IMPROVED HIGH PURITY NIOBIUM FOR SUPERCONDUCTING ACCELERATOR CAVITIES

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Two phenomena limit the amplitude of rf fields in superconducting accelerator niobium cavities far below the fundamental limit, defined as the transition of superconductor to a normal state due to rf magnetic field. These are field emission and thermal breakdown (quench) as well. We want to remind, that thermal breakdown is caused by heating a defect on the cavity surface by rf currents. The defect may be of normal conducting, dielectric or even weakly superconducting or weakly cooled nature. Also field emission induced quenching has been often observed especially in low frequency cavities. As a result of such heating the temperature of the surrounding superconductor increases and finally exceeds the critical temperature. Correspondingly, the cavity Q-value falls down at first slowly and finally abruptly in the quench. The use of superconducting material with high thermal conductivity λ for effective cooling of the defect and the cavity surface makes it possible to shift the Q-degradation as well as the instability to higher field levels. One can show [1], that for large (>50 μm) defects and not very high thermal conductivity the quench threshold of the rf magnetic field H_q scales with $\sqrt{H_q}$. Computer calculations, which take the increase of rf power dissipation in the surrounding surface into account, show slower growth of the quench threshold for higher RRR values [2]. Fig. 1 illustrates this.

One more argument for the use of superconductor with high thermal conduc-

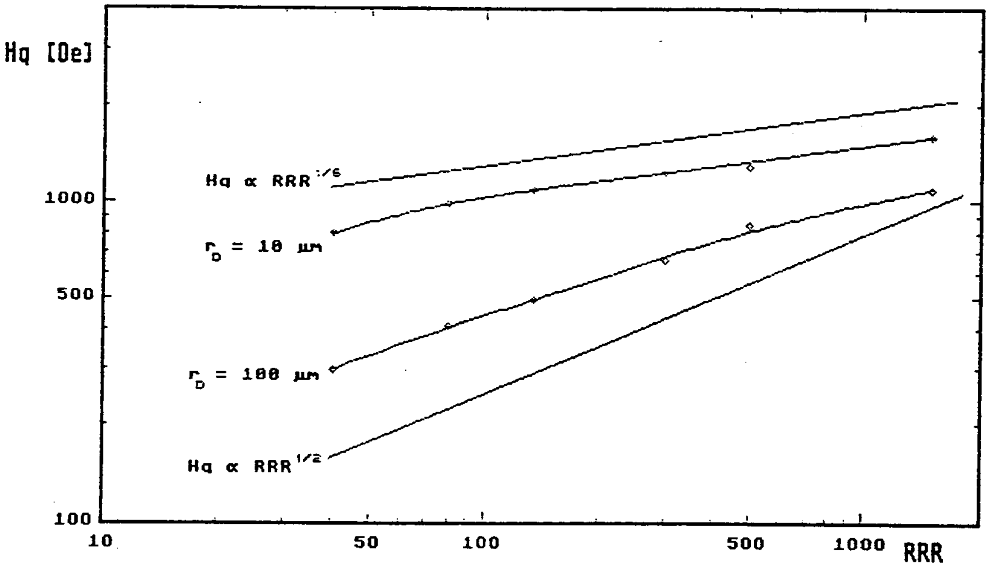


Fig. 1. Calculated dependence of the quench field level on purity grade RRR for defects of radius 10 µm and 100 µm.

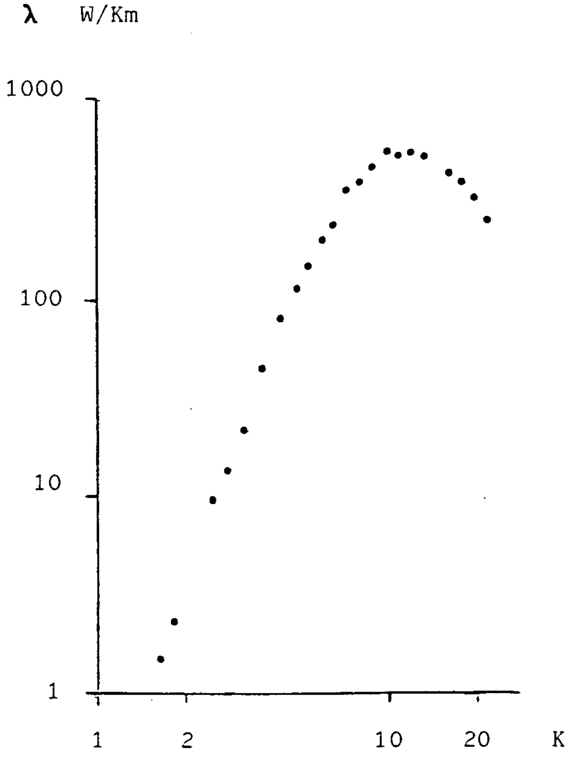


Fig. 2. Thermal conductivity versus temperature for GIREDMET sheet niobium.

tivity for high gradient cavities has to be mentioned. Since rf losses grow with the square of the field but also linearly with the surface resistance, which is larger at higher frequency at given operating temperature [3], the temperature of the inner cavity surface at high field level may differ appreciably from LHe bath temperature due to finite thermal conductivity of the cavity material. Simple estimations show that, for example, for the singlecell S-band niobium cavity with Q-value of 10^{10} and wall thickness of 2 mm, the overheating at the gradient level of 30 MV/m may be up to several hundred mK (in these estimations we used λ = 2 W/Km - the measured at 1.8 K thermal conductivity for GIREDMET sheet niobium material, Fig. 2). Such overheating causes a decrease of the Q-value due to additional BCS-losses, and at high field level thermal instability may occur [2]. It is evident, that the overheating effect becomes relaxed for superconductor with high thermal conductivity.

Thus in both cases - quenching and inner cavity surface overheating - the cavity behaviour depends strongly on the superconductor's thermal conductivity. It is well known that for a metal the thermal conductivity and in equal extent the electrical conductivity depend at low temperature on its impurity content. That is why it is usual to characterise the material purity in terms of the residual resistance ratio RRR, i.e. for niobium RRR = $C*\lambda(4.2\ K)$ [7,8], where C = 4 to 7 depending on the RRR value. Up to now high purity niobium has been commercially available with RRR value of less than 300. In GIREDMET (State Institute for Rare Metals, USSR) a method of preparation of high purity niobium with RRR = 200 to 800 has been developed and is used succesfully. Table 1 shows major impurity contents in niobium ingots used for preparation of a sheet material in comparison with material produced by other firms. One has to pay attention on the low Ta content which is about one order of magnitude less than that in the presently used niobium for accelerator cavity production. Although the influence of Ta atoms on the thermal conductivity is much less than of N, O, C atoms [4], the latter can be extracted from Nb by high temperature gettering with titanium [5]. Therefore, the remaining Ta content determines to a large extent the achievable final thermal conductivity after such post purification treatment. At the same time it is difficult to separate Nb and Ta because of their similar physical and chemical properties. Table 2 contains mechanical properties of GIREDMET bulk material in comparison to specification for niobium, which is used for accelerator cavity production at CEBAF [9]. Despite the higher purity of GIREDMET niobium, its mechanical stability still seems

Table 1. Impurity content in niobium of various suppliers.

	Ta [wt-ppm]	W [wt-ppm]	Mo [wt-ppm]	ONC [wt-ppm]	calc.RRR*
GIREDMET	< 30	< 5	< 5	< 20	12000
Wah Chang [10]	130			10	6800
HERAEUS [11]	310	100	20	20	1400

* - RRR-limit, calculated relative metal content [4]

Table 2. Mechanical properties of niobium of different kinds.

	Yield strength [klb/in^2]	Tensile strength [klb/in^2]	Elongation %	RRR
GIREDMET (bulk)	9.6	17.1	46.6	500
specification, used for cavity production [9]	7.3	18.0	38.0	300

Table 3. RRR of GIREDMET niobium after various kinds of treatments.

kind of treatment	ingot	sheet material
not treated	830 ± 50	570 ± 30
UHV 850°C	890 ± 30	620 ± 20
electropolished	740 ± 30	-
UHV 1350°C with T	1400 ± 200	1700 ± 100

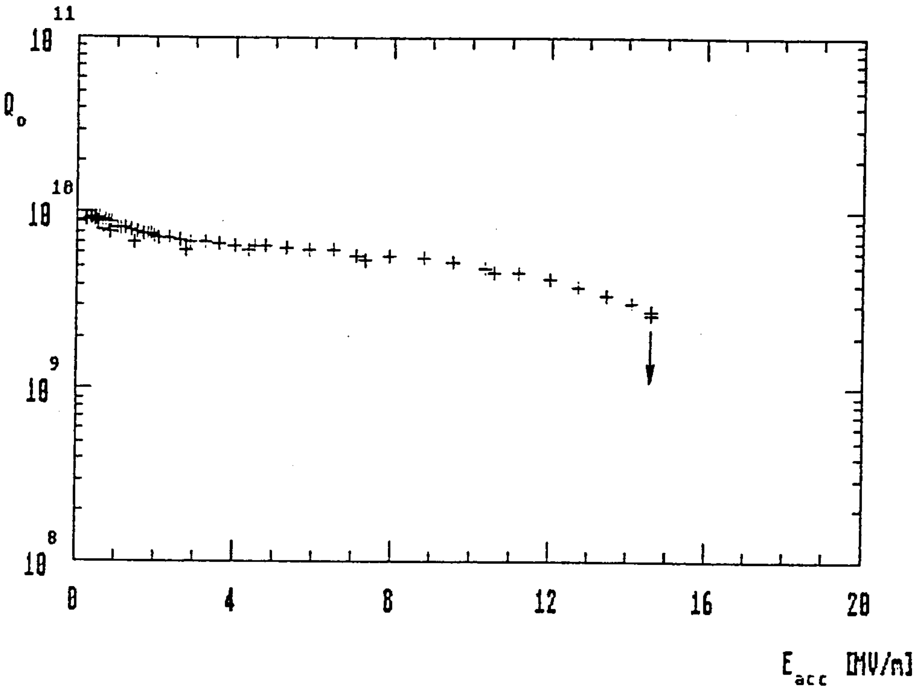
to match the requirements.

Two S-band singlecell cavities have been produced from GIREDMET niobium. One of them has the shape and size identical to one cell of the Darmstadt recyclotron 3 GHz structure, resulting in a ratio of maximum surface electric field to acceleration gradient (E_p/E_{acc}) of 2.55. It has been produced from sheet material with RRR = 500 by the usual method of deep drawing and electron beem welding. The second one has been machined from ingot with RRR = 800 and has elliptical shape with E_p/E_{acc} = 2.0. Fig. 2 and table 3 show the results of thermal conductivity and RRR measurements for the niobium that had been used for cavities production. As expected, the RRR of this material increased significantly after firing at 1350 °C in ultra high vacuum with titanium shield. As far as we know the niobium with RRR = 1700 is the most pure one ever used for superconducting accelerator cavities. At the same time we want to pay one's attention on the relatively low λ value of the raw material at temperatures between 1.5 K and 2 K, usual for S-band cavity operation that, as already mentioned, may limit the maximum field level due to overheating or thermal breakdown. However, λ at 2 K is expected to increase drastically after high temperature firing due to the phonon peak. Unfortunatly, we were not able to measure $\lambda(T)$ of the postpurified material with sufficient accuracy. It is worthwhile to mention that it may be resonable to use lower frequencies in order to decrease BCS losses and to avoid overheating of the inner cavity surface.

We have made several tests of the cavity, produced from sheet GIREDMET niobium, the first two of them are shown in Fig. 3. In all tests nearly the same maximum Q-value of about 10^{10} had been found. The maximum accelerating gradient of 14.6 MV/m at Q = 2.6 10^9 had been achieved in the first test, limited by quenching. During the next tests field emission limited the gradients at the level of about 10 MV/m. Similar behavior after similar treatment had also been found with a singlecell RRR 300 cavity from HERAEUS niobium, which showed a quench at 13 MV/m in the first test and field limitation at lower level due to field emission in the following tests.

For the preparation of the cavity we used the usual chemical polishing in standard solution of acids with rinsing for approximately 20 h in clean water and assembling in dust free class 100 room. In the two last cases, after chemical treatment we rinsed the cavity in turbulent water flow by using rotating cylinder inside rinsed cavity [6], insted of the traditional laminar rinsing resulting from slow water flow.

Test No. 1



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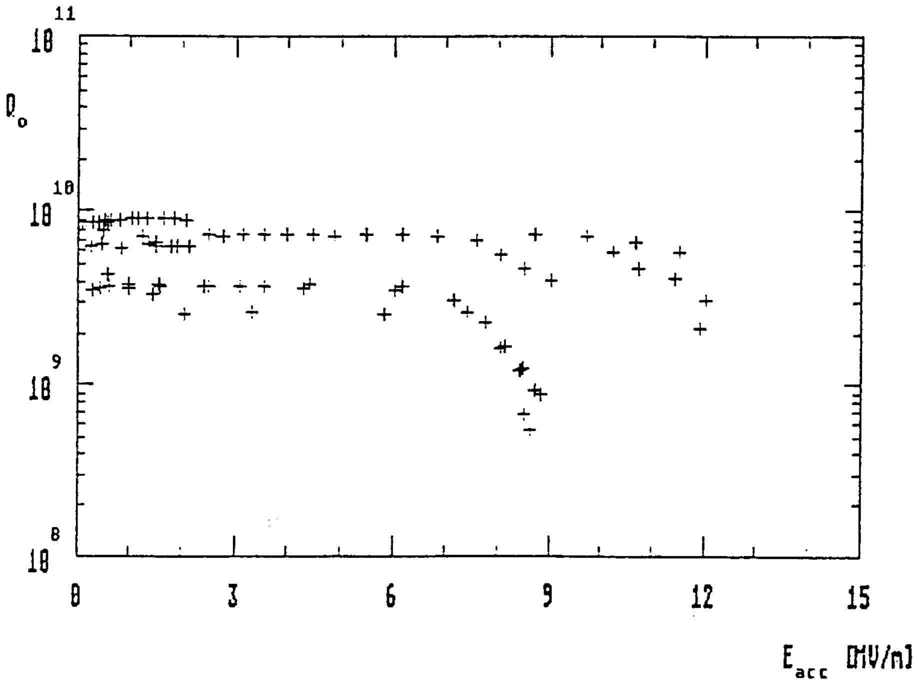

Fig. 3. Q-value dependence on gradient level for the first two tests of the S-band singlecell cavity from GIREDMET RRR 500 sheet niobium.

Cavity thermometry allowed us to locate a few field emitters in each test. During cavity suface inspection we always found bright points (that are spots, which reflected light more than nearby cavity surface) at these emitters locations, but it is not proved that they are responsible for field emission. Firing at 1350 ^{0}C in ultra high vacuum with titanium shild is planned as the next step of studying the cavity from GIREDMET niobium.

The results of our work may be formulated as following:

- A method of high purity niobium production with low Ta content has been developed at GIREDMET.
- Results of electrophysical properties measurements (thermal conductivity and RRR) prove the high purity of developed material: RRR > 500 of the raw material and RRR ≅ 1500 after post purification in UHV-furnace with Ti.
- Systematic study of the singlecell cavities produced from GIREDMET niobium has been started at the University of Wuppertal. First results may be considered as promising. We expect significant increase in gradient after high temperature firing.

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REFERENCES

[1] H.Padamsee. IEEE Trans. Magn., 19, 1322 (1983).
[2] G.Müller, Proceedings of the 3rd Workshop on RF-supercoductivity.
[3] W.Weingarten, Particle World, Vol.1, No.4, 93-103 (1990).
[4] K.Schulze, Journ. Met., Vol.33, No.5, 33-42 (1981).
[5] P.Kneisel, Journal of Less Common Metals, 139, 179-188 (1988).
[6] L.D.Landau, E.M.Lifshitz, Fluid mechanics, Perg. Pr. (1968).
[7] L.P.Kadanoff, P.C.Martin, Phys. Rev. Lett.,124 (1961).
[8] K.R.Kraft, Dissertation, Cornell University (USA) (1983).
[9] P.Kumar, Journal of Less-Common Metals, 139, 149-158 (1988).
[10] D.B.Smathers. Journal of Less-Common Metals, 139, 61-66 (1988).
[11] M.Hörmann, Journal of Less-Common Metals, 139, 1-14 (1988).