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ON A 500 MHz SINGLE CELL CAVITY WITH Nb_3Sn SURFACE

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ABSTRACT

A first experiment was performed to cover a 500 MHz niobium cavity with Nb_3Sn and to study its performances. The Nb_3Sn layer was grown by diffusion from the tin vapour. The critical temperature of the layer was measured to be (17.2 ± .3)K. At 4.2 K the low field Q value reached $2.4 * 10^{10}$. The maximum accelerating field, measured at 5.5 K was 4.9 MV/m, limited by a quench.

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1. INTRODUCTION

Following the BCS-theory the theoretical surface resistance decreases with the increasing critical temperature for a given resonator and at a fixed temperature. With the reduced surface resistance - or increased Q value - the power needed to build up a certain field, is also reduced. From this it may be interesting to study superconductors with high transition temperatures in respect to their possible accelerator application. With a critical temperature of up to 18.3 K and a thermodynamic critical field of about 5 kG Nb_3Sn is an interesting candidate for this purpose.

From the phase diagram it is known that Nb_3Sn can be produced by diffusion processes at temperatures higher than 930°C without creating the tin rich phases Nb_6Sn_5 and $NbSn_2$ which are poor superconductors [1]. Especially for resonators the diffusion of the tin from the vapour into the bulk niobium [2] seems easy to applicate. Therefore to cover a niobium cavity with Nb_3Sn this process was chosen.

2. PREPARATION OF THE Nb_3Sn LAYER

The experiments were performed on a cavity made from 4 mm niobium sheet material with an RRR of 25. Before the diffusion process the surface was chemically polished as described in [3]. To avoid a pollution of the available vacuum furnace the cavity had to be vacuum tight. Therefore two covers, one containing a recipient for the tin, the other a probe holder were prepared and electron beam welded to the cavity. Fig. 1 shows the ensemble. The numbers give the sequence of the weldings. The last welding was done after pumping the electron beam welding machine over a week-end, resulting in a residual pressure of about $1 * 10^{-5}$ Torr.

The heat treatment was performed in the large CERN furnace. After heating the cavity up to 1025°C within 3 h, the cavity was kept at this temperature for 8 h. It cooled down to 300°C by radiation, then cooling down was forced by introducing nitrogen. A first measurement was performed without rinsing. The performances of the cavity showed that the layer thickness was insufficient.

To increase the layer thickness the diffusion process was repeated at 1050°C after rinsing with methanol and welding in the same way described above. This time the cavity was rinsed with ultrapure water before testing.

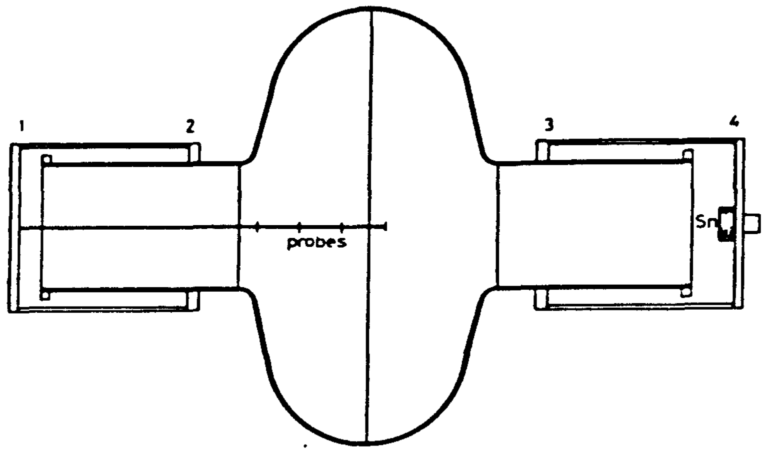

Fig. 1 500 MHz cavity prepared for heat treatment

After each heat treatment the vacuum of the cavity was broken by drilling a hole in one of the covers, which was done in a dustfree hut as the only precaution. To open the cavity the covers were sawed off outside the dustfree hut.

In a third series of tests the cavity was anodized in a 5% nitric acid solution with 20 V anodisation voltage, rinsed in ultrapure water, and measured with the oxide layer.

It should be noted that only existing CERN facilities were used and no systematic study of deposition parameters could be made.

3. RESULTS AND DISCUSSION

Besides, the studies of the r.f. cavity performances measurements on the layer thickness, on the composition, and on the critical temperature were done.

3.1 Layer thickness

The growing of the Nb_3Sn layers by the diffusion from the tin vapour depends mostly on the diffusion time and the reaction temperature. The layer thickness grows in a time t and at a temperature T as given by:

$$x = a(T) * t^{.36}$$

Fig. 2 shows the growth rates a(T) for diffusion processes done by different groups on different types of resonators.

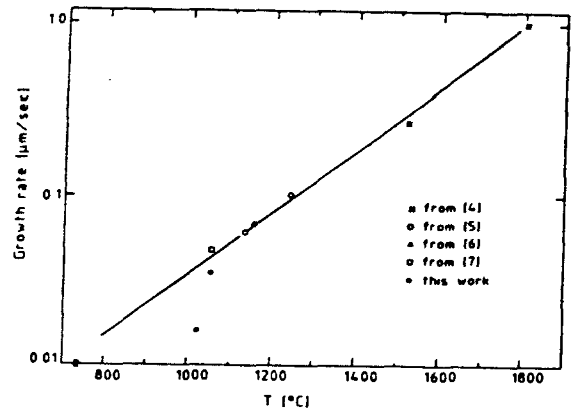

Fig. 2 Growth rate of Nb_3Sn layers by diffusion from the vapour

To avoid a surplus of tin at the surface which can react to the unwanted niobium tin phases during cooldown, at the first diffusion process only 9 g of tin were added to the cavity. This amount was calculated to be sufficient for a Nb_3Sn layer of about 4 µm. The heat treatment resulted in a layer thickness of (.55 ± .1)µm measured by means of a scanning electron microscope. The second heat treatment with additional 16 g of tin gave a Nb_3Sn layer of (0.9 ± .1)µm and a growing rate as expected (fig. 2).

3.2 Composition and critical temperature

The composition of the Nb_3Sn layer was determined by the characteristic x-rays to be (21 ± 1)at.% tin and (79 ± 1)at.% niobium. No impurities of elements with atomic masses higher than 19 were detected within 0.5% resolution.

The analysis of the Nb_3Sn layer by Auger spectroscopy during depth profiling shows the decrease of oxygen and carbon, which contaminate the surface, to the noise level within about 4 nm. On the contrary, nitrogen stays at about 3% within the same depth (fig. 3(a)). Again no other impurities are to be seen in the spectra (fig. 3(b)). To estimate the composition we used the sensitivity factor of .9 given by [8] and calculated a tin content of (26 ± 2)at.%. But to give the correct composition of the bulk by this method is difficult because (a) the remaining nitrogen may reduce the niobium peak and (b) the surface composition is probably changed to that of the bulk due to preferential sputtering [8].

The measurement of the critical temperature done inductively on a sample with a Nb_3Sn layer of 0.55µm shows the onset of the transition at 17.1 K and the midpoint at 17 K (fig. 4). The transition of the bulk niobium is seen at 9.1 K, probably because of boundary effects.

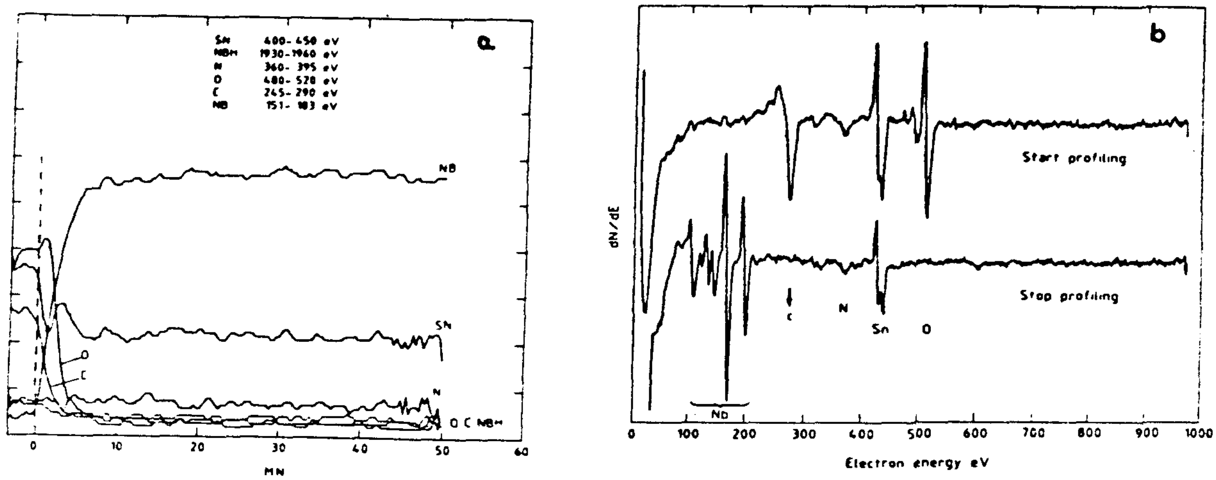

Fig. 3 Auger analysis: (a) depth profiling; (b) spectra at start and stop of profiling

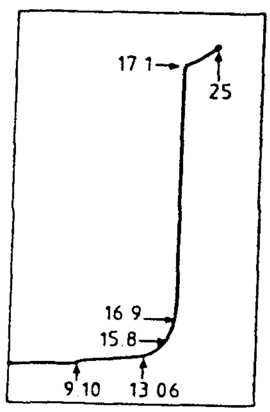

Fig. 4 Critical temperature measured inductively

To measure the critical temperature of the layer on the cavity the expulsion of trapped flux was observed during warming up. To do this, the cavity was cooled down in an external field of 300 mG perpendicular to the equator. The trapped magnetic flux was recorded by measuring the voltage of a Hall probe rotating around the equator [10]. With the external field compensated at 6.2 K, the trapped magnetic flux is expelled at the transition from the superconducting to the normal conducting state. Fig. 5 shows the signal of the Hall probe at 4.5 K and at 17.8 K. In fig. 6 the amplitude of the sinusoidal hall signal is plotted against the temperature. The complete expulsion of the flux is indicated at (17.2 ± .3)K by the reduction of the amplitude to 3 µV. This is the signal of the remaining external fields plus the noise level. The transition of niobium, probably polluted with tin, is to be seen at (8.6 ± .3)K.

Plotting the critical temperature against the tin content within the relative large errors our values fit to the correlation given in [11] (fig. 7).

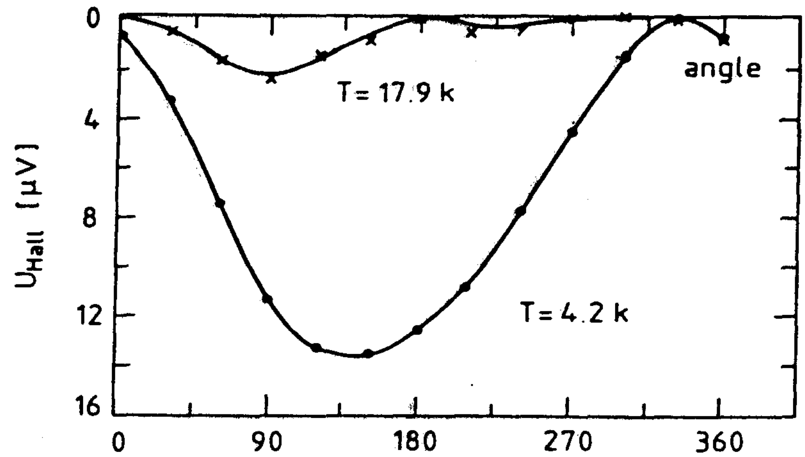

Fig. 5 Signal of the rotating Hall probe

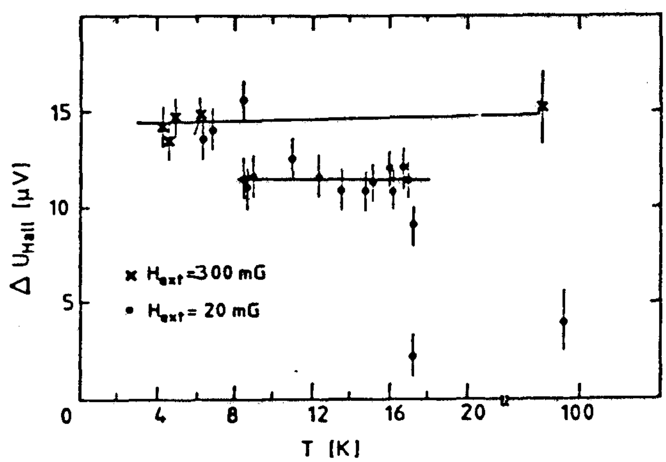

Fig. 6 Amplitude of the Hall signal

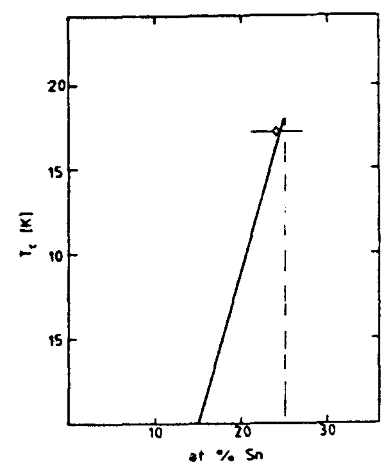

Fig. 7 Dependence of the critical temperature on the tin content

3.3 r.f. measurements

The cavity was studied in respect to the accelerating field behaviour, the influence of external magnetic fields on the surface resistance, and the temperature dependence of the surface resistance.

3.3.1 Accelerating fields

The first test of the Nb_3Sn covered cavity, with a layer thickness of 0.55 µm gave a residual Q of $2 * 10^9$, due to the underlaying niobium, which is "seen" by the r.f. field. The field was limited by strong electron loading to 2.9 MV/m reducing the Q to 10^8.

The second test, with the 0.9 µm layer, resulted at 4.2 K in a low field Q of 2.4 * 10^{10}, decreasing to 10^{9} at 4.2 MV/m. Initial electron loading which limited the field to 2.8 MV/m in a quench was overcome by helium processing. But operating the cavity in the quench led to a reduction of the Q value. After warming up the cavity to 25 K the initially measured values were found (fig. 8).

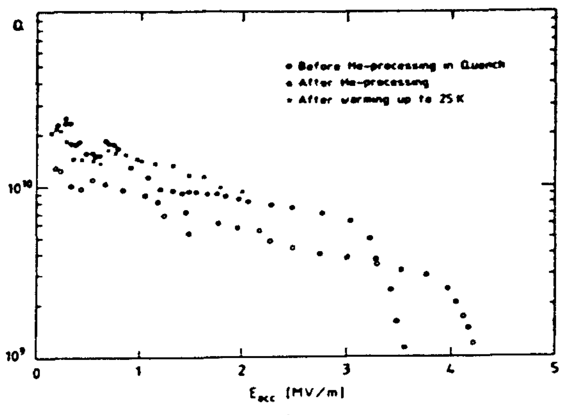

Fig. 8 Q(E) of the .9 µm Nb_3Sn layer at 4.2 K

The field was finally limited by the quenching of a defect, that already can be seen on the temperature maps at the lowest fields (fig. 9). The inspection showed a black spot of about 1 mm diameter at the quench location. The dark colour is probably due to oxidation of the hot spot.

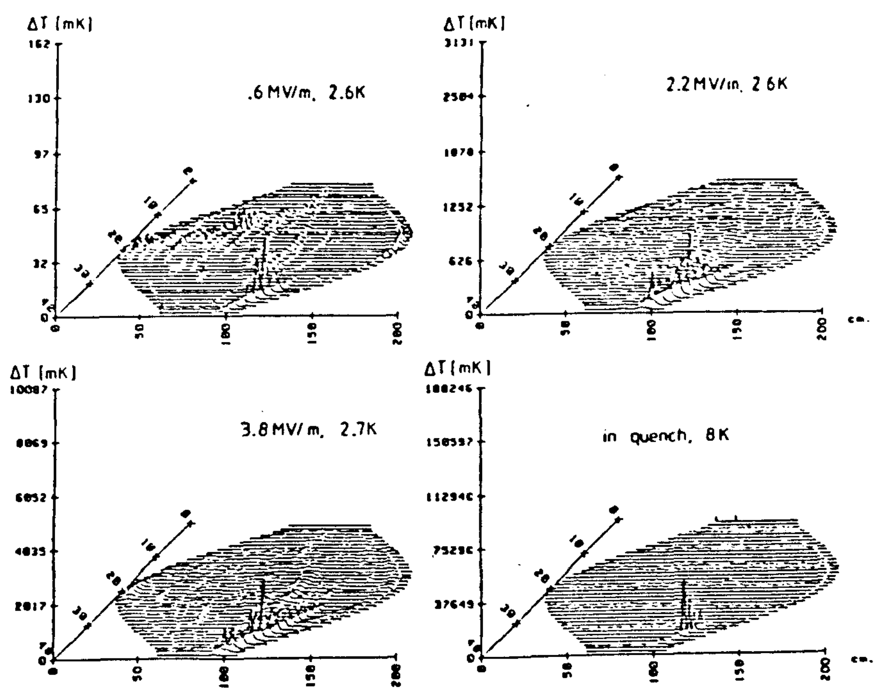

Fig. 9 Temperature maps at different field levels

At a third test after anodisation a leak opened during cooldown and the measurements could be only performed with the cavity cooled by helium vapour. At a temperature of (5.5 ± .2)K the low field Q was $1.6 * 10^{10}$. Immediately the field could be increased to 4.9 MV/m, with a Q value still $5.9 * 10^{9}$. At about 5 MV/m quenching occurred (fig. 10). Electron activity at the first field increase seems to be similar compared to bulk niobium cavities.

3.3.2 Influence of external magnetic fields

It is well known [12] that external magnetic fields increase the residual resistance of a superconducting cavity by the normal conducting cores of the trapped flux. Increasing the external magnetic field to 300 mG increased the residual resistance to 22.5 nΩ (fig. 11). Compared to niobium cavities the influence is less important because of the smaller coherence length.

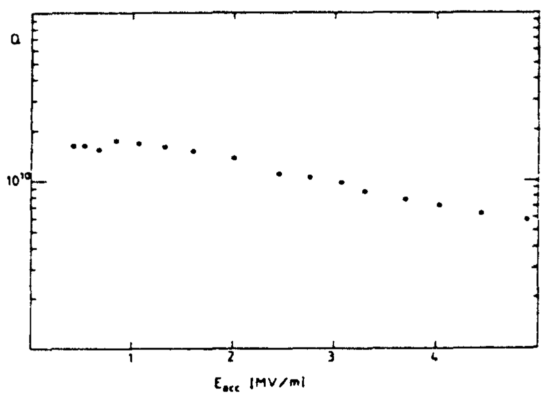

Fig. 10 Q(E) of the anodized Nb_3Sn cavity at 5.5 K

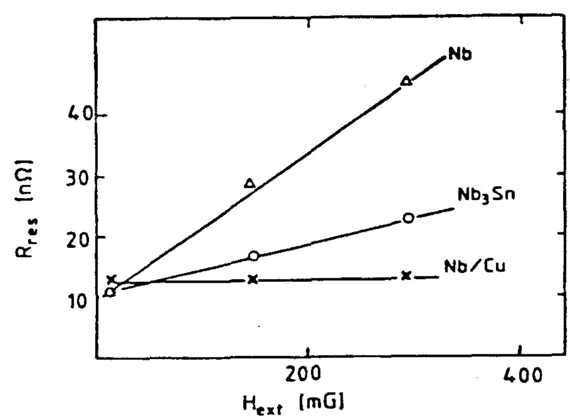

Fig. 11 Dependence of the residual resistance on external magnetic fields (Courtesy W. Weingarten)

3.3.3 The surface resistance

Extrapolated from measurements on Nb_3Sn coated cavities at 3 GHz [13] and at 8 GHz [14] the theoretical surface resistance at 4.2 K may be about 140 times lower than the one for niobium. Fig. 12 shows the temperature dependent BCS curve and our measured surface resistance. Even our value of 11 nΩ is far from theory. But certainly the performances are still influenced by the underlaying niobium, as the layer of .9 μm is thin related to a penetration depth of 0.11 μm to 0.15 μm.

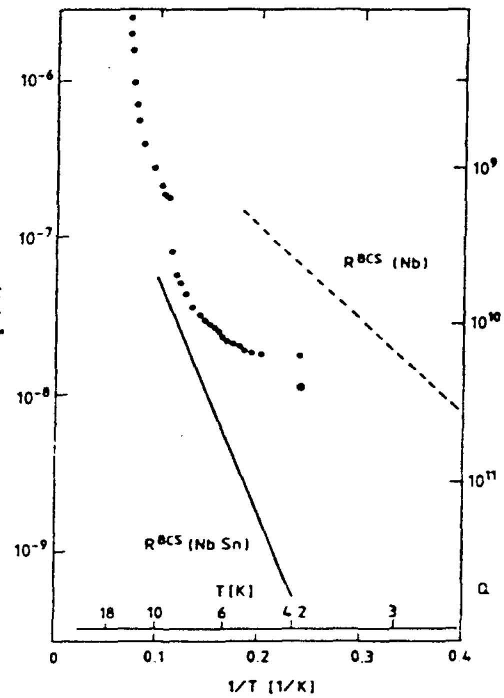

Fig. 12 Dependence of the surface resistance on the temperature

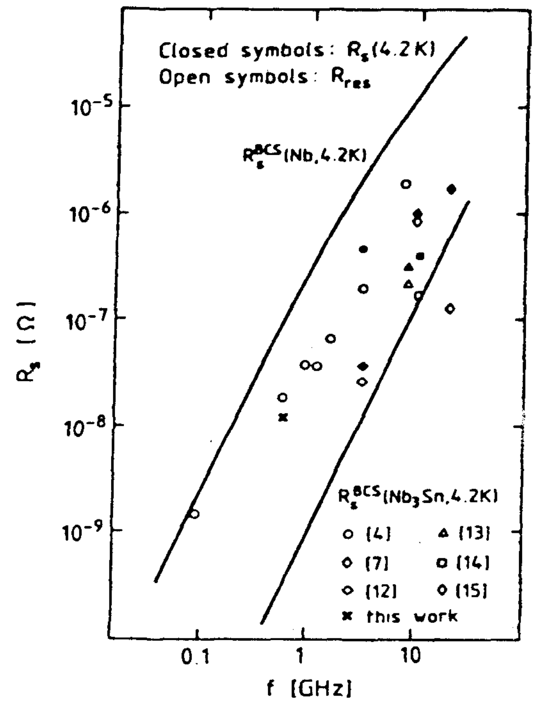

Fig. 13 Dependence of the surface resistance on the frequency

Fig. 13 shows the surface resistances at 4.2 K and the residual resistances plotted against the frequencies. For β = 1 structures our value is the lowest reached to date. The plot shows a tendency towards lower surface resistances at lower frequencies demonstrating the "state of the art" in surface preparation.

4. CONCLUSION

A bulk niobium cavity was coated with a Nb_3Sn layer via diffusion of the tin from the vapour. The transition temperature of this layer was measured to (17.2 ± .3)K. After anodisation at 5.5 K a Q value of $1.6 * 10^{10}$ was reached at low fields. The maximum accelerating field was 4.9 MV/m limited by a quench. At this field, practically the design field for LEP II, the Q was still $5.9 * 10^9$, roughly a factor of two higher than the LEP design Q. Reaching these values regularly in LEP structures would considerably reduce the refrigeration costs.

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