Behavior of Electropolished Niobium Cavities Under Different Cooldown Conditions*

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ABSTRACT

Two single cell 1500 MHz cavities with elliptical cross-section have been electropolished at KEK using the standard procedures for cavity production at this laboratory. After final treatment and shipment under vacuum to CEBAF, the cavities were tested under different cooldown conditions. Results of these tests are presented and compared with measurements obtained on cavities after standard chemical polishing in a buffered solution.

INTRODUCTION

After fabrication, superconducting niobium cavities have to be chemically treated to remove the surface damage layer introduced by the material manufacturing and cavity fabrication processes. After removal of > 60 μm the cavities usually perform well if proper steps are taken to ensure surface cleanliness of the surfaces exposed to high electromagnetic fields. The standard process used by several laboratories is a chemical polishing in a buffered solution consisting of hydrofluoric, nitric and phosphoric acids of varying compositions. Such mixtures introduce hydrogen into the high purity niobium material, which has recently been identified to be the cause

* This work was supported by the U. S. Department of Energy under contract DE-AC05-84ER40150.

of observed degradations of cavity performances. An alternate method to remove the surface damage layer from the niobium surfaces is the electropolishing process, which is used at KEK. During this process large amounts of hydrogen evolve in the polishing solution and significant portions are dissolved in the niobium. A 700° C annealing step for 1.5 hours under high vacuum conditions has routinely been part of KEK's treatment procedures to remove the interstitially dissolved hydrogen. The niobium material used for the fabrication of the TRISTAN superconducting cavities was lower in purity (RRR = 150) than the material used for CEBAF's cavities (RRR > 250) and at KEK no degradation problems were encountered with the applied process. It is of interest whether the KEK - process can successfully be applied to cavities made from niobium of higher purity.

This investigation was carried out to compare both processes especially with emphasis on cavity deteriorations due to absorption of hydrogen into the base cavity material of a Residual Resistance Ratio of 370.

CAVITY FABRICATION

Two single cell cavities of the CORNELL/CEBAF design were fabricated out of 1/8" thick high purity niobium with a RRR - value of 370 supplied by Fansteel. The cavities were resonating at 1471 MHz and 1480 MHz at 4.2K; other cavity parameters are as follows:

Geometry Factor 270 Ohm, Shunt Impedance 100 Ohm,

$E_{peak}/E_{acc} = 1.81$, $H_p/E_{acc} = 44.9$ G/MV/m.

After fabrication at CEBAF the cavities were electropolished in a horizontal position at KEK as shown in Figure 1 (in detail see reference 1) and a total of 120 μm was removed within four hours. The current density in the electropolishing process was 57 mA/cm^2 and the temperature of the HF/H_2SO_4 - mixture was held at 32° C. The next step of the process consisted of a annealing at 710° C for three hours at a pressure of $\leq 10^{-4}$ torr to remove the dissolved hydrogen from the niobium. During this step both cavities were heat treated simultaneously and were surrounded by a Ti

- box as shown in Figure 2. Figure 3 shows the vacuum profile during the temperature cycle: even after three hours at 710^{0}C the pressure in the furnace remained at 10^{-4} torr, an indication that the outgassing process is not completed after three hours at this temperature. Upon return to room temperature, the vacuum in the furnace improved to 10^{-7} torr.

Subsequently an additional 5 μm was removed by electropolishing within 12 minutes. After thorough rinsing with high purity water, stainless steel blank-off flanges and an all-metal valve were attached to the beam pipes of the cavities with indium gaskets and the cavities were evacuated. One cavity was baked at 80° C for ten hours, whereas the second cavity was not baked. In both cases the pressure in the cavities improved to 10^{-9} torr. The valves were closed off and the cavities were sent to CEBAF by air.

At CEBAF the cavities were let up to dry nitrogen gas, the flanges and the indium were removed, the cavities were rinsed twice with reagent grade methanol in the clean room and assembled in the standard way as described in reference 2.

TESTING AND RESULTS

The cavities were cooled down to 4.2K in less than one hour (fast cool-down) after a vacuum of $< 5 \times 10^{-7}$ torr had been reached in each cavity at room temperature. During cooldown the ambient field near the cavity was shielded to $\leq$ 10 mG by an active magnetic shielding coil. The surface resistance of each cavity was measured as a function of temperature between 4.2K $\geq$ T $\geq$ 1.7K and at the lowest temperature the change of Q-value with increasing electric field was obtained. The results of this experiment are shown in Figure 4 and Figure 5. In a second test each cavity was warmed up to $\approx$ 120 K and kept at this temperature for 21 hours before being cooled down again fast. Again R(T) and Q vs E_p was measured (see Figure 5).

DISCUSSION

The experimental data were fitted to the expression for the surface resistance

$$R(T) = A/Texp(-\Delta/kT) + R_{res}$$

(R_{res} = residual surface resistance, Δ/kT_c = energy gap) resulting in data for A, Δ/kT_c and R_{res} (see Figure 4). In a second fit, R(T) - R_{res} was compared to J. Halbritter's surface resistance program[3,4] with the mean free path ℓ and the energy gap as fitting parameters and with the following material parameters for niobium:

London penetration depth λ: 360 $\dot{A}$

Coherence length ξ: 640 $\dot{A}$

Critical Temperature T_c: 9.25K

The fitted results are shown in Figure 6 and the numerical values for the fit-parameters are listed in Table 1.

Table 1: Numerical values for material parameters for niobium after fitting to experimental results.

Treatment	$T_c[K]$	Δ/kT_c	$\lambda[\dot{A}]$	$\xi[\dot{A}]$	$\ell[\dot{A}]$	$R_{res}[n\Omega]$
e-polished cavity #1 fast cooling	9.25	1.88	360	640	947	32.9
Warmup to 120K, 21hours fast cooling	9.25	1.83	360	640	227	28.6
e-polished cavity #2 fast cooling	9.25	1.81	360	640	842	31.6
BCP(1:1:1) cavity #3 Fast cooling	9.25	1.85	360	640	1172	5.1

The results of these experiments can be summarized as following:

a). The cavities did not exhibit any degradation in Q-value when kept at an intermediate temperature of 120 K for several hours in contrary to chemically polished surfaces (Figure 5). As expected from this result, the temperature dependence of the surface resistance remained exponential.

b). The mean free path resulting from the data analysis is $\ell = 900\dot{A}$ in the case of fast cooldown. However, after warmup to an intermediate temperature, the value of the fitted mean free path is reduced.

c). Transportation of the cavity under vacuum with subsequent disassembly and rinsing resulted in good cavity performance.

CONCLUSION

The electropolishing process as performed at KEK with an intermediate annealing step at 710° C and a short polishing cycle afterwards does not lead to Q-degradation of a cavity. Even though dissolved hydrogen is not completely degassed from the cavity material at this temperature, a heat treatment at 710° C seems to be sufficient to avoid precipitation of residual hydrogen in the niobium during cool-down to cryogenic temperatures.

ACKNOWLEDGEMENT

This investigation has been carried out as part of the KEK/CEBAF collaboration. The authors would like to thank all colleagues, who supported this effort, in particular Prof. Y. Kimura for his continuous encouragement, C. Liang at CEBAF for his assistance in making the data fitting program available and to K. Miyamoto at KEK for his technical help.

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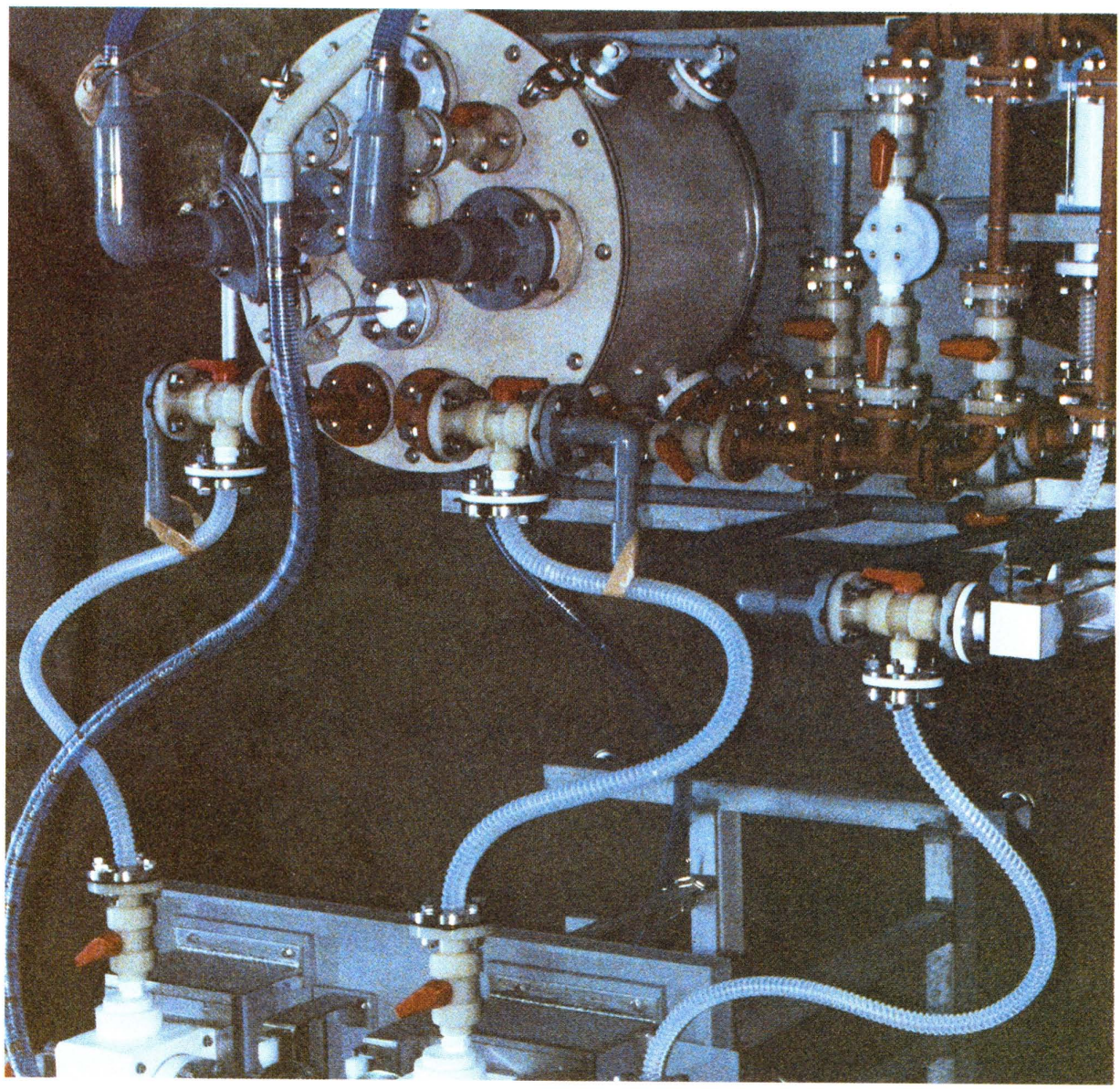

Fig. 1: Electropolishing Set-up

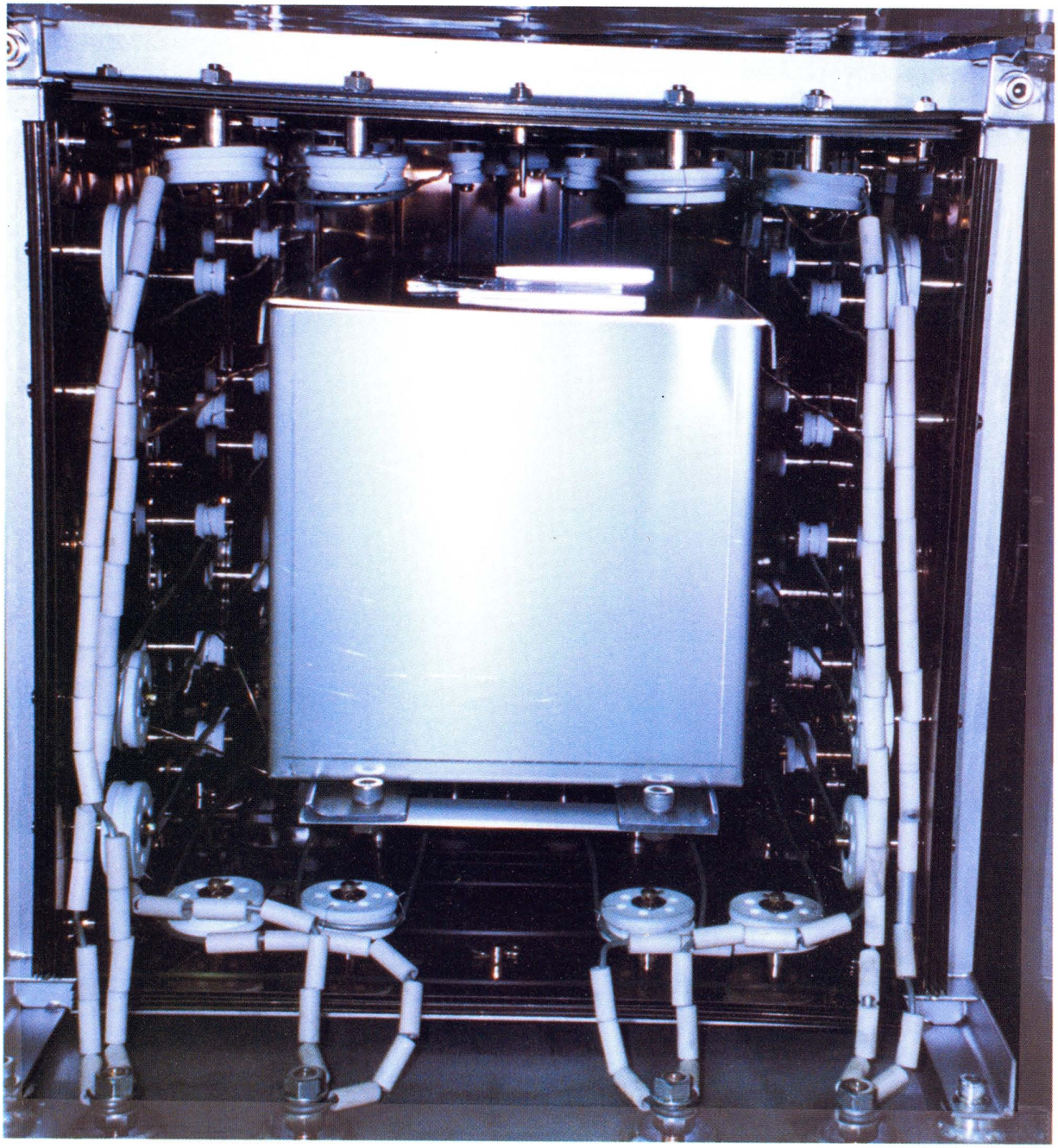

Fig. 2: Heat Treatment Furnace with Titanium Box

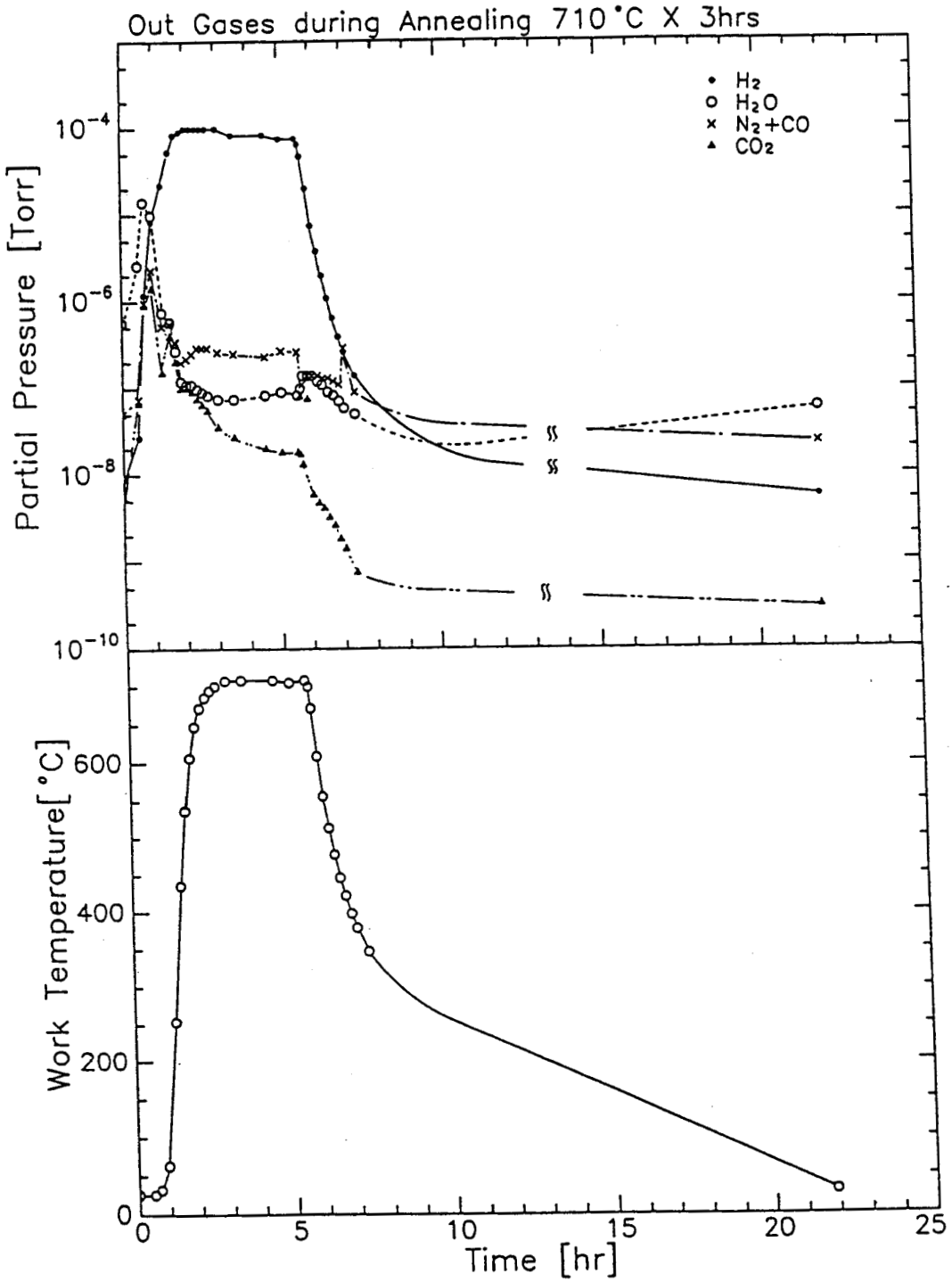

Fig. 3: Outgassing cycle for electropolished 1.5 GHz cavities
Upper part: partial pressure in furnace
Lower part: temperature-time profile

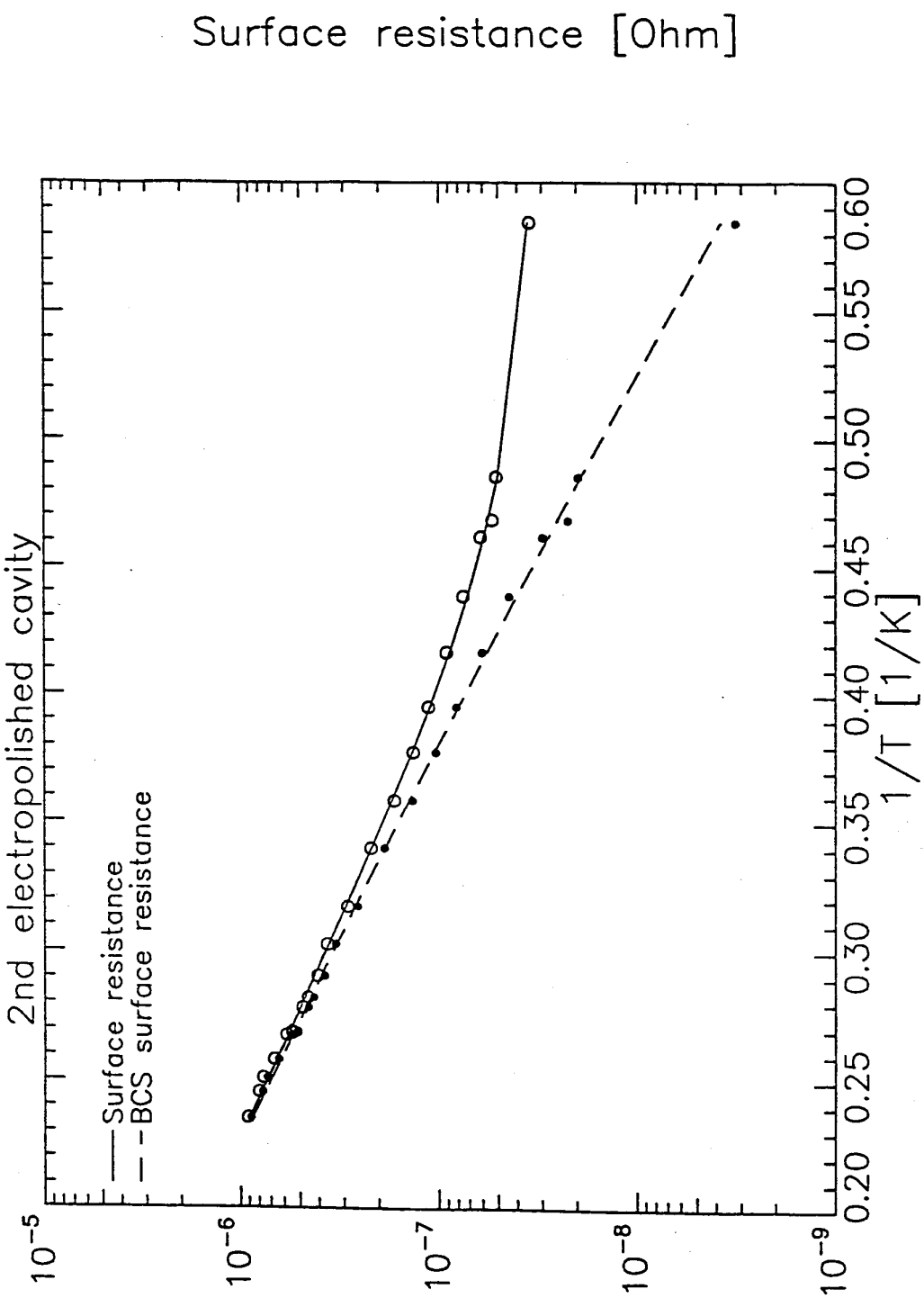

Fig. 4: Temperature dependence of surface resistance

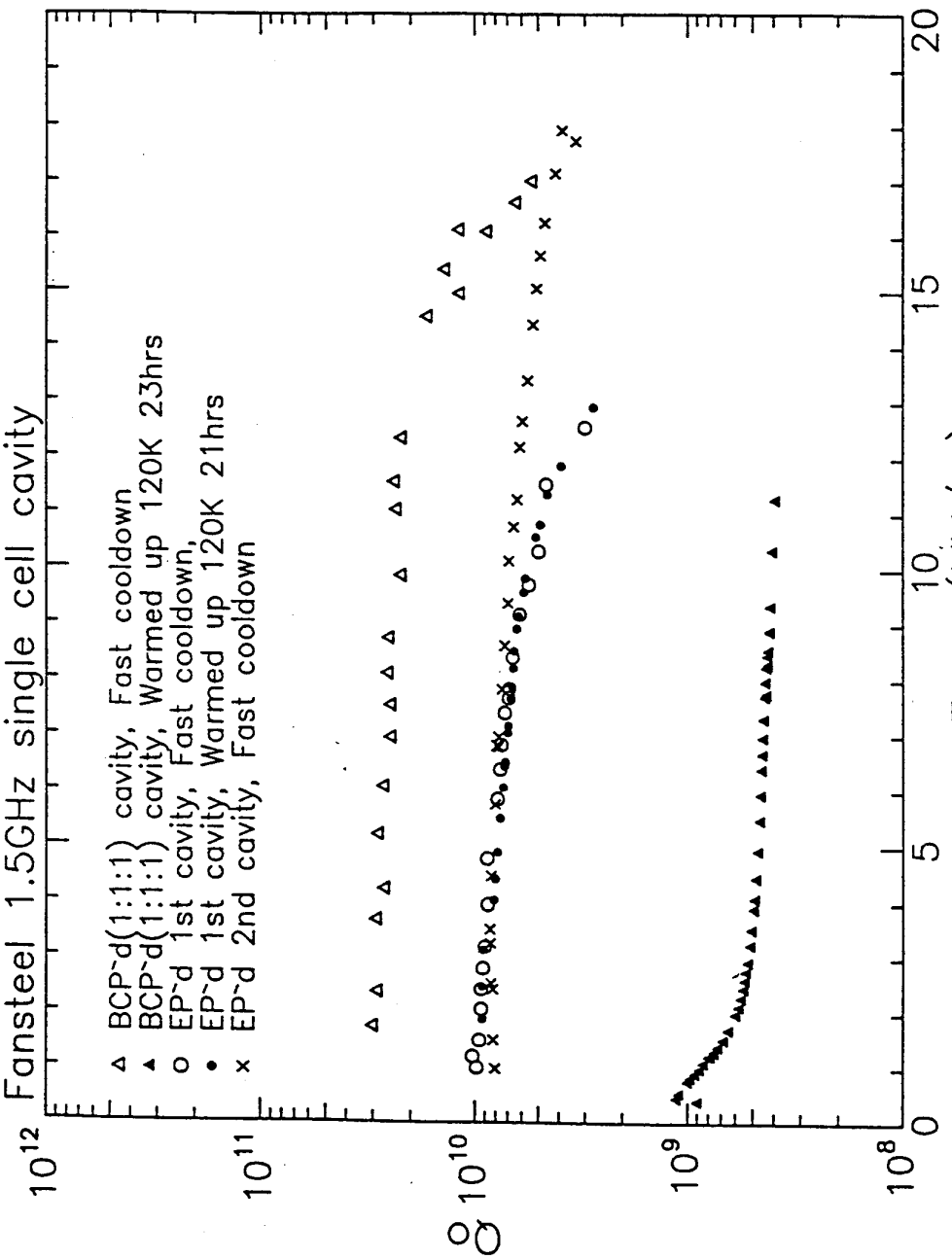

Fig. 5: Summary of Q vs. E_{acc} measurements of 1.5 GHz single cell cavities after various surface preparations

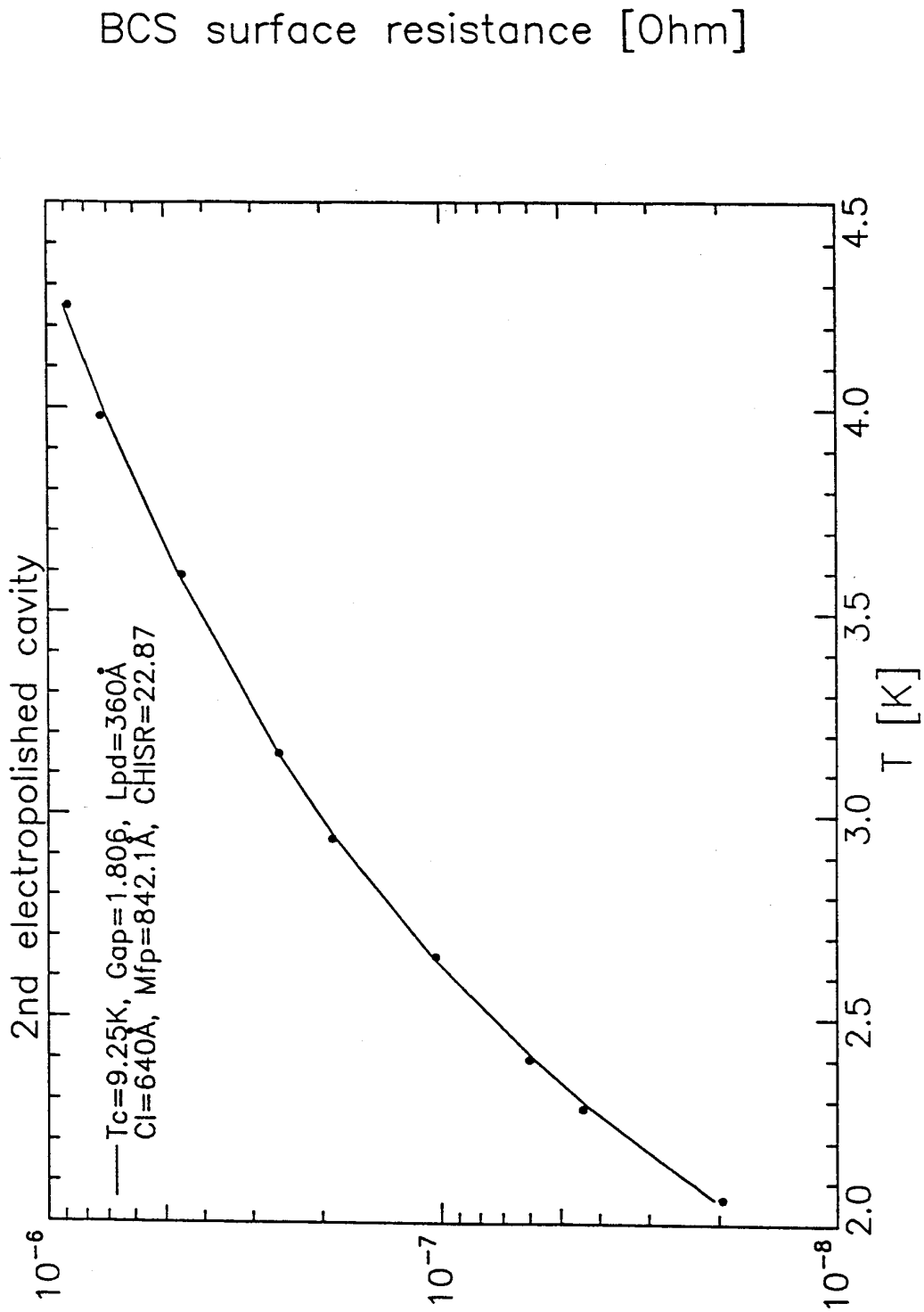

Fig. 6: Fit of experimental surface resistance data to BCS theory with mean-free path and gap as parameters