Results of Postpurified 3 GHz Accelerator Structures

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Abstract

In order to improve the performance of the 3 GHz superconducting accelerator structures for the Darmstadt Recyclotron, we have applied high temperature annealing at 1300°C and at 1350°C under exposure to titanium vapor to single cell cavities as well as to five and twenty cell structures fabricated from 2 mm reactor grade and medium purity Nb sheet metal. The achieved accelerating fields reproducibly increased in case of a single cell cavity from about 8 to 27 MV/m, in case of a 5-cell structure from about 5 to 13 MV/m, and in case of a 20-cell structure typically from about 4 to 8 MV/m. The fields were limited by thermal instability (quench), only when rinsing in demineralized water was the final treatment field emission was the limiting phenomenon. It has been demonstrated that purification by exposing only the outside of the structure to titanium vapor gives a good or even better results than purification from inside and outside. This technique has moreover the advantage that there is no frequency shift due to a subsequent chemical polishing.

Introduction

The main obstacles limiting the performance of superconducting cavities and accelerator structures are thermal instabilities and field emission since multipacting has been overcome by special shaping of the cavity. Field emission is related to the rf surface, whereas field limitation by thermal instability depend on the surface and the bulk material properties. Purification and homogenization of the cavity material by solid state gettering [1] increases the thermal conductivity of the material and shifts the instability limit to higher values because the threshold field of local thermal breakdown scales with the square root of the thermal conductivity. The effect of solid state gettering on the field emission process is not yet clear and will be discussed

below. Dc-field emission measurements on niobium samples have shown that electron emission originates from micron size particles and foreign material inclusions, and the measurements show further that Nb surfaces can be made free of field emission up to 200 MV/m by high temperature firing above 1400°C [2]. The technique of solid state gettering has been applied to single cell cavities several times with great success [3]. In this paper we report on the application of multicell structures in order to increase the performance of the accelerating structures for the Darmstadt-Recyclotron which have been built in 1984.

Single Sided Postpurification

In an earlier paper [3] we reported on the postpurification of a single cell 3GHz cavity fabricated from reactor grade niobium with an RRR = 30. In this cavity, heat treated in an UHV-furnace at 1850°C for several times, we achieved quench limited accelerating field levels of up to 7.3 MV/m and residual Q values of up to $7 \cdot 10^{10}$. After high temperature annealing at 1300°C and exposing the inside and the outside of the cavity to titanium vapor an accelerating field of 25 MV/m at a Q (1.5K) of $1 \cdot 10^{10}$ was achieved. Of course the titanium had to be removed from the rf surface of the cavity by etching of a 50 µm surface layer in a 1:1:1 solution of 48% HF : 65% HNO_3 : 85% H_3PO_4 (BCP). Therefore the frequency of the cavity dropped by about 1.5 MHz. Then this cavity was used to form the substrate of a Nb_3Sn coated cavity. It was exposed to Sn vapor at about 1100°C. The main problem was the reduction of the purity of the niobium bulk in the coating furnace to an RRR ~ 60 [4]. As the diffusion length increases with temperature exponentially it was obvious to expose the inside of the cavity with Sn vapor to form Nb_3Sn and the outside with titanium vapor to purify and to protect the niobium bulk material from impurities in the coating furnace. The cavity became one of the best Nb_3Sn coated cavities, an accelerating field level of about 10 MV/m was achieved.

Experimental Technique

The heat treatment is done in an UHV furnace. The total pressure at 1350°C was less than $3 \cdot 10^{-7}$ mbar.

After the promising result which was achieved with the single cell cavity S3 the

technique of solid state gettering was applied to a five cell and a 20 cell structure. Both were annealed under exposure of the inside and the outside of the structure to titanium vapor. For this purpose a titanium rod was put inside, and the outside was wrapped up in a titanium foil of .2 mm thickness. To protect the furnace against titanium vapor the whole structure was surrounded with a niobium foil, the cut off tubes were closed with niobium caps. To carry out the single sided purification the inner rod was omitted and the end caps were modified to protect the inside of the structure against titanium vapor. The heat treatment temperature was increased from 1300°C to 1350°C, the time from 8 hrs to about 20 hrs. Two resonators have been treated in this way: the single cell cavity S3 which had a reduced purity due to the treatments in the Nb_3Sn coating furnace and the 20 cell structure D20. To avoid an exceeding of the yield strenght during heat treatment the 1.3 m long 20 cell structure was fastened to a support made from niobium. The structure was fixed at the seventh and the 14th cell and at its lower cut off tube.

After an inside-outside purification the getter material was removed in a BCP solution. Because of the enhanced diffusion of titanium along the grain boundaries a surface layer of at minimum 50 μm was removed to avoid a Q_0 degradation. The final surface preparation consisted of an extensive rinsing in demineralized dustfree water and drying in a class 100 dustfree room. Only in case of the 20 cell structure C20 a heat treatment at 850°C for 3 hrs was added due to the much more complicated cleaning procedure for multicell structures.

After application of the single sided purification the titanium was removed from the outside of the single cell cavity in a BCP solution, the inside was rinsed in dustfree methanol. The structure D20 was mounted to the vacuum system of the test equipment without any further preparation after purification.

The preparation technique together with the rf measurement results are summarized in table 1.

Results and Discussion

The field levels achieved in cavities and structures after purification by solid state gettering exceed the levels measured in the same resonators treated according to a more conventional technique. In a single cell cavity an accelerating field of 25 to 27 MV/m has been reached reproducibly. For multicell structures the results reflect the well known fact that the maximum field level drops with increasing number of

Test No.	HT-Condition T(°C)	type	t(hrs)	Estimated RRR	Q_o	$Q_o(E_{max})$ [MV/m]	E_{max} [MV/m]	E_p [MV/m]	H_p [mT]	Limited by	BCP [μ]	Δf [MHz]	Comment
1-cell S3													
a	1850		5	30	$8 \cdot 10^{10}$	$3 \cdot 10^{10}$	7.3	18.6	30	Q			
b	1350	o	18	220	$9 \cdot 10^{9}$	$4.3 \cdot 10^{9}$	27.2	69.4	113	Q			rinsed in dustfree methanol
5-cell E5													
a	1100		5	30	-	$4 \cdot 10^{9}$	5.1	15.8	21	Q			
b	1300	i,o	8.5	200	$1.2 \cdot 10^{10}$	$1.5 \cdot 10^{9}$	12.6	39	52	FE	70	1.8	rinsed in class I water
20-cell C20													
a	1100		3	30	$\sim 7 \cdot 10^{9}$	$5 \cdot 10^{9}$	4.1	12.7	17	Q			
b	1300	i,o	11.5	190-200	$5 \cdot 10^{9}$	$1 \cdot 10^{9}$	6.7	20.8	28	FE	75	2.2	rinsed in class I water 850°C, 3 hrs
20-cell D20													
a	1100		6	30	$2.3 \cdot 10^{9}$	$1.3 \cdot 10^{9}$	3.8	11.8	16	Q			
b	1350	o	21	200	$3 \cdot 10^{9}$	$1.7 \cdot 10^{9}$	7.8	24.3	33	Q			

TABLE 1: Summary of treatment and of experimental results measured at T = 1.6 K.
Test a: before b: after purification
HT-Condition type: i means exposure of inside of cavity to Ti vapor
o " " " outside" " " " "

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cells in a structure. In the five cell structure the accelerating field was limited by field emission above 12 MV/m, in the 20 cell structure a thermal instability limited the fields just below 8 MV/m. These values are calculated from the measured rf data. Figs. 1 and 2 show the quality factors as a function of the (rf) accelerating field levels.

One reason for the drop of the measured field strength for an increasing number of cells certainly is the different excitation of cells in a not field flat structure. An example of an extreme unflat structure is the 20 cell structure D20. It was flat within ± 10% in E when we started the heat treatment. Afterwards the profile could not be measured because the structure was directly carried to the rf test stand. An indication of an unflat profile is given by a temperature map which was taken at 4.2 K. It is shown in Fig. 3. Assuming that the surface resistance is equal in each cell one can deduce from the temperature map and the measured rf data that the field level in the cell with the highest excitation must be in the range of 16 to 18 MV/m, corresponding to the rf field level of 8 MV/m. One can further estimate that an electron traversing the structure would gain about 6 MeV.

Considering the type of field limitation one can find that the field emission occurred in tests in which the structures were rinsed in water. The purification method will not enhance the field emission process but it increases the thermal stability.

Conclusion

Single sided purification effects the same enhancement of structure performance as double sided purification. Moreover, it has the advantage that there is no frequency shift due to a subsequent chemical polishing. Therefore, it can be applied several times even to accelerator structures. Due to the high annealing temperature one has to take care of the mechanical stability of long structures.

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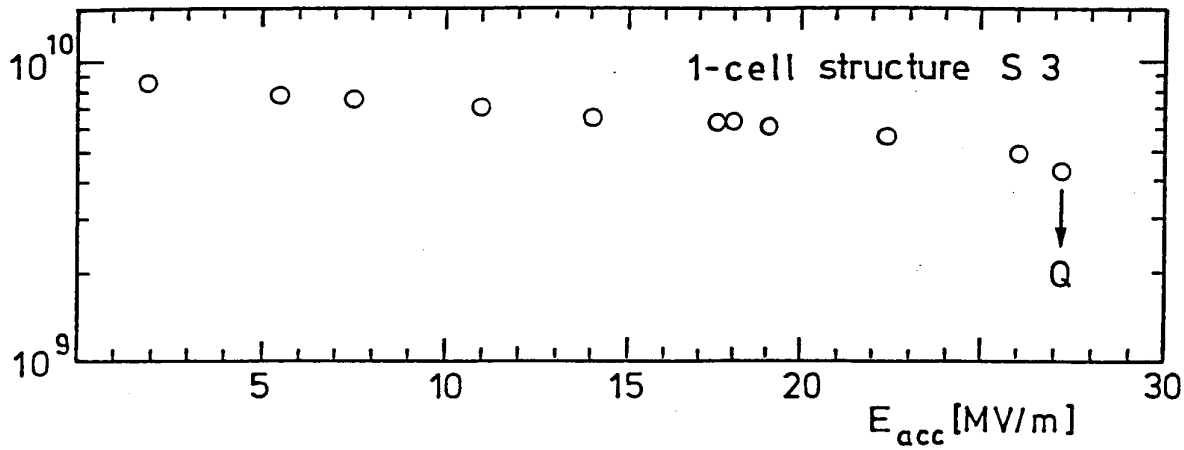

Fig. 1 : Q_o (E_{acc}) dependence of single cell.

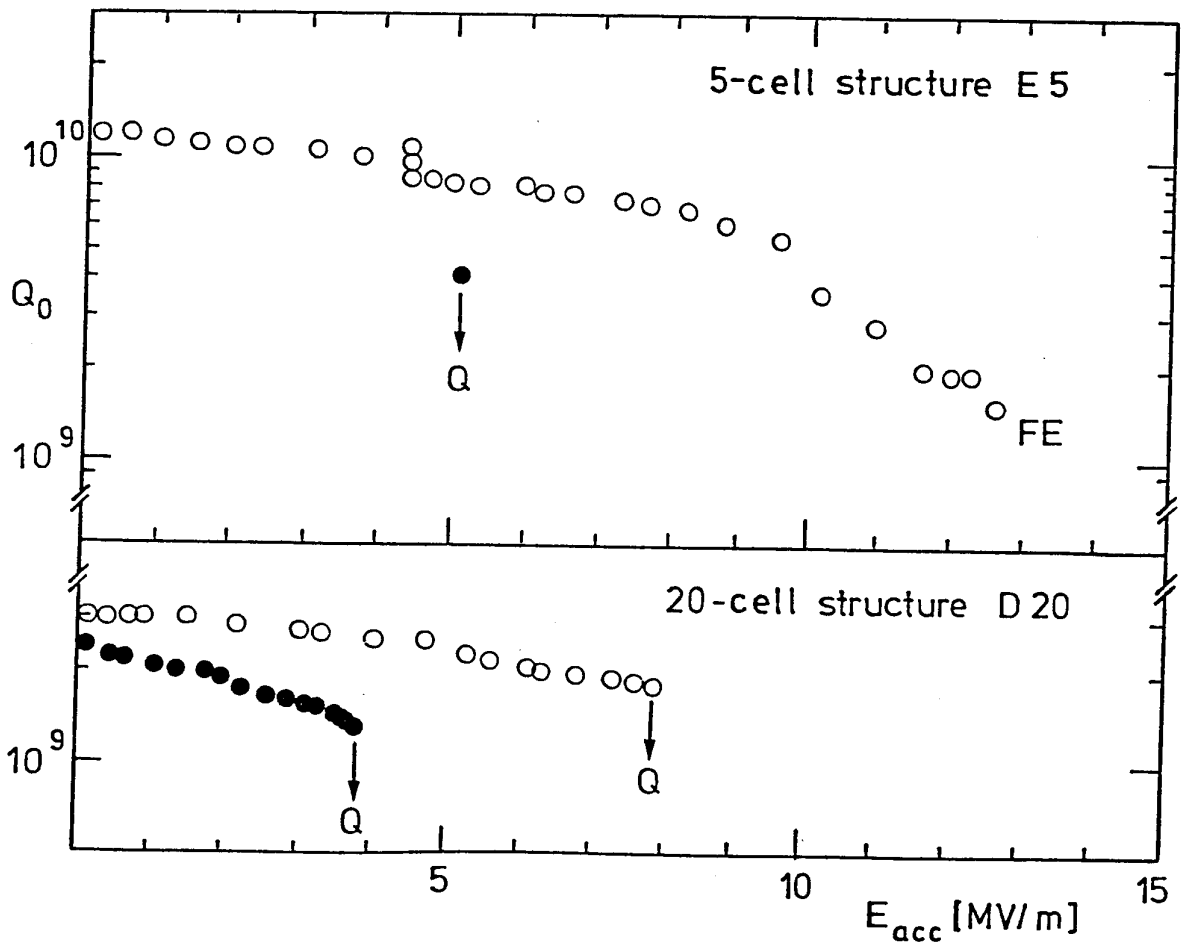

Fig. 2: Q_o (E_{acc}) dependence of five cell, and 20 cell structure
full circles: before purification
open circles: after purification.

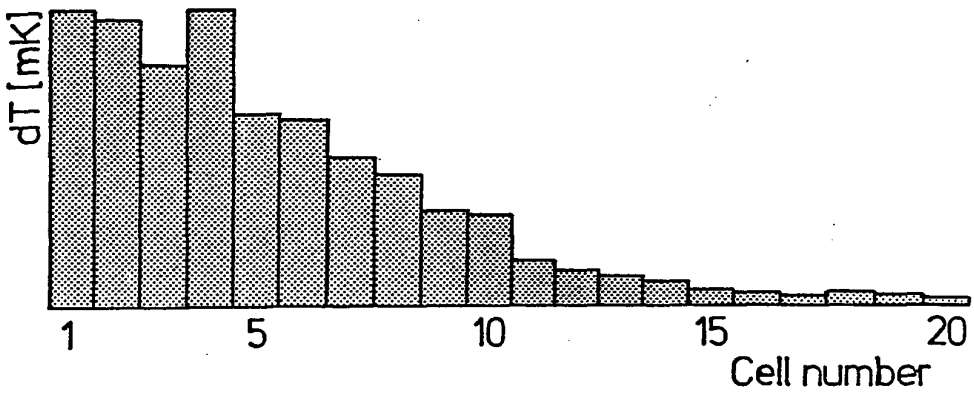

Fig. 3: Temperature map of structure D20 taken at 4.2 K.

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