PARAMETER OPTIMIZATION FOR LASER POLISHING OF NIOBIUM FOR SRF APPLICATIONS

Liang Zhao[1,2], J. Michael Klopf [2], Charles E. Reece [2], Michael J. Kelley [1,2]
[1] Applied Science Department, The College of William and Mary, Williamsburg, VA 23187
[2] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

Abstract

Surface smoothness is critical to the performance of SRF cavities. As laser technology has been widely applied to metal machining and surface treatment, we are encouraged to use it on niobium as an alternative to the traditional wet polishing process where aggressive chemicals are involved. In this study, we describe progress toward smoothing by optimizing laser parameters on BCP treated niobium surfaces. Results show that microsmoothing of the surface without ablation is achievable.

BACKGROUND

Surface topography plays a role in SRF cavity performance [1]. Different surface treatment methods are adopted to obtain clean and smooth inner surfaces of niobium cavities. The commonly used buffered chemical polishing (BCP) removes material rapidly but leaves sharp features, which may cause performance limitations. A proposed field enhancement model [2] explains how such local sharp features affect performance of the whole cavity. Electropolishing (EP) is widely used to smooth out sharpness, but EP is relatively slow. Both of these chemistry methods involve using hazardous acids and have potential hydrogen absorption problems due to direct contact between the metal and an aqueous liquid. Laser polishing avoids wet chemistry and can be much faster due to its controllable high density of energy. In this study we show that laser polishing is experimentally achievable by applying the proper energy density (or fluence).

Laser polishing of metal surfaces began to be reported in the 1970's and several processing strategies have evolved since. A recent review presents the history, the fundamentals and the process applications [3]. The broad theme in laser polishing is that the laser energy melts some or all of the surface; levelling proceeds by melt flow under the influence of surface tension until solidification intervenes. The events may be viewed in terms of lower and higher energy density regimes, shallow surface melting (SSM) and surface over-melting (SOM), respectively [4]. In SSM, melting occurs at prominences and capillary forces cause the melt to diffuse into depressions. In SOM, a liquid layer covers the surface. While surface tension driven levelling proceeds, other mechanisms can give rise to oscillations manifested as regular ridge structures. As noted earlier, elimination of sharp features is the most important aspect of SRF surface topography modification.

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mkelley@jlab.org

EXPERIMENT

Laser Treatment System

The laser source was a Spectra-Physics High Intensity Peak Power Oscillator (HIPPO) tabletop laser. The wavelength used was 1064 nm. The beam was directed through a beam rastering and focusing system and into the UHV chamber of a PVD Products PLD-5000 System. The area of the focused laser spot on the sample was 7.84×10^{-5} cm^2 (96 μm x 104 μm FWHM). The repetition rate was 19 kHz, and the pulse width was 8 ns FWHM.

Niobium Sample

Samples of RRR grade niobium used for SRF cavity production were cut into 49 mm diameter discs with a thickness of 3.2 mm. The samples were treated in a 1:1:1 BCP solution (1 part hydrofluoric acid, 1 part nitric acid, 1 part phosphoric acid) for 1 minute, rinsed with de-ionized water, then air-dried. The samples were loaded in the PLD chamber and pumped down to ~ 10^{-7} - 10^{-8} Torr before laser polishing, as shown in Fig. 1.

Figure 1: Niobium samples on the sample holder in the PLD chamber.

Laser Treatment Parameters

Each niobium disk received 10 treatment tracks, each with different parameters. The 1st ring is the outer most ring and the 10th ring is the inner most ring. In this study, fluence (defined as energy per unit area per pulse) is the main parameter to be optimized. The fluence range reported here is from 0.18 J/cm^2 to 0.73 J/cm^2, and the corresponding laser power used ranges from 1.51 W to 6.00 W. The distance along the track between successive laser pulses (pulse displacement) was always 1.82 um, providing 53 pulses overlapped within one spot width. The beam travel speed was 34.2 mm/s, and the

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corresponding treatment rate was 3.6 mm^2/s. The target rotating speed was adjusted according to the pulse displacement requirement and ring diameter. The time per track was then calculated according to the target rotating speed. Table 1 lists the parameters used for setting up experiments.

Table 1: Parameters for Experiment

Ring number	Fluence (J/cm^2)	Laser power (W)	Target rotating speed (rpm)
1^{st}	0.73	6.00	17
2^{nd}	0.67	5.50	18
3^{rd}	0.61	5.00	20
4^{th}	0.55	4.50	22
5^{th}	0.49	4.00	25
6^{th}	0.43	3.50	28
7^{th}	0.37	3.00	32
8^{th}	0.30	2.50	38
9^{th}	0.24	2.00	46
10^{th}	0.18	1.51	59

Characterization

Optical microscopy and atomic force microscopy (AFM) were used to exam the laser polished samples. Topography and roughness information was obtained by AFM. Power spectral density (PSD) analysis was calculated from the AFM data for detailed roughness information, using the method described in article [5].

RESULTS

Figure 2 is a sample with laser treated rings. For most of the rings, the laser tracks were clearly visible by eye, which typically corresponds to damaging of the surface. The inner most three rings show only a faint difference in the reflection but no grooves into the surface. They are not as obvious as the others; however, they are more reflective than the others if examined carefully.

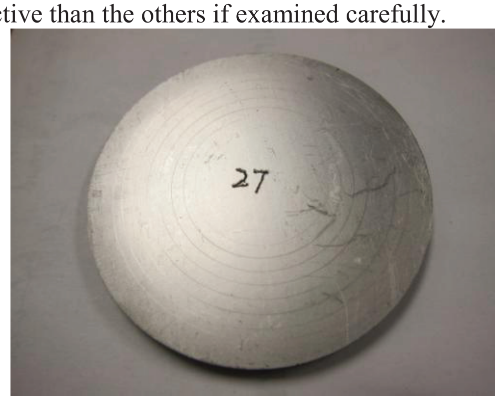

Figure 2: A niobium sample with laser polished rings on the surface.

Table 2 shows measurements of roughness and topography change due to laser polishing on the inner most three rings.

In Fig. 3, AFM images of the locations with and without laser polishing are shown. The scanning areas were 25 um x 25 um. In Figure 3(a), an AFM scan of the untreated disc center shows the surface of a BCP treated sample before laser polishing. The characteristic sharp edges from the BCP process are clearly observed. The surface in Figure 3(b) was treated by 0.3 J/cm^2 fluence. Grooves were visible by eye on the surface and ripples can be seen under microscope in some parts of the laser treated ring. This is an example of over treatment with excessive laser fluence. The reason for ripple production is not clear yet, but is possibly due to overheating. With fluences above 0.3 J/cm^2, the surface was obviously damaged rather than polished. The AFM scans in Figure 3(c) and 3(d) were treated by 0.24 J/cm^2 and 0.18 J/cm^2 respectively, and for these laser treatments, the sharp edges were completely removed and the transition at grain boundaries were smooth as well. When the fluence goes too low, the surface was not melted enough to smooth out the fluctuation.

Table 2: Surface Roughness Before and after Laser Polishing

Ring number	Fluence (J/cm^2)	RMS roughness (R_q) (nm) 25um area	RMS roughness (R_q) (nm) 50um area
center of sample	0 (no laser applied)	177.1	338.1
8^{th}	0.30	260.3	390.0
9^{th}	0.24	169.8	248.2
10^{th}	0.18	234.5	242.2

To better analyze the surface topography, we used PSD analysis, which provides a detailed description about contributions to the RMS roughness by different frequency components on the surface [5]. Amplitude from features of different scales is plotted as a function of spatial frequency. Surfaces with sharp edges (like BCP treated surfaces) usually show a straight line on the logarithmic PSD plot, while smoother surfaces (like EP surface) shows a curved PSD plot with two distinguishable stages.

The smoothing effect from laser polishing is similar to that of electropolishing (EP) in terms of the PSD analysis [5], as shown in Fig. 4. At high spatial frequency range from about $3x10^{-4}$ nm^{-1} to $1x10^{-2}$ nm^{-1}, which equates to 0.1 um to 3.33 um, the PSD of polished surface is lower than that of the original BCP surface.

At 0.18 J/cm^2, the ring became so narrow that it was difficult to locate. This may be due to the Gaussian shape of the laser beam, where the energy is highest at the center and decreases gradually towards the edge. Fluence around 0.24 J/cm^2 produces the best range of polishing for a treatment of ~ 50 laser pulses per unit area of Nb surface. Studies of the effect of the number of laser pulses per unit area and different rastering recipes are ongoing.

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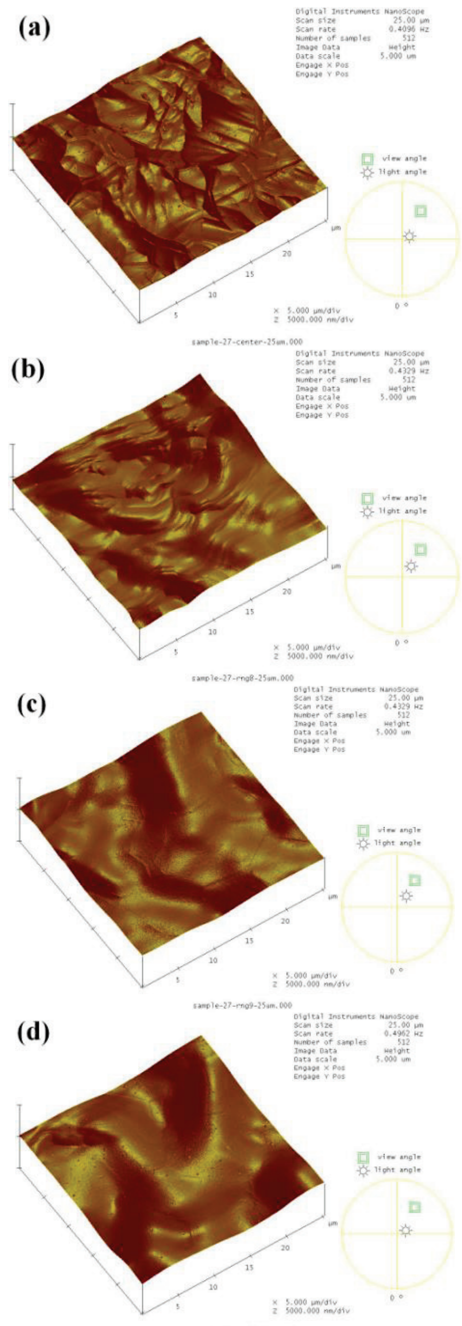

Figure 3: AFM images of starting BCP surface (a), after 0.3 J/cm^2 laser treatment (b), after 0.24 J/cm^2 laser treatment (c), and after 0.18 J/cm^2 laser treatment (d).

CONCLUSION

- By selection of the proper parameters, laser smoothing is achievable.
- A laser treatment of 53 pulses per spot width and a fluence of ~ 0.18 - 0.24 J/cm^2 is sufficient to melt the surface without damaging it. Microscopy shows that sharp edges are removed, as well as the step at grain boundaries. However, over-treating can result in larger surface waviness.

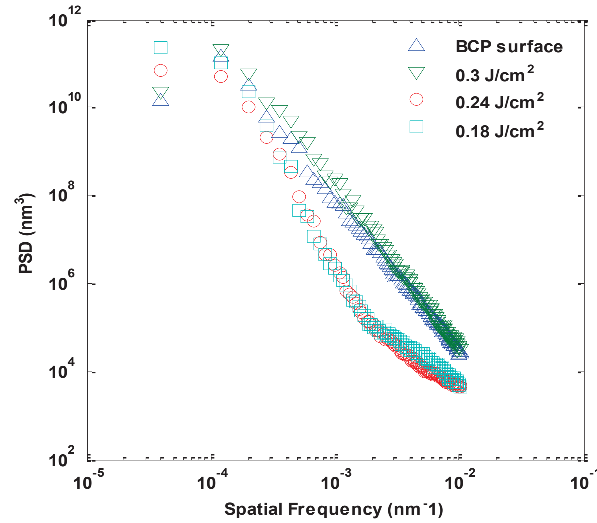

Figure 4: Comparison of topographic PSD of BCP and laser polished (LP) surfaces.

- Laser polishing is a promising candidate for surface polishing in the pursuit of environment friendly and fast treatment methods.
- Engineering realization of laser polishing on cavity interior is foreseeable with the latest progress in cavity calibrated optical profilometry system (CYCLOPS) at JLab, which is able to optically map and profile the entire inner surface of a cavity with precise control [6].

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