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EFFECTS OF CHEMICAL TREATMENTS ON THE SURFACE ROUGHESS AND SURFACE MAGNETIC FIELD EHANCEMENT OF NIOBIUM-3 TIN FILMS FOR SUPERCONDUCTING RADIO-FREQUENCY CAVITIES*

R. Porter†, F. Furuta, D. L. Hall, M. Liepe, and J. T. Maniscalco
Cornell Laboratory for Accelerator-Based Sciences and Education (CLASSE), Ithaca, NY, USA

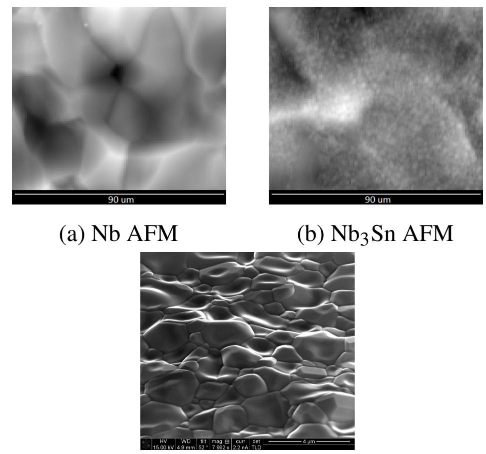
Abstract

Current niobium-3 tin (Nb_3Sn) films produced via vapor diffusion have rougher surfaces than typical electropolished niobium surfaces causing significantly enhancement of the surface magnetic fields. Reducing surface roughness of Nb_3Sn surfaces may be necessary to achieve higher gradient accelerator cavities with high Q. Previous work at Cornell has shown the impact of several chemical treatments on the surface roughness of Nb_3Sn films; however, it had not been evaluated how the changes in surface roughness impact the surface magnetic field enhancement. In this paper we present simulations of the surface field enhancement of oxipolished Nb_3Sn, which was shown to be effective at reducing the surface roughness of Nb_3Sn. The surface magnetic field enhancement data is compared to those of unetched Nb_3Sn to find that the surface magnetic field enhancement (and surface roughness) has been roughly halved.

INTRODUCTION

Current niobium-3 tin coated niobium produced at Cornell University using tin vapor diffusion [1–5] has a significantly rougher surface than conventional electropolished niobium (see Fig. 1) [6, 7]. Previous work has shown that this roughness can significantly enhance the surface magnetic field (1% of the surface has magnetic fields enhanced by at least 45%), possibly lowering the maximum achievable quench field or causing other deleterious effects [6]. This is further supported by high-pulsed power klystron testing done near T_c (see Fig. 2) that suggests the maximal achievable quench field of Nb_3Sn (extrapolated to 0 K) would be 230 mT [8]. This is much less than theoretical predictions of 400 mT [9]. However, if 1% of the cavity becoming normal conducting was sufficient to cause quench then the data suggests a maximal quench field (extrapolated to 0 K) of 330 mT, much closer to the theoretical superheating field.

Work is being done to find chemical treatments that can reduce the surface roughness and destroy possible surface defects without destroying the thin ($2-3\ \mu$m) Nb_3Sn surface layer [7, 10]. Recent results have found standard electropolishing and buffered chemical polish (1:1:2) to be ineffective for reducing the roughness of Nb_3Sn, but that oxipolishing



(a) Nb AFM (b) Nb_3Sn AFM

(c) Nb_3Sn SEM image.

Figure 1: Surface images of Nb and Nb_3Sn. Notice that the grain sizes of Nb_3Sn are on the order of microns, much smaller than Nb.

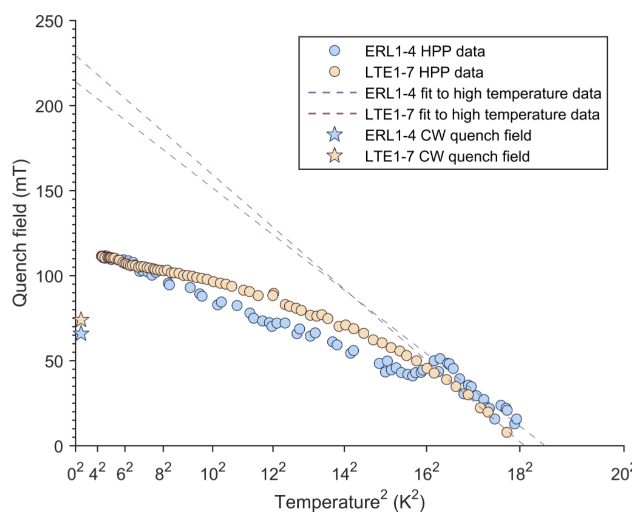


Figure 2: Plot of quench field (calculated from internal energy) versus T^2 from klystron high pulsed power measurements of Cornell Nb_3Sn cavities [8]

can half the surface roughness while etching away less than 1 µm (see Fig. 3) [7], with further reduction likely with additional polishing; however, it is has not been evaluated how this surface roughness reduction impacts the surface magnetic field enhancement. This paper uses surface height maps from Atomic Force Microscopy (AFM) to calculate

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† rdp98@cornell.edu

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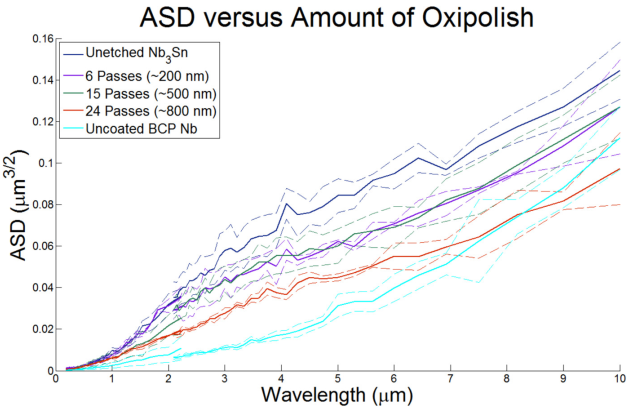

Figure 3: ASD of Nb_3Sn samples receiving different amounts of oxipolish. Approximate amount of removal listed.

the surface magnetic field enhancement of a surface etched using oxipolish and compares it to previous calculations for unetched Nb_3Sn.

METHOD

A Nb_3Sn sample that received 24 passes of 30 V oxipolish sample was used for this study (the surface roughness of the sample is shown in Fig. 3). In the oxipolish process the sample was anodized to 30 V in order to build up an oxide layer, then exposed to hydroflouric acid until the oxide was burnt off. This process was repeated 24 times removing $\approx$ 800 nm. After polishing, three 20 µm × 20 µm AFM scans of the surface were made to obtain surface height maps.

The method of calculating the surface field enhancement was previously described in [6] and a detailed description is provided there. Here we provide a brief summary of the technique.

In this method line segments (several microns long) from AFM surface scans of Nb_3Sn are rotated to make a rotationally symmetric 3D surfaces (azimuthal symmetry required by simulation code). This surface replaces part of the walls of a cavity model in an area where the magnetic field is fairly uniform (the end of cylindrical cavity in the TE111 mode).

The surface magnetic fields are calculated using SUPERLANS2 (SLANS2), a 2 D finite element eigenmode solver [11]. This code calculates non-azimuthally symmetric modes in azimuthally symmetric cavities. The surface magnetic fields are also calculated for a completely smooth geometry. The surface magnetic fields on the rough surface are compared to the surface magnetic fields for a smooth geometry (on the line through the center of the rough patch that is parallel to the magnetic field) and the surface magnetic field enhancement factor is computed[1] (see Fig. 4 for an example of surface magnetic field enhancements).

A procedure was followed to choose line segments: A cross section was taken through an AFM scan; a flat spot near

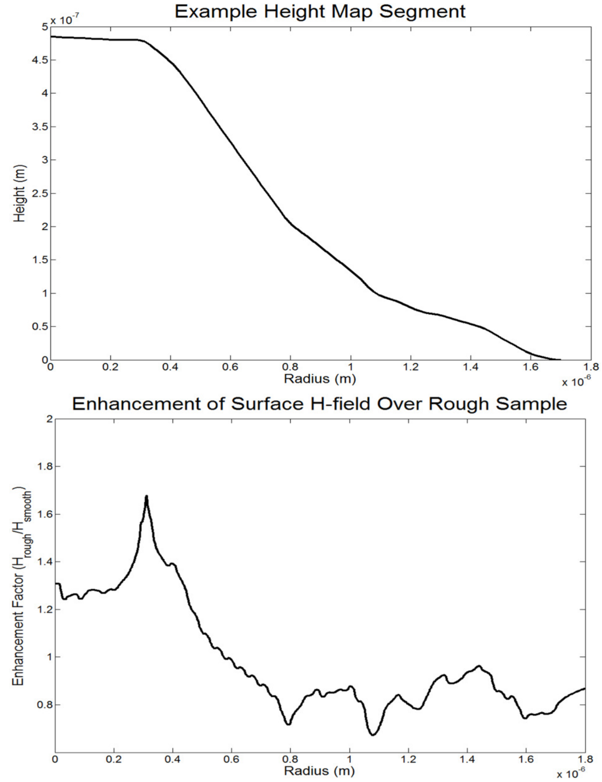

Figure 4: Top: A 1D AFM height map from an unetched Nb_3Sn surfaced used for simulating surface H-field. Bottom: The field enhancement found for the height map shown above [6].

the average height of the scan was chosen as one end point; the furthest flat point away from the first but within 11 µm was chosen for the second point (longer line segments often cause SLANS2 to fail); the cross section was moved 2.5 µm and another line segment was chosen. 23 line segments were used from three 20 µm × 20 µm AFM scans for the oxipolished sample (only 5 line segments were used from one of the AFM scans). For the unetched Nb_3Sn 20 shorter lines were used from two 20 µm × 20 µm AFM scans [6].

RESULTS AND DISCUSSION

The surface magnetic field enhancement data was binned and weighted by the total surface area[2] with magnetic field enhancement in that range.

A normalized histogram of the oxipolished Nb_3Sn data is shown in Fig. 5 along with the unetched Nb_3Sn data [6]. For the oxipolish Nb_3Sn, 10% of the points are over 1.08, 5% of the points are above 1.15 and 1% of the points are above 1.21. This is less than half the magnetic field enhancements found for unetched Nb_3Sn where 10% of the points are over 1.2, 5% of the points are above 1.29 and 1% of the points are above 1.45.

[1] The surface mangetic field enhancement, β, is calculated as: $\beta(r) = H_{\text{rough}}(r, h(r))/H_{\text{smooth}}(r, 0)$, where $H_{\text{rough}}(r, h(r))$ and $H_{\text{smooth}}(r, 0)$ are the surface magnetic fields on rough and smooth surface respectively.

[2] Because enhancement data was 1 D, it was actually weighted by length, but this should be equivalent to surface area.

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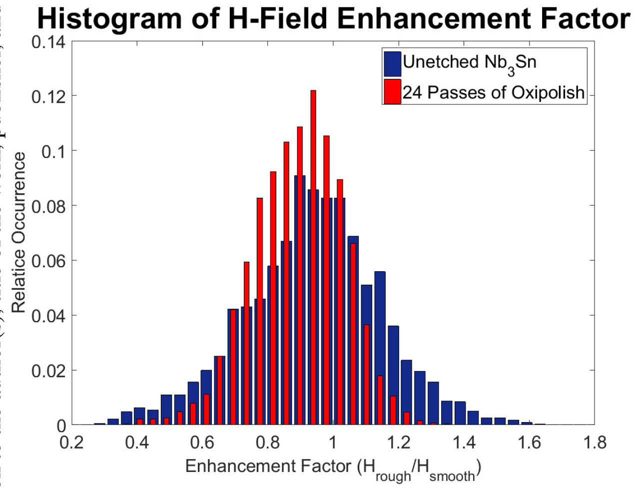

Figure 5: Histogram of relative area with a certain surface magnetic field enhancement factor of unetched and oxipolished Nb_3Sn.

The oxipolish histogram has a center of 0.914 ± 0.007(stat) while the histogram of the unetched sample has a center of 0.958 ± 0.011(stat). Having an average less than 1 is not unexpected as sharp peaks with a large surface magnetic field can depress the magnetic field over a large area, lowering the mean value of the enhancement factor. It is interesting that the oxipolished histograms center is less than the unetched samples' center. This could be due to unaccounted for systematic errors in our analysis, but could also be caused by etching changing the shape of the surface. If we shift the oxipolish histogram to have the same center as the unetched histogram, then 1% of the points are above 1.25.

CONCLUSION

Oxipolishing was able to roughly half both surface roughness and surface magnetic field enhancement of Nb_3Sn produced via tin vapor diffusion when used to etch 800 nm. For unetched Nb_3Sn 1% of the surface had surface magnetic field enhancement factors above 1.45; oxipolishing reduced this to an enhancement factor of 1.21. Only 800 nm of the 2 – 3 µm surface layer was removed, allowing for more oxipolishing to be done before Nb_3Sn layer becomes too thin. Additional oxipolishing may further improve results.

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