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STUDY OF COPPER MICROSTRUCTURE PRODUCED BY ELECTROFORMING FOR THE 180 GHz FREQUENCY CORRUGATED WAVEGUIDE

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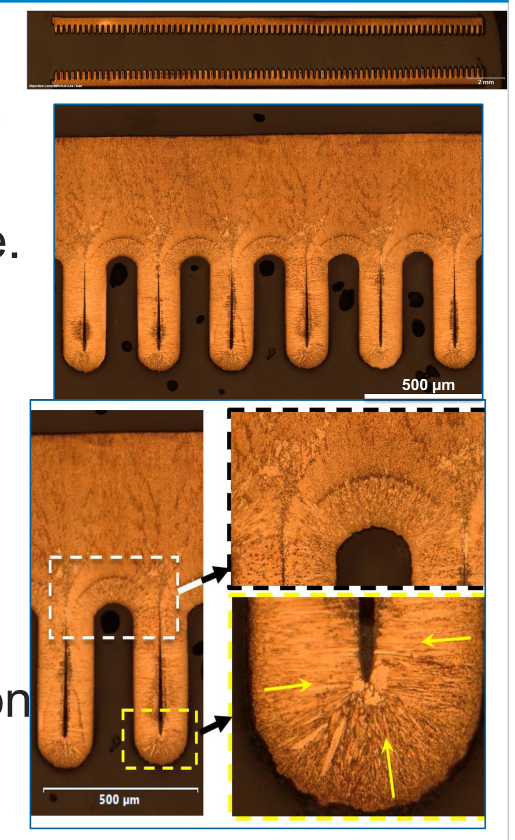
ABSTRACT

- Fabrication of a corrugated structure that generates a field gradient of 100 MV/m at 180 GHz is challenging, requiring unconventional manufacturing methods.
- The corrugated waveguide with 2 mm-inner-diameter will be produced by electroplating copper on an aluminum mandrel as proposed in ref.[1].
- A thin seed layer is applied to achieve uniform wetting of the aluminum mandrel. After fabrication, the copper is retrieved by chemically removing the mandrel.
- Uniform copper plating and chemical removal of the aluminum are crucial steps to keep the surface uniformly smooth and free of impurities that are especially necessary for ultra high vacuum RF applications.
- Previous studies suggest that electroplated copper has variations in both electrical and mechanical properties as compared with those of bulk copper from different production batches.
- We discuss the copper micro-structure produced by the elecroforming method and literature study on the variations, that can be attributed to the disparity of the crystallinity of grains structure in plated material

1ST PROTOTYPE



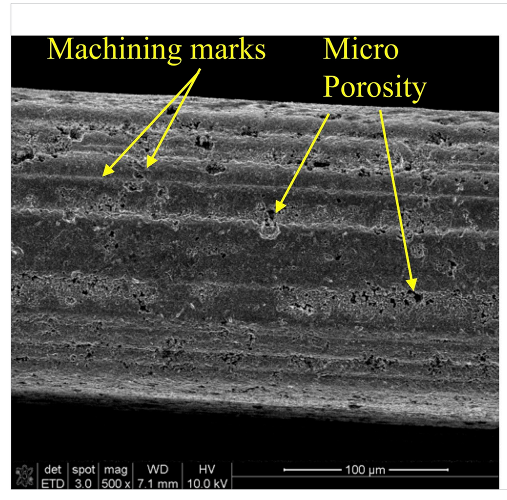
Cross-sections of an early prototype electroformed copper waveguide.

Enlarged etched microstructure of two corrugations.

(Top Right) Magnified view of the corrugation root radius

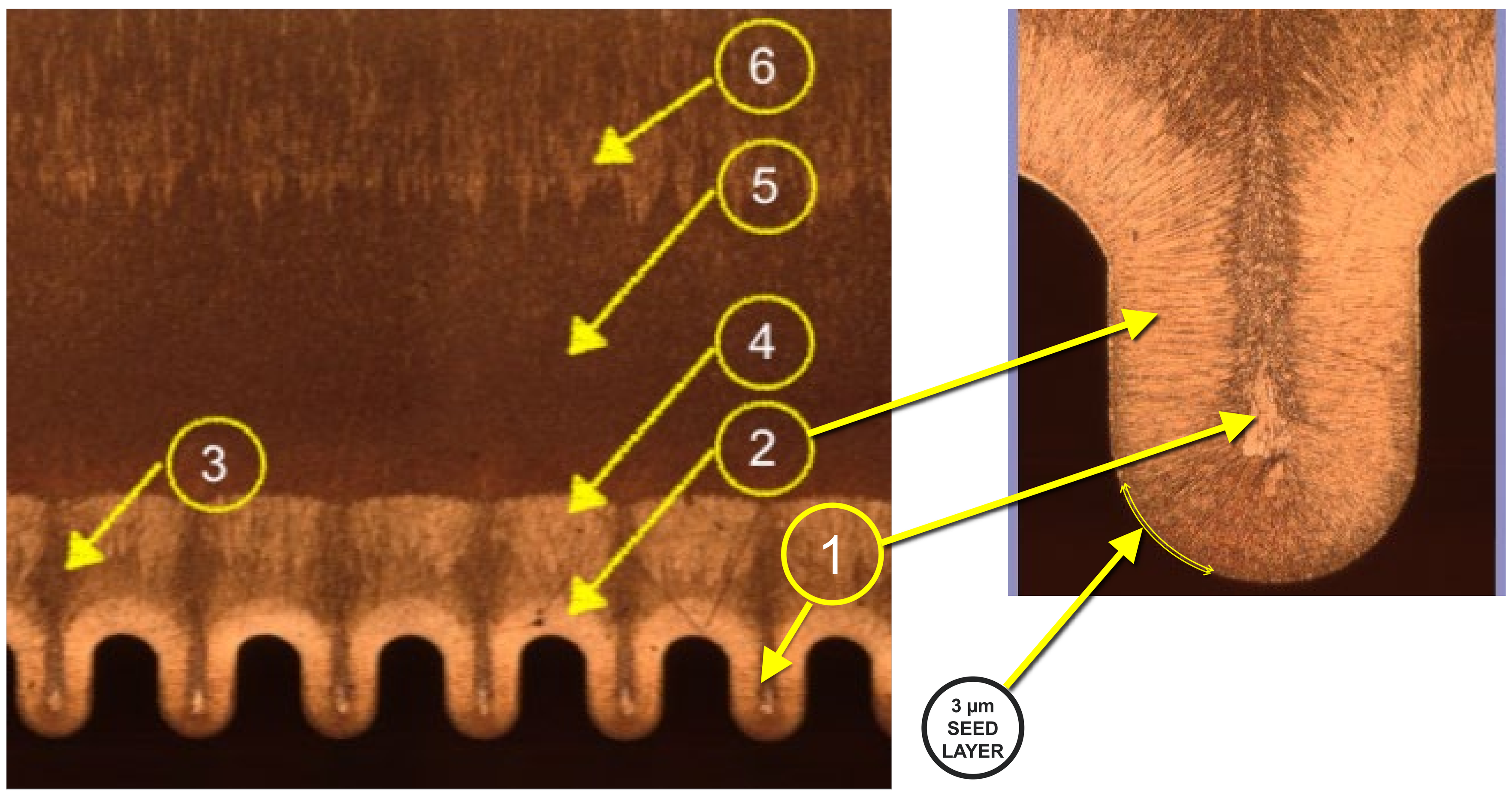
(Bottom Right) Magnified view of the waveguide inner diameter corrugation radius with highly directional, acicular crystalline growth highlighted by yellow arrows.

MANDREL DEFECTS



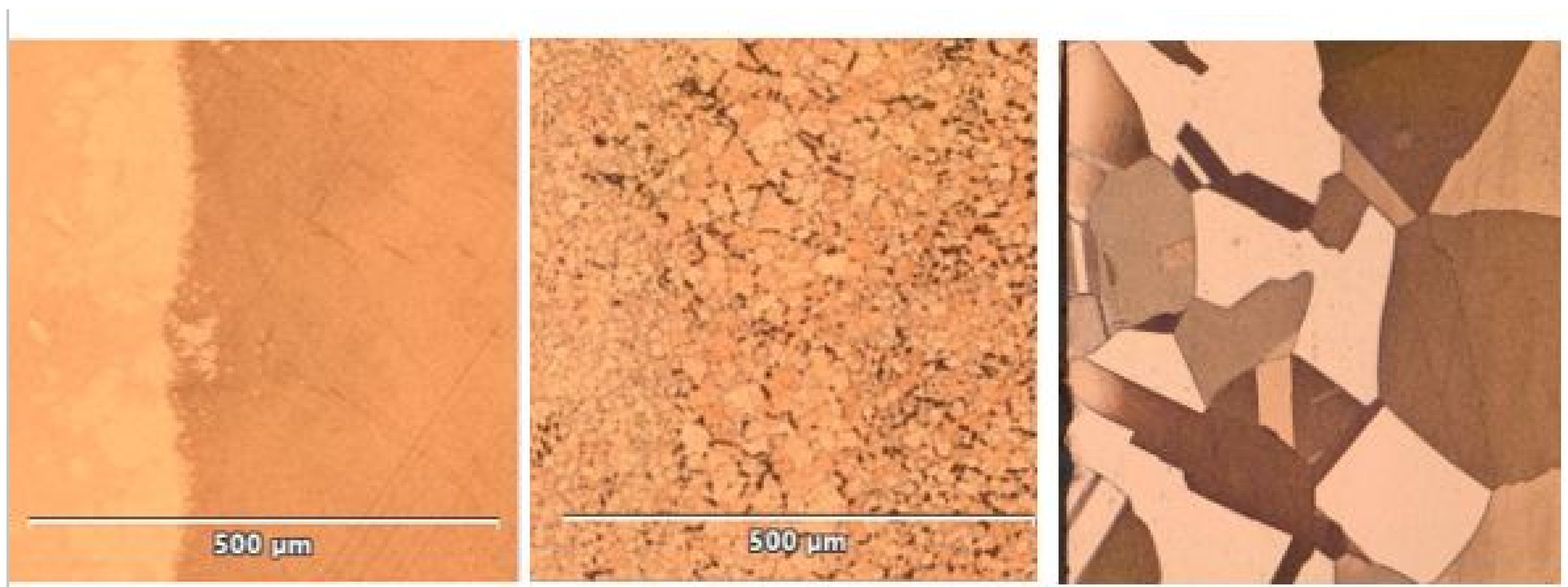
Mandrel defects will imprint onto the electroformed structure inner surface. Machining marks on the aluminum mandrel, inadvertent scratches from handling or shallow pits created during cleaning form the template that is duplicated during the electroforming process.

IMPROVED PROTOTYPE MICROSTRUCTURE



(1) small cluster of large equiaxed grains at the apex of each corrugation.
(2) layer highly elongated layer of single crystal follow the seed layer contour
(3) copper with a more amorphous character
(4) layer with a degree of recrystallization preferentially oriented away from (2)
(5) the darkest, smallest grain, most amorphous, and the highest hardness region
(6) layer with the same nascent recrystallization characteristics as region (4)

COMPARISON MICROSTRUCTURES



Porous or sparse grain boundaries can decrease bulk thermal conductivity, increase electrical resistivity and cause variations in mechanical properties.

(Left) Electroformed copper remains uniform and featureless except for the distinct interface between dark and light regions that indicates a material change [noted as region (4) in panel at left]. Typical grain size is sub-µm.

(Center) When fully annealed, the microstructure recrystallizes and, grains grow to roughly 8 µm in diameter with void coalescence at grain boundaries.

(Right) A typical microstructure of oxygen-free copper (UNS C10100). Note large grains, variations in crystallographic orientation (color) and twinning (linear bands within grains).

MEASUREMENTS

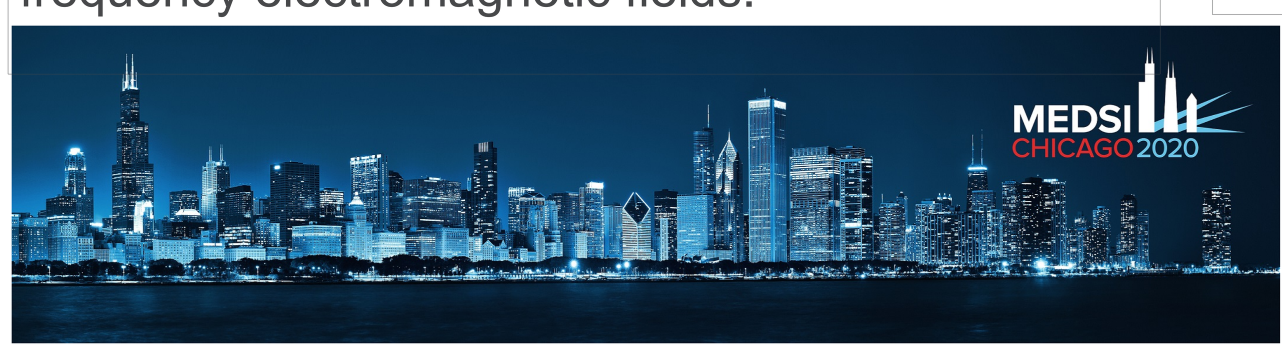
Micro-hardness Measurements
Average micro-hardness measured across this waveguide was Vickers HV = 170 ± 25 kgf/mm² equivalent to an ultimate tensile strength (UTS) of approximately 500 MPa. This surpasses the strength of GlidCop® and Copper-Chromium-Zirconium alloys. If fully annealed, the hardness dramatically reduced to HV 29 kgf/mm² equivalent to a UTS near 90 MPa.

Micro-roughness Measurements
Average surface roughness of the interior convolutions is measured Ra = 6 µm. (230 µin). A high temperature anneal, equivalent to subjecting the waveguide to a brazing cycle, reduces the average roughness by 30%.

Electrical Conductivity Measurements
The electrical conductivity of the electroplated copper is equal to about 88 ± 2 %International Annealed Copper Standard (IACS), whereby 100% IACS is 58.108 MS/m at 20 C. The corresponding skin depth is estimated to be 88 µm, which is much smaller than the sample thickness.

SUMMARY

Electro-forming of components can be a high precision and cost-effective method of producing complex parts. This study has examined the underlying material properties that affect component physical and mechanical performance in a unique accelerator application. Electroplated copper showed highly directional growth of grains. After annealing at 750°C for 30 minutes to simulate a brazing cycle, grains increased in size developing large void accumulations at grain boundaries. Micro-hardness measurements showed a high hardness value for electroplated copper however, that can be reduced significantly by annealing. Similarly, the electrical conductivity measurement showed about 12% IACS reduction. We conclude that the researcher should exercise great care using electroformed components in the applications using high vacuum and high frequency electromagnetic fields.



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