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STUDY ON THE LASER TREATMENT OF Nb AND Nb_3Sn THIN FILMS ON COPPER SUBSTRATE WITH A kW NANOSECOND FIBER LASER

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Abstract

Surface annealing using intense nanosecond laser pulses is an emerging technique for SRF cavities. This technique can effectively reduce the cavities' surface defects and improve their RF performance. However, previous studies in this field limited themselves on solid state lasers or gas lasers, which have very low average power and are not practical for processing actual SRF cavities with ~m^2 inner surface area. IMP innovatively built a practical whole-cavity processing system with a kW-level nanosecond fiber laser, which is designed to process an SRF cavity within a working day. In this work, the system design and feasibility analysis will be given, together with the comparison between pristine Nb thin film sam-ples and Nb_3Sn on copper substrates and their fiber laser processed counterparts. The results show that our fiber laser system can deliver comparable surface treatment as that from the solid-state laser system, but with higher efficiency. The authors believe such results could boost the application of laser surface annealing technique in the particle accelerator community.

INTRODUCTION

Conventional superconducting cavities are developed by bulk niobium, which is a material of its own the ther-mal conductivity of niobium at 4.2 K (100 W/m·K) [1-2] is much lower than that of copper (600 W/m·K). The ther-mal conductivity of niobium at 4.2 K (100 W/m·K) is much lower than that of copper (600 W/m·K). The Nb cavity is thick (about 3-4 mm) and the thin-walled cavity is very sensitive to the external environment, resulting in poor mechanical stability. This leads to poor mechanical stability. Therefore, the pure niobium superconducting cavity suffers from mechanical instability. In order to solve these problems, researchers combined the high mechanical stability and high thermal conductivity of the thick copper substrate with the good low-temperature RF properties of pure niobium. Some researchers[3] found that the Q-slope[4-5] phenomenon is related to the quality of the niobium film and that the presence of the niobium film on the surface of copper based niobium thin film cavity surface with defects in the niobium films, large surface roughness, and the problems such as excessive grain boundaries. The above factors limit the RF super-conductivity of the niobium-plated cavities.

Nb_3Sn has a higher Tc and Hsh compared to niobium, and can reach a theoretical acceleration gradient of 100 MV/m, but it also face a severe Q-slope. For the above problems, surface treatment is needed to reduce defects and thus improve RF performance.

The use of traditional surface treatment methods (EP, BCP) is not only dangerous, but also easy to introduce impurities and oxidation. Therefore, we want to use laser surface treatment[6-7] to replace the traditional treatment. The laser has self-cleaning ability, high safety and high efficiency. For thin films, its heat affected layer is shallow and more suitable for surface treatment of thin films.

EXPERIMENTAL SETUP AND METHODS

Preparation of copper-based niobium samples using magnetron sputtering and copper-based niobium tri-tin samples using the bronze method. Laser processing using a kW nanosecond fiber laser system built by IMP.

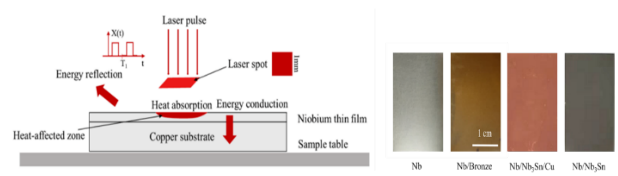

Figure 1: (left) Laser annealing schematic. (right) Diagram of the heat treatment process for Nb/Bronze precursors.

RESULTS AND DISCUSSION

A field emission scanning electron microscope and atomic force microscopy were employed for the observations of the Nb_3Sn thin film surface morphology. Ele-mental compositions of the Nb_3Sn thin film were ob-served by energy dispersive spectroscopy (EDS, Oxford X-max 80). Crystalline property and orientation of films were determined by x-ray diffractometer (XRD) with Cu Kα radiation (λ = 0.1542 nm).

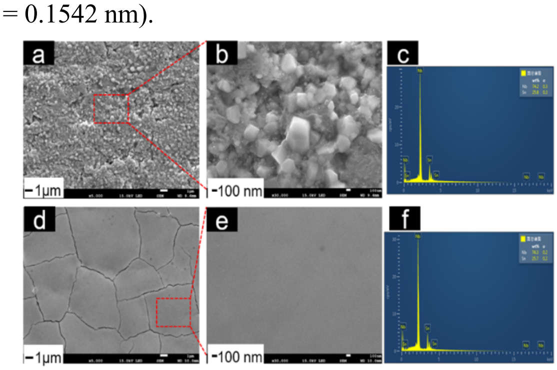

Figure 2: SEM image of the surface of Nb_3Sn-coated Nb samples. (a and b) untreated; (d and e) laser Annealing.

The surface morphologies of the initial and laser an-nealing samples are shown in figure 1. As can be seen in Fig.2 a-b, the Nb_3Sn particles was formed by heterogene-ous aggregation of sub-micro sized particles including some

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voids. The surface smoothness and uniformity are poor. The surface of the sample treated by laser annealing has no particle structure and is more uniform (Fig.2 d-e). The surface cracked due to the presence of stress. The laser annealing process readily induced mi-crocracks or quasi-microcracks on the Nb_3Sn thin film due to the residual tension stress of crystalline phase transformation between irradiated and non-irradiated areas. EDS results (Fig.2c and 2f) show that the chemical composition of the Nb_3Sn films after laser annealing does not change, and the content of low melting point tin does not decrease.

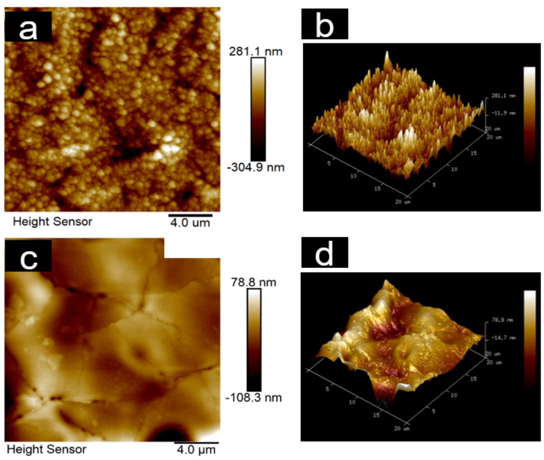

Figure 3: AFM image of the surface of Nb_3Sn-coated Nb samples. (a and b) untreated; (c and d) laser Annealing**.**

A typical topographic scan measured by means of AFM for the Nb_3Sn sample was given in figures 3. The spherical precipitates can be clearly and distinctly seen, in accordance with the SEM results. Through statistical analysis, the average size was in good agreement with the average size of the precipitates detected by the SEM. The root-mean-square roughness of the untreated and laser annealing Nb_3Sn samples measured over an area of 16*16 μm^2 was 59 nm and 18 nm, respectively. The results indi-cate laser annealing can remelt the film and improve the flatness and uniformity.

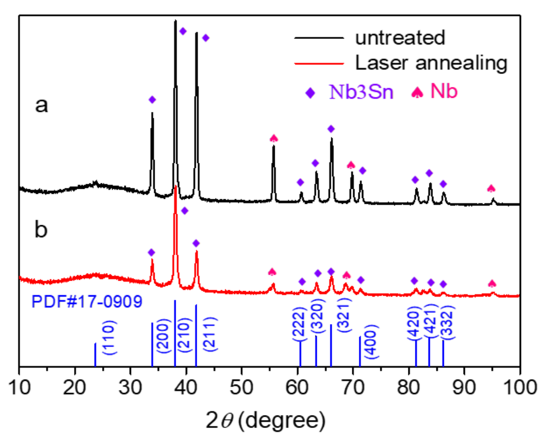

Figure 4: GIXRD patterns of Nb_3Sn-coated Nb samples. (a) untreated; (b) laser Annealing.

To acquire a better understanding of the superficial chemical composition and physical structure change caused by laser annealing, crystallographic information of Nb_3Sn samples was obtained from GIXRD measurement and the results are shown in Fig. 4. The diffraction reflexes all belong to Nb_3Sn. In Fig.4b, the GIXRD pattern of the laser annealing sample is displayed, from which the diffraction reflexes for Nb were still seen but with smaller peaks intensity, which was attributed to the thermal-induced crystal growth, as can be seen in the SEM images presented in figure 3(d).

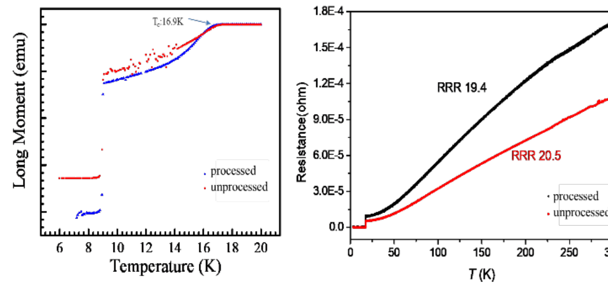

Figure 5: M-T and R-T measurement of the sample

The test of superconducting properties is not very satisfactory, and the difference between laser treated and untreated samples is not significant. The main reason is due to the large cracks generated after treatment as can be seen in Figure 2(d).

CONCLUSION

Laser treatment methods can effectively reduce surface defects and improve the surface condition of the material. As a new surface treatment method, its high efficiency and cleanliness are expected to make it the standard post-treatment method for superconducting cavities in the future.

We can achieve the replacement of traditional post-processing methods with laser processing methods, but the laser processing technology is not yet mature and needs to overcome the technical defects caused by cracks.

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