fabricate nearly any superconducting Nb3Sn structure using either the Bronze Route (BR) or Internal-Tin (IT) processes. Due to the ease of the BR melt casted approach, initial efforts were geared primarily towards this process; however, our patent pending process can be used for a wide variety of RF structures, including the IT Nb3Sn fabrication technique as well as normal conducting copper conducting cavities.
Multiple 10 mm x 10 mm coupons of varying tin (Sn) content ranging from 11% to 19 % (Sn atomic weight) were reaction heat treated using a modified BR processing technique. All of the coupons were mechanically polished and cleaned prior to Nb film deposition but were not chemically etched. The mechanically polished bronze coupons of varying Sn content were initially coated with a 0.5-1 um thick Nb film at JLAB using an Electron Cyclotron Resonance (ECR) RF sputtering technique under varying processing conditions of substrate temperature and incident ion energies. After Nb film deposition in JLAB's ECR chamber, samples were then heat treated in a separate furnace in an attempt to form the superconducting Nb3Sn phase. Samples were heat treated in both a vacuum furnace at JLAB and inert Ar atmosphere at e2P. Samples heat treated in the vacuum furnace at JLAB showed superior surface smoothness. Post heat treated samples were then tested for its superconducting transition temperature (Tc) using AC susceptibility measurements.
Most of the heat treated samples that were examined using SEM/EDX seemed to show a reasonable correlation of Tc onset and transition width (delta T) of the initial/starting Sn content to the desired stoichiometric Nb3Sn phase, where the lower starting Sn content coupons resulted in lower Tc's with broader transition widths and the higher starting Sn coupons resulted in higher Tc's with narrower transition widths. The best samples had Tc's ~18 K and delta T's ~ 1 K.
Two samples were further tested for RF surface resistance (Rs) and Quality Factor (Q) at JLAB. These RF measurements were performed at 7.5 GHz using a calorimetric technique and showed a Tc onset ~ 16 K; however, values of Rs were quite disappointing with corresponding Q values ~ 1065 nearly 4 orders of magnitude lower than similar high quality Nb3Sn films directly deposited substrates by JLAB.
Substantial improvements in the processing variables ranging from higher quality of the initial melt casted structures with higher Sn content, to better polishing and chemical surface treatments will be necessary to realize improved RF performance metrics.

Primary authors: Dr REY, Christopher (e2P); Dr VALENTE-FELICIANO, Anne-Marie (JLAB); Dr EREMEEV, Grigory (FNAL)

Presenter: Dr REY, Christopher (e2P)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **3** Type: **Oral presentation**

Temperature-Dependent Characteristics of Sputtered Nb3Sn Thin Films (for Accelerator Applications)

Thursday, 12 November 2020 09:55 (20 minutes)

Nb3Sn thin film is the most promising candidate for the next-generation superconducting radio frequency (SRF) cavities. In this work, we successfully enabled the DC sputtering deposition of Nb3Sn films with varying thickness (100 nm - 2 μm) on either Nb or Cu substrates. More importantly, we systematically explored the effects of annealing both in situ and post-sputtering in order to achieve optimal conditions for constructing films. Preliminary results show that the sputtered films are essentially smooth, although deficiency of Sn occurred as indicated in our energy dispersive X-ray spectroscopy (EDS) analysis. After thermal anneals of increasing temperature, we observed removal of nanometer-size pinholes and a slight increase in grain size, in addition to cracking and changes in grain organization in some samples. Interestingly, triangle shaped grains were observed in one of our non-in situ-annealed samples. We can infer how the grains nucleate at the initial stage through comparison of our data from post-sputtering with recent data after high-temperature anneals. From X-ray diffraction (XRD) results, we found that our anneals can effectively crystallize film as suggested by the increased amplitude of diffraction peaks. Especially on our Cu substrate samples, we observe the appearance of Nb3Sn peaks after 600 C annealing. These initial results encourage us to refine our process to obtain high quality films for SRF use and fundamentally understand the nucleation process of sputtered Nb3Sn.

Primary author: HOWARD, Katrina (CLASSE)

Co-authors: SUN, Zeming (CLASSE); LIEPE, Matthias

Presenter: HOWARD, Katrina (CLASSE)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **4** Type: **Oral presentation**

Conduction cooled SRF photogun for UEM/UED applications

Friday, 13 November 2020 10:00 (20 minutes)

The Superconducting RF (SRF) photocathode gun is a promising candidate to produce highly stable electrons for applications where a high repetition rate beam is needed. It operates in an ultrahigh Q, CW mode, and dissipates a few watts of RF power, which make it possible to achieve a 10s ppm level of beam stability by using modern RF control techniques. Euclid, in collaboration with Fermilab, is currently developing a novel L-band conduction cooled Nb3Sn SRF photogun. This approach can greatly save on both construction and operational costs. The back wall of the gun is used as a photocathode. The quantum efficiency of bare Nb surface can exceed 10E-5 at 266 nm. This metal photocathode is very robust, and a mW-scale UV laser power is sufficient to generate the electron beam currents required for many applications, including the MeV ultrafast electron microscopy. The design, development, and timeline of the project, as well as the up to date progress are presented. The project is funded under DoE SBIR Grant DE-SC0018621.

Primary authors: Dr KOSTIN, Roman (Euclid); Dr JING, Chunguang (Euclid); Mr AVRAKHOV, Pavel (Euclid); Mr ZHAO, Yubin (Euclid); Dr LIU, Ao (Euclid)

Presenter: Dr KOSTIN, Roman (Euclid)

Session Classification: Applications

Track Classification: Applications

Contribution ID: **5** Type: **Oral presentation**

Electrochemical deposition for generating Nb3Sn films with low surface roughness and stoichiometry

Thursday, 12 November 2020 11:20 (25 minutes)

Reducing surface roughness and attaining stoichiometry of Nb3Sn superconductors are required for radio-frequency accelerator applications. We explore the electrochemical deposition of Sn, Nb, and Nb-Sn films, and also investigate the thermal annealing of the plated films to Nb3Sn. Current progress shows that high quality Sn pre-depositions via electroplating on the Nb surface can significantly reduce the surface roughness of the resultant Nb3Sn superconductors with pure stoichiometry, owing to sufficient Sn supply and uniformly distributed events during nucleation. We find that the surface roughness of Nb3Sn is minimized to an average roughness of 65 nm that is 5 times lower than the values from conventional vapor diffused samples. Fast Fourier transformation tests confirm a dramatic reduction in power intensity at medium spacial frequencies that are important for moderating the field enhancement. Structural and superconducting property measurements demonstrate a Nb3Sn A15 phase with a stoichiometry of 25 at% Sn that is crucial to the superconducting properties and thus achieving a high critical temperature of 18 K (Nb3Sn limit) at zero magnetic field. Ongoing efforts include the electrochemical deposition of Nb and Nb-Sn films, and they will also be briefly discussed in the workshop.

Primary authors: SUN, Zeming (CLASSE); PORTER, Ryan; BARAISSOV, Zhaslan; DOBSON, Kevin D. (Institute of Energy Conversion); SITARAMAN, Nathan; KELLEY, Michelle (Cornell); HOWARD, Katrina (CLASSE); OSEROFF, Thomas; GE, Mingqi (Cornell University); DENG, Xiaoyu (University of Virginia); HIRE, Ajinkya (Graduate Student- University of Florida); CONNOLLY, Aine (Cornell University); THOMPSON, Michael O. (Cornell University); HENNIG, Richard; SETHNA, James; MULLER, David; ARIAS, Tomas; LIEPE, Matthias

Presenter: SUN, Zeming (CLASSE)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **6** Type: **Oral presentation**

First principles study of the impact of grain boundaries on Nb_3Sn

Tuesday, 10 November 2020 09:30 (20 minutes)

We present the first comprehensive study of grain boundaries in Nb_3Sn from first principles. While most conventional superconductors, such as Nb, are not significantly impacted by the presence of grain boundaries, Nb_3Sn is much more sensitive to defects and disorder owing to its relatively short coherence length of ~3 nm. Indeed, experiments suggest a link between grain-boundary stoichiometry and the performance of Nb_3Sn superconducting radio frequency (SRF) cavities, and mesoscopic simulations point to grain boundaries as a candidate mechanism that lowers the vortex-entry field in SRF cavities. Our density-functional theory (DFT) calculations on tilt and twist grain boundaries provide insight into general trends on quantities such as the local Fermi-level density of states, antisite defect formation free energies, local electronic properties from grain boundaries with added point defects, and how grain boundary composition affects the local Tc around grain boundaries in Nb_3Sn. In this talk we will use our findings to explain recent experimental findings and provide insight on promising modifications to the growth procedure of the material to optimize the performance of SRF cavities.

Primary author: KELLEY, Michelle (Cornell)

Co-authors: SITARAMAN, Nathan; ARIAS, Tomas

Presenter: KELLEY, Michelle (Cornell)

Session Classification: Fundamental Studies

Track Classification: Fundamental Studies

Contribution ID: **7** Type: **Oral presentation**

Critical Fields of Nb3Sn

Tuesday, 10 November 2020 11:25 (20 minutes)

The field of first vortex penetration was measured on Nb_3Sn samples under DC and RF fields using the muon spin rotation technique and a quadrupole resonator. Those methods also enabled direct and indirect measurements of the London penetration depth from which the lower critical field and the superheating field are derived. The combined results confirm that Nb_3Sn cavities are indeed operated in a metastable state above the lower critical field but currently limited to a critical field well below the superheating field. This possibly non-fundamental limitation is also visible in the temperature dependence of the RF critical field deviating from the expected quadratic behavior.

Primary author: KECKERT, Sebastian (Helmholtz-Zentrum Berlin)

Co-authors: JUNGINGER, Tobias; BUCK, Terry; HALL, Daniel (Cornell U.); KOLB, Philipp; KUGELER, Oliver; LAXDAL, Robert; LIEPE, Matthias; POSEN, Sam (FNAL); PROKSCHA, Thomas; SALMAN, Zaher; SUTER, Andreas; KNOBLOCH, Jens

Presenter: KECKERT, Sebastian (Helmholtz-Zentrum Berlin)

Session Classification: Fundamental Studies

Track Classification: Fundamental Studies

Contribution ID: **9** Type: **Oral presentation**

CONSTRUCTION OF Nb3Sn COATING SYSTEM AND TRIAL OF SAMPLE COATING AT KEK

Wednesday, 11 November 2020 08:00 (20 minutes)

A tin vapor diffusion system was constructed for Nb3Sn cavity R&D at KEK. The vapor diffusion system consists of a vertical vacuum furnace, a coating chamber made of niobium, and a heating device for tin evaporation. In the thermal design of the coating system, the temperature distribution of cooling and coating part was investigated using ANSYS. After construction of the vapor diffusion system, we carried out the commissioning of the furnace. We have performed Nb3Sn coating tests on niobium samples with various coating time and temperature for each sample. Sample surface, cross section, and tin composition ratio are observed. The critical temperature of the samples is measured by Quantum Design MPMS. Some samples measured have a critical temperature around 18 K and tin composition ratio around 25 at%. In this presentation, design and construction of the coating system and sample coating results are reported.

Primary author: Mr TAKAHASHI, Kotaro (SOKENDAI/KEK)

Co-authors: UMEMORI, Kensei (KEK); ITO, Hayato (SOKENDAI/KEK); KONOMI, Taro (KEK); HIROSHI, Sakai (KEK); KAKO, Eiji (KEK); Mr OKADA, Takafumi (SOKENDAI)

Presenter: Mr TAKAHASHI, Kotaro (SOKENDAI/KEK)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **10** Type: **Oral presentation**

Nb3Sn Coating of Complex Cavity Structures for SRF Accelerator Applications.

Wednesday, 11 November 2020 10:25 (20 minutes)

The recently demonstrated performance of Nb3Sn cavities makes this material attractive for SRF accelerator applications. While the majority of research efforts are focused on the development of elliptical single-cell and multi-cell cavities, the potential of this material is evident to other cavity types, which may have complex geometries. We are working towards the development of Nb3Sn-coated Half-wave resonator and twin axis cavity at JLab. The Half-wave resonator with a coaxial structure provides data across different frequencies of interest useful for particle accelerators worldwide, whereas the twin axis cavity with two accelerating axes has been proposed for the Energy recovery linac applications. With their advanced geometries, larger surface area, increased number of ports and hard to reach areas, the usual coating approach must be evaluated and may need to be adjusted. We are commissioning a secondary Sn source in the coating system and will modify the current coating protocol to coat different complex cavity models. This presentation aims the current updates on such modifications and results we could obtain so far.

Primary author: TISKUMARA, Jayendrika (Old Dominion University /JLab)

Co-authors: PUDASAINI, Uttar (Jefferson Lab); Dr EREMEEV, Grigory (FNAL); REECE, Charles (Jefferson Lab); DELAYEN, Jean (Old Dominion University)

Presenter: TISKUMARA, Jayendrika (Old Dominion University /JLab)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **11** Type: **Oral presentation**

Optimization of vortex pinning by nanoparticles using simulations of the time-dependent Ginzburg-Landau model

Tuesday, 10 November 2020 10:05 (20 minutes)

Incorporating nanoparticles into superconducting materials has been established as an efficient route to enhance their current-carrying capability. We explored vortex pinning by randomly distributed spherical nanoparticles using large-scale numerical simulations of time-dependent Ginzburg-Landau equations. First, we investigated a vortex lattice interacting with an *isolated* defect [1]. We found a series of first-order phase transitions at well-defined magnetic fields, when the number of vortex lines occupying the inclusion changes. The pin-breaking force has sharp local minima at those fields. As a consequence, in the case of isolated identical large-size defects, the field dependence of the critical current is composed of a series of peaks located in between the occupation-number transition points. Furthermore, exploring the magnetic-field dependences of critical current for superconductors containing *finite density* of spherical inclusions with different sizes, we found several pinning regimes that indeed are mostly characterized by the average occupation numbers of inclusions with the vortex lines[2]. The distinct peak effect, however, only exists for very small inclusion densities when the vortices form a regular lattice. Finally, we also found optimal size and density of particles, which maximize the critical current for fixed magnetic field[3]. For every particle size, the critical current reaches maximum value at certain particle density, typically corresponding to 15-22% of the volume fraction filled by the particles. Moreover, we found that, as the magnetic field increased, the optimal particle diameter slowly decreases from 4.5 to 2.5 coherence lengths. This result shows that pinning landscapes have to be designed for specific applications taking into account relevant magnetic field scales.
The work was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division.

[1] *Peak effect due to competing vortex ground states in superconductors with large inclusions*, Roland Willa, Alexei E. Koshelev, Ivan A. Sadovskyy, and Andreas Glatz, Phys. Rev. B, **98**, 054517 (2018).
[2] *Strong pinning regimes by spherical inclusions in anisotropic type-II superconductors*, R. Willa, A. E. Koshelev, I. A. Sadovskyy, and A. Glatz, Sup. Sci. Techn., **31**, 014001(2018).
[3] *Optimization of vortex pinning by nanoparticles using simulations of time-dependent Ginzburg-Landau model*, A. E. Koshelev, I. A. Sadovskyy, C. L. Phillips, A. Glatz, Phys. Rev. B **93**, 060508 (2016).

Primary author: Dr KOSHELEV, Alexei (Materials Science Division, Argonne National Laboratory)

Co-authors: Dr WILLA, Roland (Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology); Dr SADOVSKYY, Ivan (Station Q, Microsoft Research); Dr GLATZ, Andreas (Materials Science Division, Argonne National Laboratory)

Presenter: Dr KOSHELEV, Alexei (Materials Science Division, Argonne National Laboratory)

Session Classification: Fundamental Studies

Track Classification: Fundamental Studies

Contribution ID: **12** Type: **Oral presentation**

Nb3Sn growth by sequential sputtering: film morphology and its RF properties

Thursday, 12 November 2020 10:15 (20 minutes)

Due to higher superconducting critical temperature and superheating field, and lower BCS surface resistance, Nb3Sn is considered a promising alternative to standard niobium for SRF application. Multilayer sequential sputtering method is a promising alternative to the conventional vapor diffusion method to grow Nb3Sn films inside a niobium cavity. In this method, multiple thin layers of Nb and Sn are annealed at high temperature to fabricate Nb3Sn. The thickness of multilayers can be varied to adjust the film stoichiometry, which significantly affects the superconducting properties of Nb3Sn films. We have examined the growth process of Nb3Sn films by varying the deposition conditions (thickness, annealing temperature, annealing time, and substrate temperature during growth). The film properties were characterized by scanning electron microscopy, transmission electron microscopy, X-ray diffraction, atomic force microscopy, and energy-dispersive X-ray spectroscopy. The DC superconducting properties of the films were characterized by the four-point probe technique down to cryogenic temperatures. RF surface resistances of some films were studied using the surface impedance characterization system at the Jefferson Lab. For both measurements, the films showed superconducting properties close to bulk Nb3Sn.

Primary authors: SAYEED, Md Nizam (Old Dominion University); Dr EREMEEV, Grigory (FNAL); REECE, Charles; PUDASAINI, Uttar (Jefferson Lab); Dr ELSAYED-ALI, Hani (Old Dominion University)

Presenter: SAYEED, Md Nizam (Old Dominion University)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **13** Type: **Oral presentation**

Nb3Sn Formation Using Electroplating Method for SRF Cavity

Thursday, 12 November 2020 08:40 (20 minutes)

A novel electroplating method to form Nb3Sn film onto an Nb substrate has been developed and optimized at Fermilab. In this method, a Cu interlayer is plated between an Sn layer and the Nb substrate, then a bronze layer formed in the first step of sequential thermal treatment. Subsequently, the Nb3Sn layer is formed at 700C by a solid diffusion reaction between the bronze layer and the Nb substrate. In order to advance the research on this method, KEK has started the electroplating for Nb3Sn formation with the same method but different plating solutions under the US-Japan cooperation. The thermal treatment and characterization of Nb3Sn samples are performed in the cooperation of NIMS and Tohoku University. Besides, at KEK, remove the excess bronze layer after heat treatment is tried out using several chemical solutions. In this presentation, the result of the Nb3Sn formation by the electroplating method and the progress on surface treatments to remove the bronze layer are reported.

Primary author: Dr ITO, Hayato (KEK)

Co-authors: Dr HAYANO, Hitoshi (KEK); Dr MONJUSHIRO, Hideaki (KEK); Dr KASHIWAGI, Shigeru (Tohoku University); Dr HONDA, Fuminori (Tohoku University); Dr KIKUCHI, Akihiro (NIMS); Dr BARZI, Emanuela (FNAL)

Presenter: Dr ITO, Hayato (KEK)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **14** Type: **Oral presentation**

Surface Resistance, Frequency Dependence, and Field Limitation in Nb3Sn Cavities

Friday, 13 November 2020 08:20 (25 minutes)

In this talk, we present the current performance of Nb3Sn SRF cavities at Cornell University and recent research/progress towards improving their performance. We particularly focus on high frequency Nb3Sn cavities (> 1.3 GHz) and on understanding and improving the maximum accelerating gradient of Nb3Sn cavities (currently limited to 17 MV/m at Cornell University).

Primary author: PORTER, Ryan

Co-authors: KOUFALIS, Peter; LIEPE, Matthias; MANISCALCO, James

Presenter: PORTER, Ryan

Session Classification: Performance

Track Classification: Performance

Contribution ID: **15** Type: **Oral presentation**

Growth Studies and Optimization of Nb3Sn Coatings

Wednesday, 11 November 2020 08:45 (20 minutes)

Improving the performance of Nb3Sn cavities requires altering the growth process to produce better films. A good understanding of how Nb3Sn grows via the Sn diffusion process is required in order to know how to modify the process to achieve a better film. Here we present experimental studies of Nb3Sn layer growth that further our understanding of the Nb3Sn growth process. This includes microscopy of samples that were grown with different substrate preparations, modified growth processes, or stopped during growth. The results are interpreted and methods proposed to prevent several forms of defects from forming (thin film regions, Sn-depleted sites, and surface roughness).

Primary author: PORTER, Ryan

Co-authors: HU, Hannah (Cornell University); BARAISSOV, Zhaslan; SITARAMAN, Nathan; MULLER, David; LIEPE, Matthias; CUEVA, Paul; ARIAS, Tomas; SUN, Zeming (CLASSE)

Presenter: PORTER, Ryan

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **16** Type: **Oral presentation**

Accelerator Stewardship with Nb3Sn at JLab

Friday, 13 November 2020 11:05 (20 minutes)

Jefferson Lab is funded by a grant from the DOE Accelerator Stewardship to demonstrate operation of an SRF cavity with a cryocooler to an accelerating gradient compatible with an electron energy gain of 1 MeV for possible use in an accelerator for environmental remediation. This presentation describes the current plan and initial test results on a 952 MHz single-cell cavity coated with Nb3Sn

Primary authors: CIOVATI, Gigi (Jefferson Lab); RIMMER, Robert (JLab); PUDASAINI, Uttar (Jefferson Lab); CHENG, Gary (JLab)

Presenter: CIOVATI, Gigi (Jefferson Lab)

Session Classification: Applications

Track Classification: Applications

Contribution ID: **17** Type: **Oral presentation**

PVD deposition of Nb3Sn from an alloy target on copper.

Thursday, 12 November 2020 08:00 (20 minutes)

We report on the PVD deposition of Nb3Sn on Cu substrates with and without a thick Nb interlayer to produce Cu/Nb/Nb3Sn and Cu/Nb3Sn multilayer structures. The Nb3Sn was sputtered directly from an alloy target at room and elevated temperatures. The dependence of the superconducting properties of the total structure on deposition parameters has been determined. The films have been characterized via SEM, XRD, EDX and SQUID magnetometer measurements. Analysis showed that the composition at both room and elevated temperature was within the desired stoichiometry of 24–25 at%. However, superconductivity was only observed for deposition at elevated temperature or post annealing at 650 ℃. The critical temperature was determined to be in the range of 16.8 to 17.4 K. In the case of bilayer deposition, copper segregation from the interface all the way to the surface was observed.

Primary author: VALIZADEH, reza (STFC)

Presenter: VALIZADEH, reza (STFC)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **18** Type: **Oral presentation**

Nb3Sn growth in vapor diffusion: process design for large surface area coatings

Wednesday, 11 November 2020 10:05 (20 minutes)

Following the recent progress made in the Nb_3Sn coatings on single-cell SRF cavities, development is ongoing to reproduce single-cell cavity results on practical SRF structures. Those structures may include multi-cell and single-cell cavities having a larger surface area than regularly coated ~1.5 GHz single-cell cavities. Early CEBAF five-cell cavities coated with a typical coating procedure resulted in high low-field quality factors, but strong low-field Q-slopes and early quenches typically limited the cavities. Followed by a material analysis of witness samples positioned in strategic locations during cavity coating, several changes from the original process design for single-cell cavity coating were introduced to improve the quality of Nb_3Sn films for large surface area coatings. The best Nb3Sn-coated CEBAF 5-cell cavities have reached accelerating gradients useful for cryomodules. We will discuss process designs used to coat CEBAF five-cell cavities and a 952 MHz single-cell cavity at JLab.

Primary authors: PUDASAINI, Uttar (Jefferson Lab); Dr EREMEEV, Grigory (FNAL); REECE, Charles; KELLEY, Michael (Jefferson Lab); CIOVATI, Gigi (Jefferson Lab)

Presenter: PUDASAINI, Uttar (Jefferson Lab)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **19** Type: **Oral presentation**

Nucleation of Nb3Sn films in a tin vapor diffusion process

Wednesday, 11 November 2020 09:05 (20 minutes)

The tin vapor diffusion coating of Nb cavity interiors via a two-step nucleation-then-growth sequence appears to be the most promising path so far to produce Nb3Sn cavities. To elucidate the role of nucleation, we manipulated the accessible range of process variables and studied the niobium surface nucleated under varying process conditions using an array of materials characterization tools. Broadly, nucleation deposits tin as a thin surface phase and, under some conditions, as near-micron sized particles as well. Conditions that impair nucleation promote the formation of defects, such as patches, in subsequent coating growth. This presentation discusses the nucleation stage in a typical vapor diffusion coating in practice to produce Nb3Sn-coated SRF cavities.

Primary authors: PUDASAINI, Uttar (Jefferson Lab); Dr EREMEEV, Grigory (FNAL); REECE, Charles; KELLEY, Michael (Jefferson Lab); TUGGLE, Jay (Virginia Tech)

Presenter: PUDASAINI, Uttar (Jefferson Lab)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **20** Type: **Oral presentation**

Recent Nb3Sn cavity results from Fermilab

Friday, 13 November 2020 09:10 (20 minutes)

In this contribution, we present measurements from vertical testing of Nb3Sn cavities at Fermilab. Results include measurements on single cell cavities as well as 9-cell cavities. Most results are at 1.3 GHz, with some at other frequencies. Correlations are made to coating appearance.

Primary author: POSEN, Sam (FNAL)

Presenter: POSEN, Sam (FNAL)

Session Classification: Performance

Track Classification: Performance

Contribution ID: **21** Type: **Oral presentation**

Growth Studies at Northwestern University of Vapor Diffusion Samples from Fermilab

Wednesday, 11 November 2020 08:20 (25 minutes)

There has been significant progress in Nb3Sn SRF cavities during the last decade and the current maximum accelerating electric field of Nb3Sn cavities exceeds ~24 MV/m for a single-cell. Collaborative research on Nb3Sn film growth studies between Fermilab and Northwestern University have been performed during the last three years. We explored effects of growth parameters such as Sn supply (amount of Sn, size of crucible etc) and furnace temperature, and tried to understand how they affect growth kinetics and imperfections in the final microstructures of Nb3Sn coatings. It has been found that the following microstructural imperfections in Nb3Sn coatings play important roles in the performance of Nb3Sn cavities: (i) patchy regions with thin-grains; (ii) Sn segregation at GBs; and (iii) surface roughness. Firstly, we found that the patchy regions with thin-grains are formed in the case of a low Sn-flux, which leads to texturing of Nb3Sn coatings on Nb, due to the orientation relationships at Nb/Nb3Sn heterophase interfaces. Secondly, a possible correlation between Sn-segregation at GBs and cavity performance is observed. We find that the chemical composition of GBs in Nb3Sn is controlled by Sn and Nb diffusion during annealing with or without a Sn-flux. And Nb3Sn SRF cavities without significant Sn or Nb segregation are achieved by a carefully designed coating procedure, which also yields a high-cavity performance without a significant Q-slope untill ~17 MV/m. Lastly, a possible correlation between surface roughness and the cavity performance is also observed: Nb3Sn SRF cavities with an extremely smooth surface are fabricated and it has a value of surface roughness (arithmetic average height, Ra) less than ~100 nm. Then, the maximum accelerating electric field of the cavities exceeds ~24 MV/m. The significantly reduced surface roughness is attributed to the smaller average grain diameter of Nb3Sn coatings (~700 nm) with thinner thicknesses (~1 μm), and further investigations on this subject are ongoing. We demonstrated that the performance of Nb3Sn SRF cavities can be significantly improved by controlling microstructural imperfections and the current study provides a pathway for fabricating high-performance Nb3Sn SRF cavities.

Primary authors: LEE, Jae Yel (Northwestern University-Fermilab); Dr MAO, Zugang (Materials Science and Engineering, Northwestern University); SEIDMAN, David (Northwestern University); POSEN, Sam (FNAL)

Presenter: LEE, Jae Yel (Northwestern University-Fermilab)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **22** Type: **Oral presentation**

Investigation of Nb3Sn Thin Films using Magnetic Field Penetration Measurements

Tuesday, 10 November 2020 11:05 (20 minutes)

Nb3Sn is currently the most promising material other than niobium for future superconducting radiofrequency (SRF) cavities. To achieve high accelerating gradient, the behavior of Nb3Sn thin films in an external magnetic field should be studied. The magnetic field at first flux penetration is one of the key physical parameters to characterize them. Therefore, it is important to have a simple, efficient, and accurate technique to measure first flux penetration into a superconducting thin film directly. The conventional magnetometers are inconvenient for thin superconducting film measurements because these measurements are strongly influenced by orientation, edge, and shape effects. In order to measure the onset of field penetration in thin films and multi-layered superconductors, we have designed and built a system combining a small superconducting solenoid capable of generating a parallel surface magnetic field up 0.5 T and Hall probe to detect the first entry of vortices. This technique can be used to study Nb3Sn thin films along with qualitative and quantitative comparison of Nb3Sn with Nb for their SRF performances.

Primary author: SENEVIRATHNE, Iresha Harshani (Old Dominion University)

Co-authors: Prof. DELAYEN, Jean (Old Dominion University); CIOVATI, Gianluigi (Thomas Jefferson National Accelerator Facility)

Presenter: SENEVIRATHNE, Iresha Harshani (Old Dominion University)

Session Classification: Fundamental Studies

Track Classification: Fundamental Studies

Contribution ID: **23** Type: **Oral presentation**

Persistence of the Nb(100) Surface Oxide Reconstruction at Elevated Temperatures

Wednesday, 11 November 2020 10:45 (20 minutes)

Helium atom scattering (HAS) and Auger electron spectroscopy (AES) measured surface structure and composition of an unexplored regime of the oxidized Nb surface at SRF Nb3Sn cavity preparation temperatures. These in situ measurements revealed the high temperature stability of a NbO surface reconstruction, specifically the (3x1)-O Nb(100). HAS diffraction peak intensity, line shape, and location showed that the atomic scale structure and surface coherence length of the (3x1)-O Nb(100) surface remain unchanged up to 1130 K. Furthermore, unchanging relative peak heights from a corresponding AES experiment confirmed a stable surface composition between 300 K and 1150 K. Due to Nb's strong affinity for oxygen, an ever-present oxide layer covers Nb surfaces. The structure of the oxidized Nb surface at temperatures of Sn deposition was previously unknown. However, these results reveal that (3x1)-O Nb(100) is present and fully formed at temperatures of Sn deposition. This implies that the interfacial mechanisms driving the quality of Nb3Sn films depend on the behavior of the oxidized Nb surface and provides crucial information for Nb3Sn growth models.

Primary authors: THOMPSON, Caleb (University of Chicago); Ms MCMILLAN, Alison (University of Chicago); Dr GRAHAM, Jacob (University of Chicago); WILLSON, Sarah (University of Chicago); Dr FARBER, Rachael (University of Chicago); Dr SIBENER, Steven (University of Chicago)

Presenter: THOMPSON, Caleb (University of Chicago)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **24** Type: **Oral presentation**

Mitigation of Performance-Limiting Mechanisms in Nb3Sn SRF Films

Tuesday, 10 November 2020 08:05 (20 minutes)

Low BCS surface resistance and large superheating field make Nb3Sn a very attractive material for low-field SRF applications. At the same time, the performance of Nb3Sn at high RF fields can be limited by current-blocking grain boundaries, small lower critical magnetic field, poor thermal conductivity and high resistivity, which make Nb3Sn prone to premature penetration of vortices and overheating effects. In this talk I discuss possible ways by which the performance-limiting mechanisms in Nb3Sn could be mitigated by surface nano-structuring and improving current transparency of grain boundaries. I will also discuss nonlinear SRF losses caused by trapped vortices.

Primary author: Dr GUREVICH, Alex (Old Dominion University)

Presenter: Dr GUREVICH, Alex (Old Dominion University)

Session Classification: Fundamental Studies

Track Classification: Fundamental Studies

Contribution ID: **25** Type: **Oral presentation**

Towards a Floquet theory of periodically driven superconductors

Tuesday, 10 November 2020 08:50 (20 minutes)

We use Floquet theory to describe dynamics and losses of superconductors under extremely high fields and frequencies.Periodically driven superconductors at high fields provide an unexplored theoretical territory relevant in modern applications (lower cryogenic costs for particle accelerators), allowing for experimental validation using Superconducting Radio Frequency (SRF) cavities. We use the Floquet formalism to solve the Cooper problem in the limit of strong AC fields (in which linear-response analysis does not apply), and discuss preliminary results combining BCS and Floquet theories to develop an experimentally-verifiable new approach for periodically-driven superconductors that provides explanation and control of dissipation.

Primary author: LIARTE, Danilo

Co-authors: SETHNA, James; LIEPE, Matthias; ARIAS, Tomas; KELLEY, Michelle (Cornell); SITARAMAN, Nathan; OSEROFF, Thomas; DEYO, Sean (Cornell)

Presenter: LIARTE, Danilo

Session Classification: Fundamental Studies

Track Classification: Fundamental Studies

Contribution ID: **26** Type: **Oral presentation**

Cryocooler conduction cooled SRF cavities: experiments and compact SRF accelerator development at Fermilab

Friday, 13 November 2020 10:40 (25 minutes)

Fermilab recently demonstrated practical accelerating gradients (~6.5 MV/m cw) on a Nb_3Sn SRF cavity with cryocooler conduction-cooling, without using the conventional liquid helium bath. The successful integration of this cryocooling scheme with an SRF cavity is a stepping-stone for realizing compact SRF based e-beam sources for high-throughput industrial applications of electron irradiation. Since the first gradient demonstration, Fermilab has continued to push up the performance of the SRF cavity as well as design a high-power e-beam SRF accelerator utilizing the conduction-cooling technique. Furthermore, construction efforts have started for a technology demonstration conduction-cooled SRF accelerator. This talk will present the results from the gradient demonstration program and progress towards the design and development of the SRF accelerators.

Primary authors: DHULEY, Ram (Fermi National Accelerator Laboratory); GONIN, Ivan (Fermilab); GEELHOED, Michael (Fermilab); POSEN, Sam (FNAL); KAZAKOV, Sergey (Fermilab); KHABIBOULLINE, Timergali (FNAL); YAKOVLEV, Vyacheslav; THANGARAJ, jayakar (Fermilab); KROC, Thomas

Presenter: DHULEY, Ram (Fermi National Accelerator Laboratory)

Session Classification: Applications

Track Classification: Applications

Contribution ID: **27** Type: **Oral presentation**

Development and Understanding of Nb3Sn films for radiofrequency applications through a sample-host 9-cell cavity

Wednesday, 11 November 2020 09:25 (25 minutes)

Nb3Sn is a promising advanced material under development for superconducting radiofrequency (SRF) cavities. Past efforts have been focused primarily on small development-scale cavities, but large, often multi-celled cavities, are needed for particle accelerator applications. In this work, we report on successful Nb3Sn coatings on Nb in a 1 m-long 9-cell Nb sample-host cavity at Fermilab. The geometry of the first coating with only one Sn source made it possible to study the influence of Sn flux on the microstructure. Based on these results, we postulate a connection between recently observed anomalously large thin grains and uncovered niobium spots observed in the past by other authors [Trenikhina 2018]. A phenomenological model to explain how these anomalously large grains could form is proposed. This model is invoked to provide possible explanations for literature results from several groups and to guide key process parameters to achieve uniform vapor-diffusion coatings, when applied to complex structures as the multi-cell cavity under study.

Primary authors: SPINA, Tiziana (Fermilab); POSEN, Sam (FNAL); LEE, Jae Yel (Northwestern University-Fermilab); SEIDMAN, David (Northwestern University); TENNIS, Brendan (Fermilab)

Presenter: SPINA, Tiziana (Fermilab)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **28** Type: **Oral presentation**

Conduction Cooling Studies for 2.6 GHz Nb3Sn SRF Cavities

Friday, 13 November 2020 11:25 (25 minutes)

A new frontier in SRF research is the use of simplified cooling methods that will allow easier access to SRF technology for industrial applications. At Cornell, we have developed a new conduction cooling setup that utilizes a manufactured cryocooler to provide the necessary heat dissipation for operation of a 2.6 GHz Nb_3Sn-coated SRF cavity. We report on various methods used to increase performance during testing, resulting in successful stable operation at 10 MV/m with a quality factor of 4E9. We also describe recent changes to the testing assembly used to minimize ambient magnetic fields and improve RF power delivery to the cavity.

Primary authors: STILIN, Neil (Cornell University); HOLIC, Adam (Cornell University); SEARS, James (Cornell University); PORTER, Ryan; LIEPE, Matthias

Presenter: STILIN, Neil (Cornell University)

Session Classification: Applications

Track Classification: Applications

Contribution ID: **29** Type: **Oral presentation**

Spatially Resolved Adsorption Structures and Diffusion Dynamics of Sn on (3×1)-O Nb(100)

Wednesday, 11 November 2020 11:25 (20 minutes)

Nb_3Sn has been identified as a promising next-generation material for superconducting radio frequency (SRF) cavities and there is significant interest in developing protocols resulting in pristine Nb_3Sn coatings. Recent work has shown that Nb_3Sn surface structure and composition significantly affects the cavity quality factor (Q) of Nb_3Sn SRF cavities; Sn homogeneity, surface roughness, and alloy thickness must be well controlled to achieve optimal cavity performance. There is not, however, a fundamental understanding of the surface mediated Sn diffusion and alloying mechanisms influencing pristine Nb_3Sn growth. In order to develop growth protocols resulting in smooth, homogeneous Nb_3Sn films, necessary for optimal Nb_3Sn cavity performance, fundamental studies investigating Sn adsorption and diffusion behavior must be conducted to identify deleterious Nb_3Sn growth mechanisms. Spatially resolved structural information of Sn adsorption structures and diffusion dynamics on oxidized Nb surfaces are needed to determine Nb_3Sn growth mechanisms resulting in heterogeneous Nb_3Sn coatings with low Q factors.

Using a combination of *in situ* ultra-high vacuum (UHV) surface science techniques, we aim to elucidate the spatially resolved Sn adsorption and diffusion behavior on oxidized Nb(100). Sample preparation and analysis was conducted in a custom built UHV experimental apparatus equipped with an electron beam (e-beam) evaporation source and quartz crustal microbalance (QCM), X-ray photoelectron spectroscopy (XPS), Auger electron spectroscopy (AES), scanning tunneling microscopy (STM), and scanning tunneling spectroscopy (STS) capabilities. Following deposition of 0.10 - 0.50 monolayers Sn, calibrated via QCM, on the (3×1)-O Nb(100) substrate, the initial Sn adsorption structure was determined using room temperature STM (RT-STM). The Sn/Nb(100) sample was then annealed at 500 ℃, 600 ℃, 700 ℃, 800 ℃, and 900 ℃ to promote Sn diffusion at temperatures relevant to the production of actual Nb_3Sn SRF cavities. RT-STM analysis following the annealing procedure revealed the formation of temperature dependent Sn adlayers on the (3×1)-O Nb(100) surface. Ongoing experimental and computational work is investigating the thermodynamic and kinetic parameters influencing the formation of the observed Sn adlayers on (3×1)-O Nb(100). The spatially resolved mechanistic information gleaned through this work is essential to guide the development of predictive Nb_3Sn growth models advancing current Nb_3Sn growth procedures.

Primary authors: FARBER, Rachael (University of Chicago); WILLSON, Sarah (University of Chicago); SIBENER, Steven (University of Chicago)

Co-authors: SITARAMAN, Nathan (Cornell University); ARIAS, Tomas (Cornell University)

Presenter: FARBER, Rachael (University of Chicago)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **30** Type: **Oral presentation**

Electrochemical Bronze-Route Nb3Sn for SRF Cavities

Thursday, 12 November 2020 09:00 (20 minutes)

Electrochemical methods are presented to prepare substrates, deposit Nb and bronze coatings, and set up reactions for Nb3Sn for a potential application in SRF cavities. Specifically, this paper presents firstly our understanding on the electrochemical mechanisms that hinder the proper preparation of substrate and coating layers and secondly methods of overcoming such limitations developed in our research. While the bronze route demands the surface preparation of Cu-Sn alloy, preferably using electropolishing, it is found to be impossible because electrochemical properties of Cu-Sn alloy, which are significantly different from those of pure copper by the presence of Sn, leads to the formation of a surface layer consisting of tin oxides and tin salts, notable tin phosphate, tin sulfate, tin chlorate, and tin chromate. These compounds have a formation energy lower in the electrochemical sequence compared to copper and copper salts, making it impractical to avoid the spontaneous formation of these surface contaminants during electropolishing. On the other hand, electroplating of a bronze thin film on niobium substrate as well as other metallic substrates, an alternate possibility of Nb3Sn cavity structure, is found to be possible by the use of either sequential deposition Cu/Sn layers or co-deposition of Cu-Sn alloy on Nb. Finally, successful plating of Nb on bronze was achieved through understanding of disproportionation reactions related to niobium ions, implementation of non-aqueous solution methods, and prevention of the chemical mechanism contaminating the Nb electrodeposits. For the first time in history, we were able to produce metallic Nb coating with quality sufficient to be considered for SRF applications. A model structure mimicking the Nb3Sn SRF cavity has been under construction by using all electrochemical processes, highlighting results of which will be presented.
This work is supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics under Award No. DE-SC 0018379. A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. DMR-1644779 and the State of Florida.

Primary author: KIM, Choong-Un (Univ. of Texas at Arlington)

Co-authors: Mr NI, Geng (University of Texas at Arlington); Mr BUTTLES, John (Bailey Tool); Dr WITHANAGE, Wenura (National High Magnetic Field Laboratory,); Prof. COOLEY, Lance (National High Magnetic Field Laboratory and FAMU/FSU College of Engineering)

Presenter: KIM, Choong-Un (Univ. of Texas at Arlington)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **31** Type: **Oral presentation**

Ultramet Thin-film CVD Nb3Sn Coating Process Development for Copper SRF Cavities

Thursday, 12 November 2020 11:00 (20 minutes)

Ultramet, an industry leader in the manufacture of refractory metal and ceramic components by chemical vapor deposition (CVD) and chemical vapor infiltration (CVI), continues to investigate and adapt CVD-based methods for the production of advanced high-gradient capable superconducting radiofrequency (SRF) cavities and components to meet the needs of the accelerator community. Ultramet researchers will provide a summary of all the Department of Energy (DOE)-funded, SRF-related Ultramet research efforts to date. The presentation will include an overview of ongoing work with Cornell's SRF Group and researchers at Florida State University's MagLab to develop thin-film CVD Nb3Sn-on-copper SRF accelerator cavities.

Primary authors: Mr MCNEAL, Shawn (Ultramet); Mr ARRIETA, Victor (Ultramet)

Presenter: Mr MCNEAL, Shawn (Ultramet)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **32** Type: **Oral presentation**

Deconvoluting Initial Nb-Sn-O Interactions: Spatially Resolved Electronic Characterization of Sn Reconstructions on (3×1)-O Nb(100)

Wednesday, 11 November 2020 11:05 (20 minutes)

The potential for lowered operating costs and higher quality factors (*Q*) motivate efforts to implement Nb₃Sn based superconducting radio frequency cavities. These benefits are contingent upon the continued optimization of coating procedures resulting in smooth, homogeneous A15 Nb₃Sn films. Specifically, the efficiency of Nb₃Sn cavity coatings is limited by the presence of surface defects including micron scale surface roughness and atomic dislocations such as Sn desegregation, high grain boundary density, and the persistence of surface oxides and subsurface oxygen. Fabricating pristine Nb₃Sn coatings requires a thorough understanding of the surface chemistry driving Nb₃Sn growth. Experimental data that outlines fundamental Nb-Sn-O surface interactions and Nb₃Sn alloying mechanisms would not only augment theoretical models detailing the superconducting and electronic consequences of various Nb₃Sn defects, but ultimately inform cavity Sn deposition procedures.

The atomic-scale interactions guiding Sn adsorption and diffusion behavior on oxidized Nb are probed using a well characterized (3×1)-O Nb(100) metal single crystal surface. An ultra-high vacuum chamber equipped with an electron beam evaporation source and quartz crystal microbalance, for precise metal deposition, paired with scanning tunneling microscopy/spectroscopy (STM/STS) enable in situ deposition, heat treatment, and analysis of the Sn/Nb interface. The (3×1)-O Nb(100) surface was exposed to precisely calibrated sub-monolayer (ML) quantities of Sn and was subsequently held at temperatures ranging from 500 − 900 ℃ to promote lateral Sn diffusion. STM images taken between annealing treatments reveal the morphology of Sn aggregates and the underlying NbO ladders. Room temperature STS spectra reveal electronic distinctions between multiple Sn reconstructions and the underlying NbO surface, demonstrating the electronic consequences of Sn adsorption and diffusion on oxidized Nb with atomic-scale spatial resolution. Ongoing work aims to elucidate the distinct structural and electronic features of Sn reconstructions as a function of Sn atomic %, temperature, and length of heat treatment. In addition to the experimental data obtained through this work, concomitant efforts using machine learning algorithms will be used to support observed surface structures and phases. Experimental observations of Sn adsorption and diffusion on a (3×1)-O Nb(100) surface aids in deconvoluting the complex surface chemistry mediating Nb-Sn alloying dynamics and mechanisms during Nb₃Sn formation.

Primary authors: WILLSON, Sarah (University of Chicago); Dr FARBER, Rachael (University of Chicago); Prof. SIBENER, Steve (University of Chicago)

Co-authors: HIRE, Ajinkya (University of Florida); Prof. HENNIG, Richard (University of Florida)

Presenter: WILLSON, Sarah (University of Chicago)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **33** Type: **Oral presentation**

Nb3Sn 5-cell cavity qualification for Nb3Sn cryomodule

Friday, 13 November 2020 08:45 (25 minutes)

Two 1.5 GHz 5-cell accelerator cavities have been coated with Nb3Sn in JLab Nb3Sn cavity coating system. The cavities were qualified at 4 K in the vertical dewar test and are progressed towards their installation into a cryomodule. One of the cavities was used to study fundamental limitation of the coating material using two-mode excitation. Results from the fundamental study as well as the practical challenges in the construction of SRF cryomodule with Nb3Sn cavities will be presented.

Primary author: Dr EREMEEV, Grigory (FNAL)

Co-authors: PUDASAINI, Uttar (Jefferson Lab); REECE, Charles (Jefferson Lab); REILLY, Tony (Jefferson Lab); PILIPENKO, Roman (Fermilab); MACHA, Kurt (Jefferson Lab); FISCHER, John (Jefferson Lab); BICE, Damon (Fermilab)

Presenter: Dr EREMEEV, Grigory (FNAL)

Session Classification: Performance

Track Classification: Performance

Contribution ID: **34** Type: **Oral presentation**

Ab Initio Calculations on Point Defect Thermodynamics in Nb_3Sn

Tuesday, 10 November 2020 09:10 (20 minutes)

Point defects play a critical role in Nb_3Sn superconducting radio frequency (SRF) cavity physics. Using *ab initio* techniques, we can calculate key properties of defects including formation and interaction free energies, hopping barriers, and their effect on T_c. Here we will focus on the experimentally-relevant cases of antisite defects and oxygen and hydrogen interstitial impurities. Based on our results, we can better understand why defects may occur at high concentrations in the material as has been observed experimentally, and what the consequences of high defect concentrations might be for SRF performance. Furthermore, we consider how changes to the Nb_3Sn coating process could alter defect behavior in the growing layer, resulting in more homogeneous layers and better performance.

Primary author: SITARAMAN, Nathan

Co-authors: ARIAS, Tomas; KELLEY, Michelle (Cornell); SUN, Zeming (CLASSE); LIEPE, Matthias; PORTER, Ryan; BARAISSOV, Zhaslan; MULLER, David; FONSECA, André (Cornell University)

Presenter: SITARAMAN, Nathan

Session Classification: Fundamental Studies

Track Classification: Fundamental Studies

Contribution ID: **35** Type: **Oral presentation**

Development of Nb3Sn cavity by vapor diffusion method at IMP

Friday, 13 November 2020 08:00 (20 minutes)

The progress in the development of Nb3Sn cavity coating by vapour diffusion method at IMP was reported. Several 1.3GHz single cell cavities were coated and vertically tested. Up to now, the unloaded Q value of IMP Nb3Sn cavity at 4.2K reached 7.6e9 at the low field region, which is about three times lower than the Cornell results. Meanwhile, the quench field was only Eacc=8MV/m. Although the superconductivity of the IMP Nb3Sn sample determined from the M-T measurement by DC magnetic field starts at 18.05K (when the magnetic moments of the sample began to decrease rapidly), it finishes at about 17.30K (when the magnetic moments of the sample began to stabilize at a minimum value). The transition width is as large as about deltaTc=0.75K, which is much larger than deltaTc=0.12K of the Cornell sample. The upgradation of the deposition system attempted to minimize the carbon contamination has been completed and the progress of the new coating work is discussed.

Primary author: YANG, Ziqin (Institute of Modern Physics, Chinese Academy of Science)

Presenter: YANG, Ziqin (Institute of Modern Physics, Chinese Academy of Science)

Session Classification: Performance

Track Classification: Performance

Contribution ID: **36** Type: **Oral presentation**

Magnetron sputtered Nb3Sn and V3Si thin films on copper substrates for SRF application

Thursday, 12 November 2020 10:35 (25 minutes)

In this contribution, we explore the growth of thin superconducting (SC) films, such as Nb3Sn and V3Si, on copper as possible candidates for the reduction of the operational surface resistance of superconducting radio-frequency (SRF) coated cavities for particle accelerators.

For an optimal SRF performance, the SC layers, grown using magnetron sputtering, have to be free of any contamination and as dense as possible. We will show that while for Nb3Sn a barrier layer of Ta is required in order to avoid any Cu intermixing into the superconducting layer, no barrier layer seems to be required for the growth of V3Si. The latter would be great interest for scale up purpose in order to minimize the number or sputtering targets to be used in a real cavity.

For Nb3Sn, the attempts to densify the coatings using high power pulsed magnetron sputtering will be discussed. For the V3Si/Cu system, the different approaches to the growth protocol will be exposed and proofs of the achieved superconductivity in these layers will be shown.

Primary author: Dr FERNANDEZ, Stephanie (CERN)

Co-authors: Dr ROSAZ, Guillaume (CERN); Dr ILYINA, Katsyarina (CERN); Dr ARZEO, Marco; Ms FONNESU, Dorothea (CERN); Dr VEGA CID, Lorena (CERN); Dr BENCAN, Andreja (Jozef Stefan Institute); Dr BARIS, Adrienn (CERN); Mrs PEREZ-FONTENLA, Ana-Teresa (CERN); Prof. CERNY, Radovan (University of Geneva); Dr CALATRONI, Sergio (CERN); Mr VOLLENBERG, Wilhelmus (CERN); Dr VENTURINI-DELSOLARO, Walter (CERN); Dr TABORELLI, Mauro (CERN)

Presenter: Dr FERNANDEZ, Stephanie (CERN)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **37** Type: **Oral presentation**

Tunneling Spectroscopy studies of Nb3Sn for SRF cavities

Tuesday, 10 November 2020 10:25 (20 minutes)

Tunneling spectroscopy measurements were carried out at ANL and CEA on Nb3Sn/Nb samples made at Cornell and FNAL with différent growth conditions. We find a linear correlation between the average gap extracted from maps of the Density of states few hundreds microns of lateral size and the corresponding RF cavity tests made under the same conditions as the samples.

Primary author: PROSLIER, thomas (CEA)

Co-authors: LIEPE, Matthias; POSEN, Sam (FNAL); HALL, Daniel (Cornell U.); GROLL, Nikolas

Presenter: PROSLIER, thomas (CEA)

Session Classification: Fundamental Studies

Track Classification: Fundamental Studies

Contribution ID: **38** Type: **Oral presentation**

Physical Vapor Deposition of Bronze-Route Nb3Sn for SRF Cavities

Thursday, 12 November 2020 08:20 (20 minutes)

We have investigated Nb3Sn film growth via bronze route by magnetron sputtering of Nb films on to bronze substrates for potential application in SRF cavities. Two main routes were followed: 1) deposition of 500 nm equivalent Nb onto hot (650 ℃ to 775 ℃) bronze substrates, where Nb3Sn formed during the Nb deposition; 2) deposition of Nb onto bronze substrates at lower temperature (200 ℃) with a follow up reaction heat treatment (650 ℃ – 775 ℃). Control of oxidation is paramount, since oxidation at the Nb-bronze interface blocks the Nb-Sn diffusion reaction, in addition to consumption of the intended coating by niobium oxides. Residual impurities P and S have deleterious effects similar to oxidation. Cu-15%wt Sn and Cu-15%wt Sn – 0.3%wt Ti bronzes with zero P were used as the substrates. Nb3Sn coatings obtained by both routes show surface roughness < 15 nm within regions defined by the bronze grain structure. Critical temperature of 14–16.5 K is obtained for films with 22 - 26% Sn, indicating a loss of ~2 K due to elastic compression of the Nb3Sn since thermal contraction is dominated by the bronze. Samples made via route 1 showed relatively large columnar grains with the length of the film thickness while samples made using the route 2 showed smaller grains. Both samples did not show any cracks in the Nb3Sn film even after a thermal cycle from room temperature to 4.2 K. Management of thermal expansion mismatches is a key challenge going forward, and adaptations using more complicated methods are ongoing.
This work is supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics under Award No. DE-SC 0018379. A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. DMR-1644779 and the State of Florida.

Primary authors: Dr WITHANAGE, Wenura (Applied Superconductivity Center, NHMFL-FSU); Mr JULIAO, Andre (Applied Superconductivity Center, NHMFL-FSU); Dr BALACHANDRAN, Shreyas (Applied Superconductivity Center, NHMFL-FSU); Mr REIS, Christopher (Applied Superconductivity Center, NHMFL-FSU); Mr ZHANG, Shengzhi (NHMFL-FSU); Dr PARK, Wan Kyu (NHMFL-FSU); Mr BUTTLES, John (Bailey Tool); KIM, Choong-Un (Univ. of Texas at Arlington); Dr LEE, Peter (Applied Superconductivity Center, NHMFL-FSU); COOLEY, Lance (Applied Superconductivity Center, NHMFL, Florida State University)

Presenter: Dr WITHANAGE, Wenura (Applied Superconductivity Center, NHMFL-FSU)

Session Classification: Growth Studies

Track Classification: Growth studies

Contribution ID: **39** Type: **Oral presentation**

Time-Dependent Ginzburg Landau simulations to guide Nb3Sn SRF cavity development

Tuesday, 10 November 2020 08:25 (25 minutes)

Interest in Nb3Sn as a material for SRF cavities is driven by its potential to operate at higher temperatures with higher quality factors and accelerating fields. In practice, performance is limited by magnetic flux that is nucleated at defects and inhomogeneities on the scale of the superconducting coherence length. Because Nb3Sn has a small coherence length, it presents many fundamental material engineering challenges. To relate observed performance to ab initio material calculations and better guide development protocols, we use time-dependent Ginzburg-Landau simulations to understand the role specific types of inhomogeneities play in vortex nucleation and dissipation. We use a finite-element formulation that incorporates a variety of material-specific parameters that can vary both spatially and temporally. Our simulations mimic experimentally observed defects and inhomogenties in real Nb3Sn cavities, such as grain boundaries with and without Sn-segregation and Sn-depleted islands. We also explore temporal effects including flux expulsion during cooling and metastability at extremely high frequencies. I discuss the implications for Nb3Sn cavity development and performance.

Primary authors: TRANSTRUM, Mark; PACK, Alden; HARBICK, Aiden

Presenter: TRANSTRUM, Mark

Session Classification: Fundamental Studies

Track Classification: Fundamental Studies

Contribution ID: **40** Type: **Oral presentation**

Investigation of Local Nonlinear Microwave Response of Nb_3Sn in the Superconducting State

Tuesday, 10 November 2020 10:45 (20 minutes)

Superconducting Radio Frequency (SRF) cavities are being widely used in new generation particle accelerators, but their performance can be limited by surface defects which lead to cavity breakdown at high accelerating gradients. The microscopic origins of SRF cavity breakdown are still a matter of some debate. To study the electrodynamics of superconductors locally, a novel near-field magnetic microwave microscope was successfully built using a magnetic writer from a conventional magnetic recording hard-disk drive [1]. This magnetic writer can create an RF magnetic field, localized and strong enough to drive superconducting Nb into the mixed state, and may have sub-micron resolution. This probe enables us to evaluate the deleterious RF properties of surface defects under conditions experienced in the SRF cavity. We mainly study the 3rd harmonic response (P_{3f}) as a function of rf field amplitude (H_{rf}) and temperature (T). In previous experiments on bulk and thin film Nb surfaces we observed two different classes of nonlinearity, which we call Low-field and Periodic. The Low-field response is the intrinsic response of the sample due to dynamics of vortex semiloops [2] created by the magnetic writer [3]. In the Periodic case the response can be linked to the Josephson effect at or near the surface and is in good agreement with the nonlinear response expected from rf-current-biased Resistively and Capacitively Shunted Junction (RCSJ) model [4]. New results on a Nb_3Sn film show evidence for multiple superconducting transitions, including a phase with a transition temperature of about 5.5 K. The most prominent nonlinear response appears to be due to the intrinsic Low-field mechanism. We summarize our results in light of the materials properties of Nb_3Sn, and compare to those previously obtained on SRF-Nb materials.

Acknowledgement:
This work is funded by US Department of Energy / High Energy Physics through grant # DE-SC0017931 and the Maryland Quantum Materials Center.

[1] T. Tai, *et al.*, IEEE Trans. Appl. Supercond. 21, 2615-2618 (2011).
[2] Gurevich, *et al.*, Phys. Rev. B 87, 054502 (2013).
[3] Oripov, *et al.*, Phys. Rev. E 101, 033306 (2020).
[4] Oripov, *et al.*, Phys. Rev. Applied 11, 064030 (2019).

Primary authors: Dr ORIPOV, Bakhrom (University of Maryland); Mr WANG, Chung-Yang (University of Maryland); ANLAGE, Steven (University of Maryland)

Presenter: ANLAGE, Steven (University of Maryland)

Session Classification: Fundamental Studies

Track Classification: Fundamental Studies

Contribution ID: **41** Type: **Oral presentation**

Welcome

Tuesday, 10 November 2020 08:00 (5 minutes)

Presenter: LIEPE, Matthias

Contribution ID: **42** Type: **not specified**

Closeout

Friday, 13 November 2020 12:00 (5 minutes)

Contribution ID: **43** Type: **not specified**

Guided discussion: Most promising pathways to higher gradients – What do we think are the current limitations?

Friday, 13 November 2020 09:30 (15 minutes)

Presenter: REECE, Charles

Session Classification: Performance

Contribution ID: **44** Type: **not specified**

Guided discussion: First applications for Nb3Sn cavities – What performance demonstrations/milestones are needed to prove readiness?

Friday, 13 November 2020 11:50 (10 minutes)

Presenter: POSEN, Sam (FNAL)

Session Classification: Applications

Contribution ID: **45** Type: **not specified**

Guided discussion: Next fundamental studies needed for advancing Nb3Sn – What are the important open questions?

Tuesday, 10 November 2020 11:45 (15 minutes)

Presenter: TRANSTRUM, Mark

Session Classification: Fundamental Studies

Contribution ID: **46** Type: **not specified**

Guided discussion: Nb3Sn vapor diffusion growth: How does the Nb substrate impact growth?

Wednesday, 11 November 2020 11:45 (15 minutes)

Presenter: FARBER, Rachael

Session Classification: Growth Studies

Contribution ID: **47** Type: **not specified**

Guided discussion: Alternative Nb3Sn growth methods - What are the challenges and next steps?

Thursday, 12 November 2020 11:45 (15 minutes)

Presenter: Dr VALENTE-FELICIANO, Anne-Marie (JLAB)

Session Classification: Growth Studies