DC FIELD EMISSION OF NB SAMPLES PREPARED IN TESLA CAVITIES

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Abstract

Field emission loading is still a major obstacle of the superconducting niobium cavities at the TESLA Test Facility especially at accelerating fields above 20 MV/m, i.e. peak electric surface fields above 40 MV/m. One of the reasons is that the cleaning of the actual ninecell cavities is much more difficult than that of small samples which do not show field emission up to surface fields of 100 MV/m after open surface preparation. Therefore, we have investigated Nb samples, which have been wet-chemically prepared inside TESLA cavities, by means of a dc field emission scanning microscope. The field emission of such samples started at surface fields of about 20 MV/m and provided a typical density of 10 emitters per cm^2 at 80 MV/m, which are mostly microparticles or surface defects. Promising results obtained by modifications of the wet preparation technique are presented.

1 INTRODUCTION

The chances for the realization of a high energy linear collider with superconducting Nb accelerating cavities as foreseen in the TESLA concept [1] depend very much on the achievable accelerating gradients. Recently, an important milestone has been reported in that respect, i.e. an accelerating gradient of more than 30 MV/m was achieved in a single ninecell accelerating structure at the TESLA test facility [2]. In order to improve the reliability of such a good result, however, the major field limiting phenomena of superconducting cavities, i.e. thermal breakdown and field emission, have to get under control. While much progress has been obtained in methods which routinely check the Nb raw material and welded cavities for the avoidance of quenching defects [3], most of the actual structures still suffer from electron loading, espe-cially at accelerating gradients above 20 MV/m, which correspond to peak electric surface fields of 40 MV/m.

DC field emission (FE) studies on small Nb samples have proven the possibility to reproducibly achieve electric surface fields of more than 100 MV/m without any electron current, if a sophisticated open sample surface cleaning technique is applied [4]. The main difficulty to reduce the FE in fully equipped accelerating structures consists in the challenge to develop an efficient surface cleaning procedure applicable to them. Therefore, we have performed systematic measurements with a field emission scanning microscope [5] on samples prepared inside TESLA cavities with various actual cleaning methods as described in the next chapter. Results on the number densities and the morphology of locally identified emitters will be given in the third and summarized in the fourth chapter.

2 SAMPLE PREPARATION

In order to get a comparable surface quality, most of the samples were prepared inside TESLA cavities as shown in figure 1. Because of the closed-cycle buffered chemical polishing (BCP) developed for large-area Nb cavities [6], the samples were assembled onto special PVDF flanges covering the HOM coupler ports at both ends of the structure. Considering the vertical acid flow and the low as well as high pressure water rinsing (HPWR), the resulting sample position is similar to that of the cavity irises, which are most sensitive for field emission. Moreover, installation of a pair of samples, i.e. at the top and bottom flange, allowed to study possible etching effects during filling intervals. Since acid residues in all flange connections usually contaminate the particle-filtered ultra-pure (18 MΩcm) water (UPW), all PVDF flanges were exchanged before the final UPW rinsing and HPWR. The latter was performed with 100 bar through a perforated sapphire nozzle which is slowly moved up and downward in the rotating structure [6].

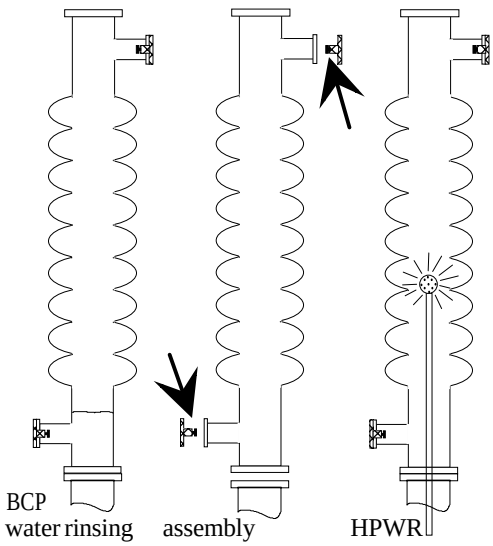

Figure 1: Schematic of the sample preparation inside ninecell cavities. Between the low and high pressure water rinsing the flanges with the samples (arrows) are shortly disassembled because of hidden acid residues.

Table 1: Overview of sample preparations performed at the TESLA test facility (see text for details).

Sample	Position	In Cavity	BCP-µm	HPWR
A +800C	bottom	C23	70+28	in D6
B +800C	top	C23	60+15	in D6
C +Ti	top	C22/C24	55/45+25	in D6
D +Ti	bottom	C22/C24	70/45+25	in D6
D2-Test1	1 year stored samples		> 200	no
D2-Test2	24h exposition in class 10 cleanroom			
D2-Test3	no BCP			mod1,yes
D2-Test4	top	C27	20	mod2,yes
D3-Test1	bottom	A15	20	mod1, no
D3-Test2	fundamental coupler test assembly on C26			

As can be seen in table 1, we have performed 10 preparations mostly in actual TESLA cavities on 6 different samples, which were machined from Heraeus Nb with RRR=300 and cleaned with ultrasound. The samples A-D were prepared pairwise as discussed above. While A/B were UHV-recrystallized at 800 C in cavity C23 before BCP, C/D were 4h purified with titanium at 1400 C together with cavity C22 after the first BCP of 55/70 µm. The different polishing amounts are caused by the position. The further BCP was done in two steps (+) using first Ti-contaminated acid and then ”pure-Nb” acid. Finally these samples were UPW rinsed in the dummy structure D6 until a water resistivity of 12 (A/B) and 17 (C/D) MΩcm was reached, followed by HPWR in D6 and drying in a cleanroom of class 10. In contrast, the samples D2 and D3 served for multiple testing to check individual preparation steps like extended cleanroom exposition and fundamental coupler assembly. Moreover, some modifications of the final rinsing procedure and the HPWR were applied, e.g. faster emptying of the acid and filling with UPW as well as a position of the last filter closer to the cavity (mod1) and a wet assembly into HPWR (mod2). The samples were tranported to DESY/ Wuppertal under special protection caps, which were only opened under cleanroom or UHV conditions.

3 DC FIELD EMISSION RESULTS

All samples were routinely investigated with the UHV field emission scanning microscope (FESM) at Wuppertal which has already been described in detail elsewhere [5]. At first, the number of emitters on each sample was determined at several electric field levels, usually by applying a dc voltage of some kV between a tungsten anode and the Nb sample cathode which was laterally scanned with step motors at a distance of typically 100 µm. Since most of the samples provided somewhat rounded edges after BCP in TESLA cavities, their varying height (some ten µm) in the FE scans was carefully controlled and continuously adjusted by means of a piezo-block translator. Four examples of such FE scans at 80 MV/m are given in Fig. 2. Stable emitters exhibit reproducible voltage reductions for a maximum set current of 20 nA.

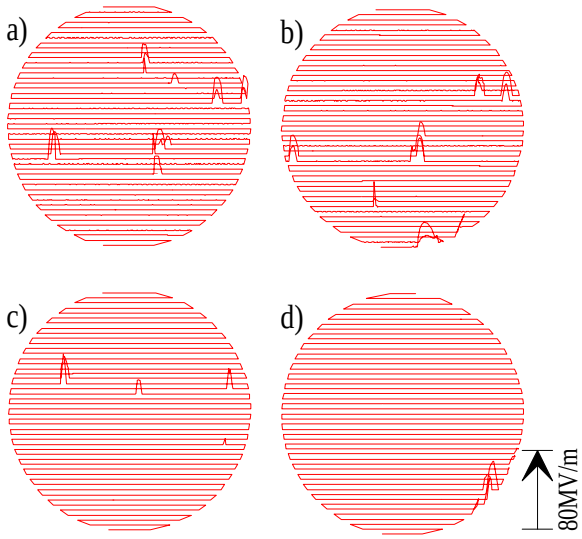

Figure 2: Comparison of FE-scans (E=80MV/m:arrow; I=20 nA; anode Ø 0.5 mm; scan area Ø 12 mm) after various preparations of samples: a) D2-Test1; b) D2-Test2; c) D3-Test1; d) D2-Test3 (see table 1).

Sometimes current spikes occured on virgin samples (e.g. in Fig. 2b) which reflect fast processable emitters and will thus be neglected. Moreover, extensively polished samples often displayed rows of emitters at their outer rim (Ø=12 mm, see Figs. 2b/d), which are caused by the protection caps at the rounded edge and not considered further. Comparing Figs. 2a and 2b, four emitters could be reidentified on sample D2, i.e. after 24h exposition in the DESY cleanroom, but three others disappeared and one new occured. Fig. 2c reveals slightly less FE on sample D3 than initially on D2, probably due to the modified UPW. It is most remarkable that HPWR removes the FE of D2 completely (Fig. 2d).

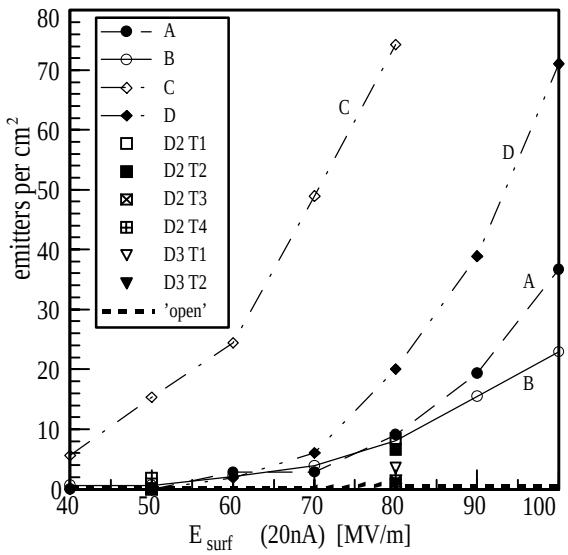

Figure 3: Number density of emitters found for all sample preparations listed in Tab. 1. The dashed line corresponds to the open sample surface cleaning technique [5].

In Fig. 3 the number density of emitters resulting from such FE scans for all sample preparations in Tab.1 is given as a function of the dc electric field level. While the density was calculated with the relevant size (Ø 12-13 mm) of the samples, the electric field was varied in steps of 10 (A-D) or 30 MV/m (D2/D3). According to the set current of 20 nA, these field levels do not reveal the onset of field emission, which is usually defined at 0.5 nA, but rather correspond to significant electron loading (Q drop) in cavities. Despite the high statistical error for such small numbers, some clear trends can be seen in Fig. 3. The strongest FE occured for sample C, i.e. the Ti-purified one assembled at the top flange. Etching effects, however, cannot be derived because of the similar or even reversed results for A and B. Comparing the rather high numbers of emitters at the beginning of the series (A-D) to those after the modifications (see Chapter 2) of the wet preparation (D2/D3), a general improvement of the prepa-ration inside TESLA cavities towards the results for open-prepared samples (bottom line in Fig. 3) seems possible.

At this point a deeper analysis of the field emitters with the FESM is required to reveal their microscopic morphology as a guide for suggestions of preparation improvements. Therefore, we have studied a total of 46 localized emitters on samples A-D first with microanodes in terms of Fowler-Nordheim parameters (onset field E_{on}(0.5nA), field enhancement factor β and emitting area S for Φ=4eV) and then with the in situ SEM. On average of all these samples, we found 49% particles mostly of submicrometer size, 31% defects like scratches or roughened surfaces extended over typically 10 µm, 3% craters caused by discharges, and 16% unresolvable features. For each of these samples, at least the 5 strongest emitters were ex situ investigated with a high resolution SEM. Examples for the two main emitter categories are shown in Fig 4. Emitting particles always provided sharp edges or antenna-like substructures (Fig. 4 left) which favor FE by geometric field enhancement in accordance with the obtained β-values [7]. Unfortunately, they have mostly been too small to identify their elemental composition by in situ AES or ex situ EDX yet. One might guess that they erect at high fields, thus causing a sudden "switch-on" of high currents [8]. Emitting defects are usually visible over larger areas (Fig. 4 right) but of a manifold microstructure. Often thin protrusions probably caused by tools suggest geometric field enhancement, which seems plausible due to similar β-values. In contrast, the S-values obtained for both emitter categories scatter over several orders of magnitude and hint for adsorbate effects [9].

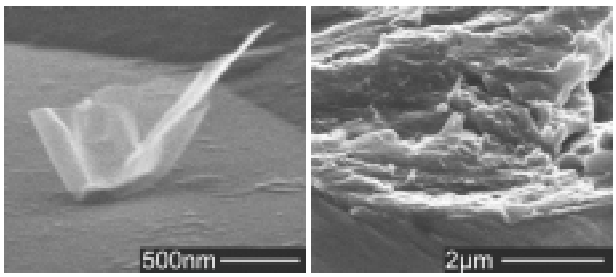

Figure 4: HRSEM micrographs of two strong emitters: side view of a small particle on A (left, E_{on}=28 MV/m, β=107, S=10^{-9} cm^2); slanted view of an extended defect on B (right, E_{on}=40 MV/m, β=88, S=10^{-12} cm^2).

4 CONCLUSIONS

DC field emission measurements on small Nb samples prepared inside TESLA cavities are well suited to help to improve their surface preparation techniques. Etching effects due to the finite filling times during BCP have not been found yet. Some modifications of the wet treatment, i.e. improved UPW rinsing and wet assembly into HPWR, resulted in reduced number densities of emitters which approach those of open-prepared samples. Extended cleanroom exposition as well as fundamental coupler assembly were not found to deteriorate the FE properties. The microscopic analyses of emitters have revealed microparticles and surface defects as main cause of FE, and must be intensified in order to get a full control of electron loading in superconducting TESLA cavities.

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