SUPERCONDUCTING NIOBIUM CAVITIES PREPARED BY ELECTROPOLISHING AND ANODIZING

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Summary

Some different surface preparation techniques are applied to TE_{011}- and TM_{010}-X-band cavities machined from solid niobium. The topography of as prepared surfaces is demonstrated by micrographs. A critical magnetic flux density of 160 mT was obtained with a single piece TM_{010}-cavity.

Surface preparation of superconducting niobium cavities is mainly done in three ways; by chemical polishing in a solution of HNO_3/HF by degassing under UHV conditions[1], sometimes combined with a decarburization[2,3], and by electropolishing[4], sometimes combined with anodizing[5]. We applied these various techniques to X-band cavities to study their efficiency in making better surfaces and to demonstrate typical features.

Electropolishing and oxipolishing are briefly reported. Furthermore topographic studies of cold and hot prepared surfaces, preliminary results of TE-cavities machined from different starting material, and results of TM_{010}-cavities are given.

All cavities were machined from solid niobium. The TE-cavities were pot-shaped with a flange for the upper end plate. The TM-cavities were single piece cavities, i.e. there was no weld and no flange. The highest unloaded quality factor Q_o and critical magnetic flux density B_c^{ac} was achieved after cold preparing, i.e. after electropolishing and anodizing.

$$TE_{011} : Q_o = 2,4\cdot 10^{10} \text{ at } B_c^{ac} = 118 \text{ mT}$$
$$TM_{010} : Q_o = 1,8\cdot 10^{9} \text{ at } B_c^{ac} = 160 \text{ mT}.$$

Electropolishing and Oxipolishing

Electropolishing was carried out in a solution of H_2SO_4/HF. The method is characterized by typical current oscillations. We usually achieved very good results by this procedure. After electropolishing about 100 µm the surface was alternately oxidized to a depth of 0,25 µm and the oxide dissolved.

One can repeat this procedure often without diminishing the surface quality. The surface flatness remains unchanged.

Oxipolishing and also anodizing may act as one step to keep the near surface region free from impurities by shifting the actual surface into deeper regions of the bulk material. An essential advance can be seen in the possibility of restoring degraded surfaces.

Topographical studies

The topography of as-machined, chemically polished, electropolished, and outgassed surfaces were studied by transmission microscopy, using the well-known replica technique. Fig. 1 and 2 show typical results.

The micrographs in Fig. 1 were taken with a normal microscope from an as-machined, chemically polished, and electropolished surface.

The grain boundary can be seen after machining with a clean-cutting steel; chemical polishing produces sharp steps at the boundary, while electropolishing exhibits a very flat surface.

Fig. 2 shows electron micrographs of an electropolished surface as well as of an electropolished plus degassed surface. In the case of the degassed surface thermal etching leads to a regular arrangement of surface steps. Distances between the steps and other features depend on the crystallite orientation. The steps can be removed by electropolishing to a depth of approximately 50 µm.

TE_{011}-cavities machined from different starting material

The reproducibility of high quality factors and critical flux densities seems to depend on the properties of the starting niobium, e.g. on the manufacturing specifications of the supplier. We studied Kawecki and Wah Chang niobium of commercial quality in the same manner.

An example of this is given in Table 1, which shows a small selection of typical results.

Kawecki niobium, only cold prepared, exhibited better results than Wah Chang niobium. On an average the critical fields as well as the quality factors were by about a factor 2 lower, in the case of Wah Chang niobium.

Table 1

Critical magnetic flux density B_c^{ac} and unloaded quality factor Q_o of niobium TE_{011}-X-band cavities (9,5 GHz) at 1,5 K

Supplier Preparation (grain size)	B_c^{ac} [mT]	$Q_o(B_c^{ac})$
Kawecki cold prepared (0,2 mm)	77 → 80	$2\cdot10^{10}$
Kawecki cold prepared (10 mm)	118	$2,4\cdot10^{10}$
Wah Chang cold prepared (0,2 mm)	23 → 35	$5\cdot10^{9}$
Wah Chang 1400°C, UHV (2 mm)	57 → 87	$2\cdot10^{10}$
Wah Chang 1900°C, UHV (5 mm)	50 → 74	$2\cdot10^{10}$

Table 2

Critical magnetic flux density B_c^{ac} and unloaded quality factor Q_o of niobium TM_{010}-X-band cavities (9,5 GHz) at 1,5 K

Preparation	B_c^{ac} [mT]	$Q_o(B_c^{ac})$
1. Electropolished, oxipolished		
Processing under Vacuum	120	$3\cdot10^{9}$
2. Electropolished, oxipolished Processing with He		
measured with He gas in the cavity	160	$2\cdot10^{9}$
without He gas	133	$3\cdot10^{9}$
3. Degassed, chemically polished oxipolished Processing with He		
measured with He gas in the cavity	153	$2,8\cdot10^{9}$
without He gas	129	$3\cdot10^{9}$

The highest critical flux density of 118 mT was associated with Kawecki niobium[6]. This material had a grain size of about 10 mm, and this was the only obvious difference between this and the other cavities. However, hot prepared, i.e. electropolished, oxipolished, and outgassed Wah Chang niobium can rise to equally good results as is to be seen in the lower part of Table 1. However, there seems to be no difference between outgassed and only recrystallized cavities. Both cavities go to high critical flux densities after several oxipolishing treatments (marked by arrows in Table 1).

Results of TM_{010}-cavities

Our single piece TM_{010}-cavity is demonstrated in Fig. 3. It shows a cross section, so one can have an impression of its dimensions. The major results of the first three cavities measured until now are summarized in Table 2.

The first and second cavity was machined from Kawecki niobium and only cold prepared. The third one was machined from Wah Chang niobium and hot prepared by degassing in consequence of the results of TE_{011}-cavities.

All cavities have undergone a field processing[7], which drove cavity one up to a critical flux density of 120 mT. We succeeded in treating cavity 1 and 2 by He-processing. He-pressure was estimated to about 10^{-3} to 10^{-4} Torr. We obtained the maximum critical flux density of 160 mT in cavity 2 filled with He gas during the measurement. This value corresponds to a maximum electric surface field strength of 73 MV/m. Somewhat lower field levels resulted from measurements without He gas in the cavities.

The critical flux density of 160 mT is in the neighborhood of the lower critical field H_{c1} of niobium. We are checking now if we have overridden this critical point, and this is the important question!

We are indebted to Mr. P. Wilson, SLAC (Stanford), for calculating the field distributions in our TM_{010}-cavity.

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References

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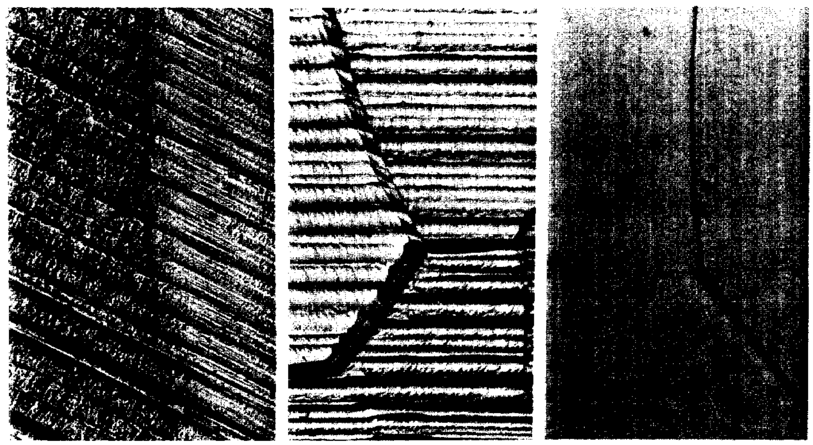
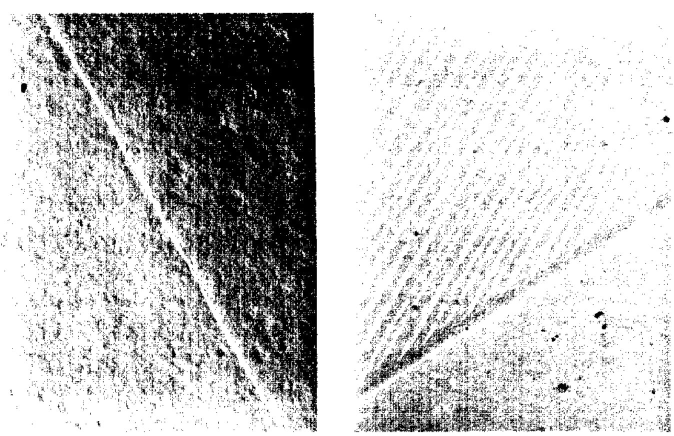


after machining — after chemical polishing (HNO_3/HF) — after electropolishing (current oscillations)

0 ⊢ 50µm

Figure 1. Niobium Surfaces



after electropolishing (current oscillations) — after electropolishing and degassing

0 ⊢ 1µm

Figure 2. Niobium Surfaces

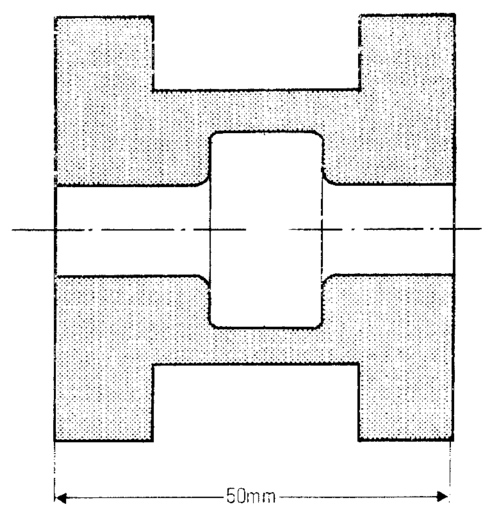


Figure 3. Single piece TM_{010}-cavity (9,5 GHz) machined from solid niobium

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It was found by Mr. Jüngst, GfK Karlsruhe, that there was a mistake in our interpretation of the computer calculation. The B^{ac}_c - values are to be divided by 1.4; this means the maximum B^{ac}_c was 114 mT.

Meanwhile, we have obtained a B^{ac}_c of 130 mT in the TM_{010} - mode and of 159 mT in the TE_{011} - mode.

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