Superconducting Films Deposition for RF Cavities

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A new technique of mechanically polishing the Pb/Sn surfaces and then re-plating has been successfully explored. The twelve split loop resonators for the ANU LINAC have been re-plated achieving average acceleration field of 3.5 MV/m off-line. The Pb-Sn plating exercised on the existing SLRs will be extended to the two-stub cavity to quickly explore the superconducting performance of the new geometry. The plating process will be improved by: the exploration of the reverse polarity of the plating cycle to enhance its electro-polishing action; increasing current density at final stage to produce a small grain deposit and exploring use of kW ultrasonic transducer to improve the condition of the substrate. The Nb coating will be pursued at later stage.

1. Introduction

The current technologies to deposit Nb film onto copper substrate is readily applied to simple RF structures but is not feasible for complex geometries like Split Loop Resonators (SLRs). On the contrary Pb-Sn plating provides fast adequate results with modest equipment and at relatively low cost. In 1998 ANU adopted MSA chemistry, motivated by the successful plating at SUNY [1], and re-plated all twelve SLRs by November 2002. This increased the ANU booster energy gain by almost 100%.

A detailed account of SLR related plating technology at ANU is given in ref [2]. Since efforts are now devoted to the development of the low velocity two-stub resonators (DVOIKA), the Pb-Sn plating expertise will be extended to the DVOIKA to quickly explore the superconducting performance of the new geometries.

2. Lead-tin plating SLRs

In the accelerating mode for SLRs, the surface charge oscillates along the ring between the beam drift tubes. The Micro Wave Studio (MWS) calculated electric field distribution is shown in Figure 1 (left). The peak surface electric field occurs at the end of each drift tube. The ratio E_p/E_{acc} is 6.5 for MWS simulation, which appears to be 34% higher compare to experimental figure reported in [3]. The MWS calculated distribution of magnetic field and surface current in SLR is shown in Figure 1 (right). The maximum H field occurs almost in the middle of the internal surface of the half loop. Its precise location is quite sensitive to the curvature of the conductor. A typical ratio B_p/E_{acc} of 17.7 mT/MV/m was calculated with MWS simulation as compare to 10.5 mT/MV/m given in [3].

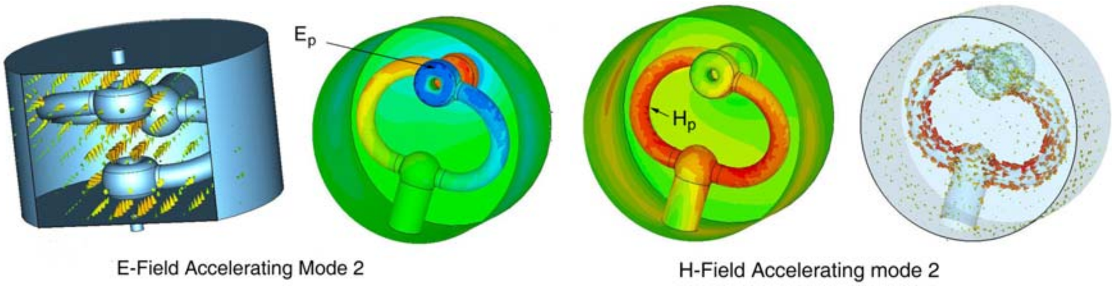

Figure 1. Low frequency accelerating mode for distributions of E-Field and H-field in SLR.

Both E- and H-field distributions should be used to identify the most important surface areas exposed to RF fields. For instance the superconducting coating deposited onto high E-field surfaces should be a smooth mirror-like surface in order to reduce field emission threshold. Similarly the quality of deposit onto the loop arms, which caries the highest current density is also critical.

In the electro-deposition process, a number of high-temperature ad-atoms migrate over the substrate surface forming a solid film [4]. Low melting point metals like Pb and Sn take a long time to solidify and the corresponding surface diffusion distance is long resulting in formation of large grains. The film purity also changes the diffusion distance of ad-atoms and thus affects the grain size. The purer the film, the larger the grain size. In summary, the grain size of low melting point metals is large, whereas that of high melting point metals is small. For low melting point metals, the surface roughness is proportional to the grain size. For high melting point metals the primary factor in the development of surface roughness is the current density distribution over the surface. Protrusions form sites where the metal ion discharge is concentrated. The size and distribution of these protrusions thus formed determine the final surface roughness. An increase in the solution temperature makes the protrusions large and vice versa. Solution agitation also affects the surface morphology. At low metal concentration/high current density or at low current density a dendrite can be generated. An individual dendrite is generally a single crystal but it may be an assembly of fine grains. Usually the film starts as a uniform layer and then a dendrite forms on top of this layer. After the initial layer formation, a metal-ion denuded zone of variable thickness is created over the substrate. Metal ions will be supplied preferentially through a thin region. Dendrites nucleate in such regions and their growth will be accelerated through the tips where the current density and temperature are very high.

3. Results

Different combinations of the plating procedures were investigated thoroughly over the past few years using the SLOTOLET lead-tin plating bath. The crucial steps were: lead-tin film is deposited at 2.5 mA/cm^2 for a film thickness of 1.5 μ; hand polishing of existing or freshly deposited lead with wipes and alcohol instead of stripping the lead; water rinse thoroughly with de-ionized, high pressure water; 15 second soak in plating solution; de-plating at 1.5 mA/cm^2 for 30 seconds; immediately reverse pulse plating at 2.5 mA/cm^2 for 7 minutes. Forward time is 5 seconds and Reverse time is 0.5 seconds.

Re-plated SLR and a SEM image of a sample deposit produced using this procedure are shown in figure 2.

Figure 2. Re-plated SLR and microstructure of deposit produced using the adopted plating procedure

This procedure has proven to be successful in re-plating ANU SLRs including few resonators with cracks in electron-beam weld. The new technique of mechanically polishing the unsatisfactory Pb surface and then re-plating, rather than chemically stripping the old Pb and hand polishing the Cu substrate, is enormously easier, faster and doesn't put at risk thin electron beam welds or repaired ones. It takes one week to re-plate three SLRs, three times faster than the old process. The re-plating using the hand polishing surface treatment and reverse pulse plating technique has yielded resonators with accelerating field of greater than 3.5 MV/m at 6 W during on-line test. The Q's at 6 watts are at or above 10^8. The best resonator, achieved E_{acc} about 3.9 MV/m at 6 Watts on-line, figure 3.

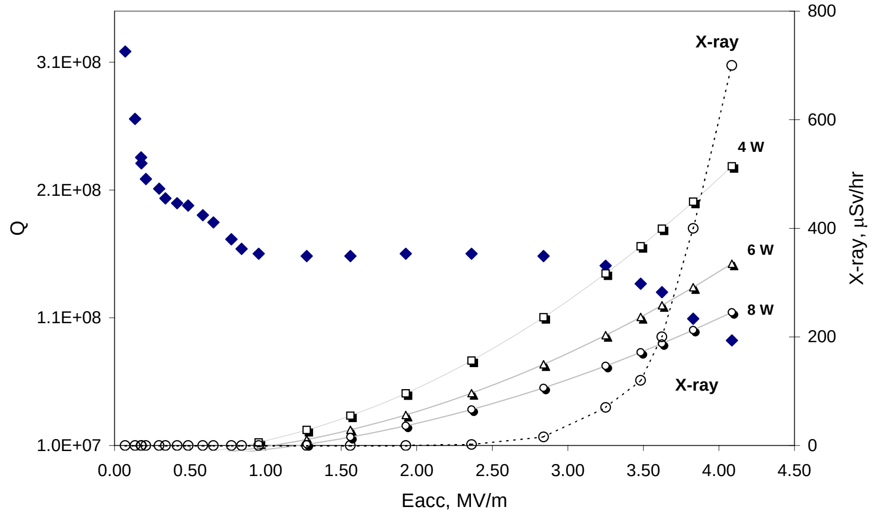

Figure 3. Q vs. E_a curves of the best ANU SLR re-plated using the Slotolet MSA process

The Q falls at low power levels from 0.2 to 2 Watts probably due to RF losses in gasket. It typically remains constant from 2 W up to 6-7 Watts following by another sharp decline caused by heavy electron emission evidenced by X-rays. High Q at RF power level up to a nominal 6 Watts is an important advantage of the hand polishing preparation technique compared to all previous procedures. During pulse conditioning, all hand polished re-plated cavities achieved peak magnetic fields of 65 mT and peak electric fields of 26 MV/m. During pulse conditioning for 30 min at peak power level of 500 W, some cavities displayed a constant breakdown pattern and some not. Nevertheless all cavities showed signs of further improvement.

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References

[1] Lipski A., Noè J. and Realmuto C., in Proceedings of the SNEAP XXX, (K. F. von Reden and R. J. Schneider ed., World Scientific), 1996, pp.76-87.

[2] N. R. Lobanov and D. C. Weisser, in Proc.11th Workshop on RF Superconductivity, Lubeck/Travemunde, Germany. 2003.

[3] J. R. Delayen, G.J. Dick and J.E. Merceau, *IEEE Transactions on Magnetics*, Vol. MAG-17, N1, 1981, pp. 939-942

[4] Tohru Watanabe, "Nano-plating. Microstructure Control Theory of Plated Film and Data Base of Plated Film Microstructure". Elsevier, 2004.