“Niobium Titanium Nitride for Superconducting accelerating cavities”

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Abstract

The results on an accelerating cavity Working at 3 GHz made in Niobium Titanium Nitride are presented.

The cavity was built by the standard technique of deep drawing and Electron Beam Welding. The material used was a 2 mm thick sheet produced by Teledyne Wa Chang starting from a standard composition (47% weight Ti) Nb-Ti alloy for Superconducting cables.

The cavity, chemically polished, was heated in our furnace up to 1300 Celsius. Electronic Grade Nitrogen (less than 10 ppm impurities) was admitted in the hot zone to allow for the reactive growth of the (Nb-Ti)N phase.

The resulting thickness of the surface phase was one micron. The Rf tests on the cavity have shown a transition temperature of 17.1 K and a Qo 3x10^9 at 4.2k, corresponding to a surface resistance of 100 nanoohm.

No further increase of the Qo was obtained by lowering the operating temperature below 1.8K.

The limitation on the field was a very strong NREL starting at about 2 MV/m. The degradation of the Qo was acceptable up to accelerating fields of 5-6 MV/m.

The Qo and accelerating field did not change in a substantial way after six months long exposure to the atmosphere.

XPS and Auger analysis of (Nb-Ti)N samples exposed to CO, CO2 and O2 showed very low reactivity of the (Nb-Ti)N, ten times lower at least then the reactivity of the niobium to the same gasses.

Introduction.

Since 1991 the Genoa Lab works (together with the Legnaro and Naples Labs of INFN) to the development of new materials and techniques for the production of Superconducting cavities.

The aim of the collaboration is to develop possibly new technologies allowing for a more reliable and cheaper construction and operation of large Linear electron-Positron colliders with a center mass energy in the TeV Range.

The Niobium Titanium Nitride is, among the other niobium based materials, very interesting for RF applications.

The high Critical temperature T_C of 17 Kelvin for the cubic phase, the insensitivity to the radiation damage, and the low secondary emission coefficient is very attractive for the production of superconducting accelerators working at High accelerating fields.

The high T_C Will allow for operation of accelerating structures at boiling liquid Helium at 4.2 K (LHeI) also at frequencies higher than one GHz, producing a strong reduction either of the installation and operation costs of the Criogenics for the accelerators.

A Refrigeration system using LHeI is simpler and cheaper than a Superfluid refrigeration plant; furthermore the overall efficiency is roughly three times higher.

Cavity Construction

Production of Niobium Nitride cavities in Genoa is based on Thermal reactive diffusion in a Furnace

The cavities are built starting from a Niobium Titanium foil following the standard method used for the bulk niobium cavities.

A Niobium Titanium sheet (two millimetres thick) is deep drawn in half cups using a dye and a Hydraulic press.

The composition of the Niobium Titanium is the standard composition (47% weight or 63% atomic) of the commercial alloy used for production of Superconducting cables[1]

The half cells and the Beam tubes are cut to the final dimension on a CNC Lathe Using Titanium Nitride hardened cutting Tools and water as coolant.

The half cells are chemically polished to remove 100-150 microns of damaged layers from the surface and Electron beam Welded together ant to the beam tubes to form a complete cavity.[1]

After the welding the complete cavities are again chemically polished removing 50 microns of material.

The shape of the cavity is shown in figure 1, the electromagnetic parameters in Table I

TABLE I

frequency	3 GHz
G	230 Ω
R/Q	133 Ω
E_p/E_a	1.9
E_a/H_p [MV/mT]	$1/3.5$

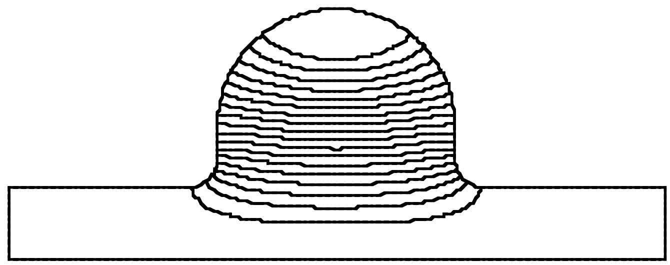

Fig 1; cavity shape with superimposed the electric field lines

Nitride Preparation

The cavity is inserted in our UHV furnace after the last chemical polishing.

After the initial pump down of furnace to 10^{-8} Torr, the cavity is outgassed increasing the furnace temperature up to 1200 C..

During the outgassing of the cavity, the vacuum in the furnace is kept always below 10^{-6} Torr.

The cavity is kept for a short period (30-45 Minutes) at 1200 C to allow for a better removal of oxygen and Interstitial carbon, and to homogenise the superconductor.

The Commercial “Cable alloy” contains a small amount of α–Titanium. This low Tc phase is very useful in the DC application, producing the defects needed to pin the magnetic flux in the superconductor at high Field.

In the case of the cavity application the α phase produces unwanted RF losses increasing the residual Losses.

After the homogenisation, we fill the reaction Chamber with 300 mbar Electronic grade Nitrogen (less than 3ppm total impurities) and we increase the Temperature up to 1600 Celsius.

We kept constant the temperature of the furnace within 5 Celsius and the Nitrogen pressure within 10 mbar for the reaction time (24 Hours).

At the end of the nitriding the temperature of the reaction chamber is lowered in the fastest possible way to avoid the precipitation of unwanted phases with lower T_C and higher losses at the grain boundaries.

RF Measurements

The measurement of the (Nb-Ti)N cavities is performed on the standard RF Setup, allowing measurement of the cavity Q and Fields in the temperature range 1.5-20 K with a refrigeration power of 5 watts at 1.8 K.

The results of the measurements of the surface resistance versus the temperature are shown in figure 2

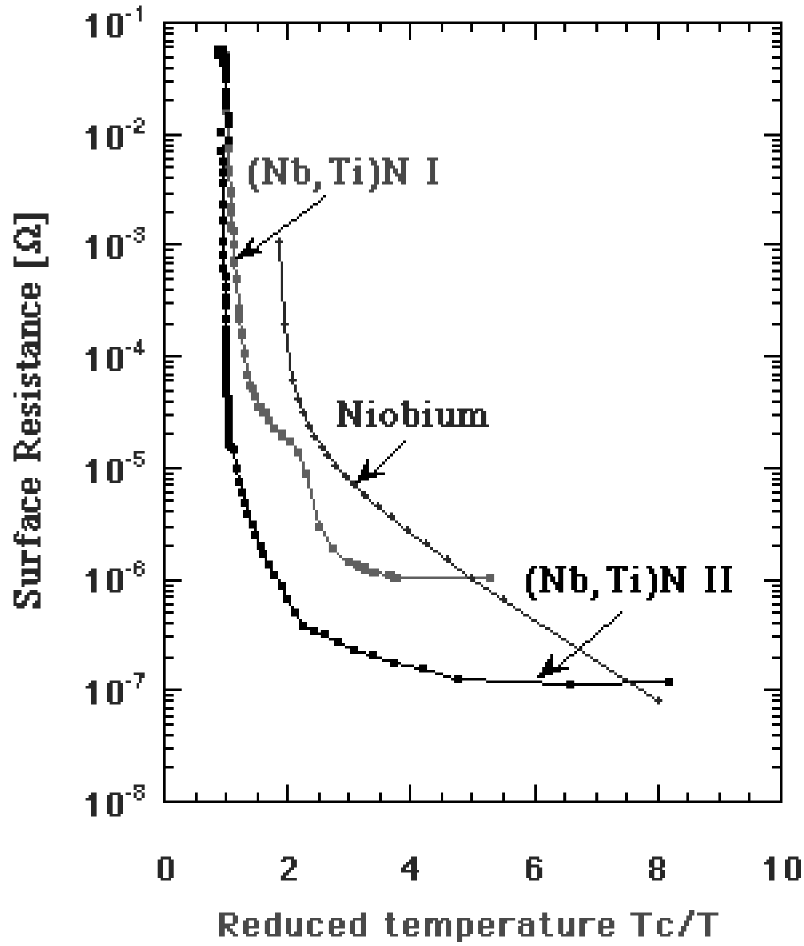

Fig 2; Surface resistance versus T_c/T for two cavities reacted for 6 hours (Nb-Ti)N I and 24 Hours ((Nb-Ti)N II. The theoretical BCS Surface resistance of the niobium is superimposed for comparison.

Simply by inspection of the plot it is straightforward to see that transition of both the cavities was a sharp transition at 17.1 confirming the values obtained either by measuring the resistive transition or the Magnetic susceptibility on small samples reacted in the same way.

The cavity reacted for the shorter time (6 Hours) shows a rather large surface resistance and a second quite broad transition around 8.5 K.

This transition is due to the insufficient thickness of the surface layer, allowing the penetration of the RF Field in the region containing lumps of Nb_2N phase mixed to α-TiN.

A longer reaction time (24 hours), producing a thicker layer of the 17K Phase, overcomes that problem as shown in the (Nb-Ti)N II plot

The surface resistance drops rather sharply reaching 100nΩ, or a Q_0 value of $2x10^9$, at 4.2K; no further gain on the surface resistance is obtained by lowering the temperature of the helium bath down to 1.8 K.

The Q_0 versus field plot, reported in figure 3, shows no significant variation of the quality factor increasing the RF field; as shown in the figure the behaviour of the cavity is very similar to the behaviour of a niobium cavity operating at 1.8 Kelvin up to about 7 MV/m

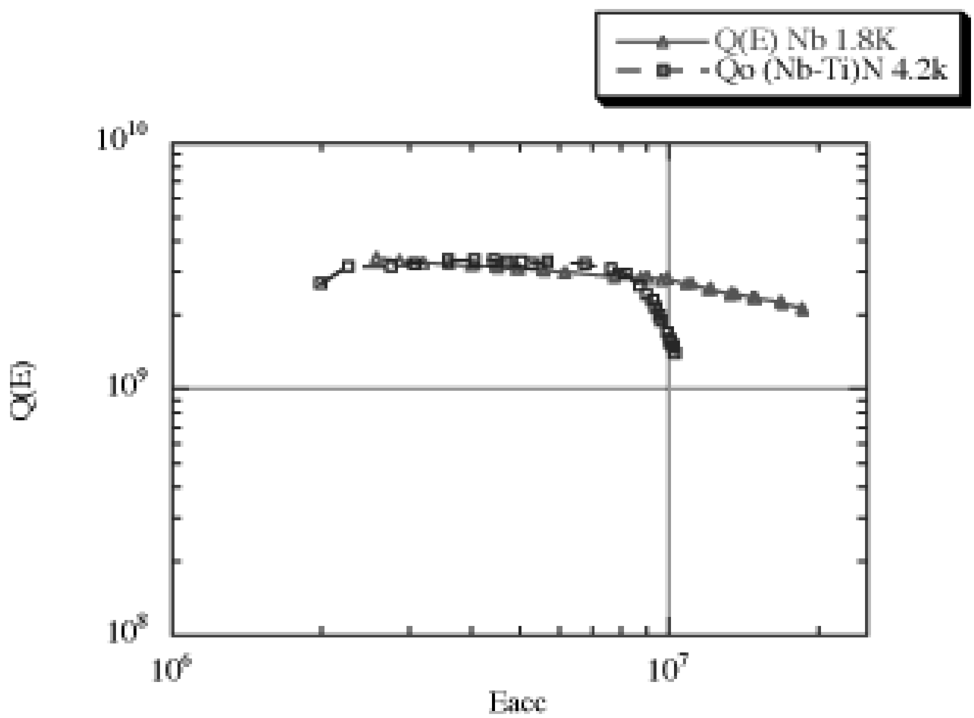

Fig 3; Quality factor versus accelerating field plot for the (Nb-Ti)N II cavity at 4.2K; the quality factor is constant as in a Niobium cavity at 1.8k till to the beginning of the NREL

The limitation on the accelerating field was produced by a very strong NREL starting at about 5 MV/m of accelerating field.

The Fowler Nordheim Plot of the Total flux of X-Rays measured outside the Cryostat gives a value of 250 for the Field enhancement factor beta.

A similar value of β=265 is found by the analysis shown on figure 4 of the RF power drained by the electron current

The reason for the strong field emission is mainly due to roughness of the surface of the cavity produced by gas metal reaction.

The growth the NbN phase on the cavity surface produces the serration of the former Crystal grains of the alloy resulting in small protrusions with a high field enhancement factor.

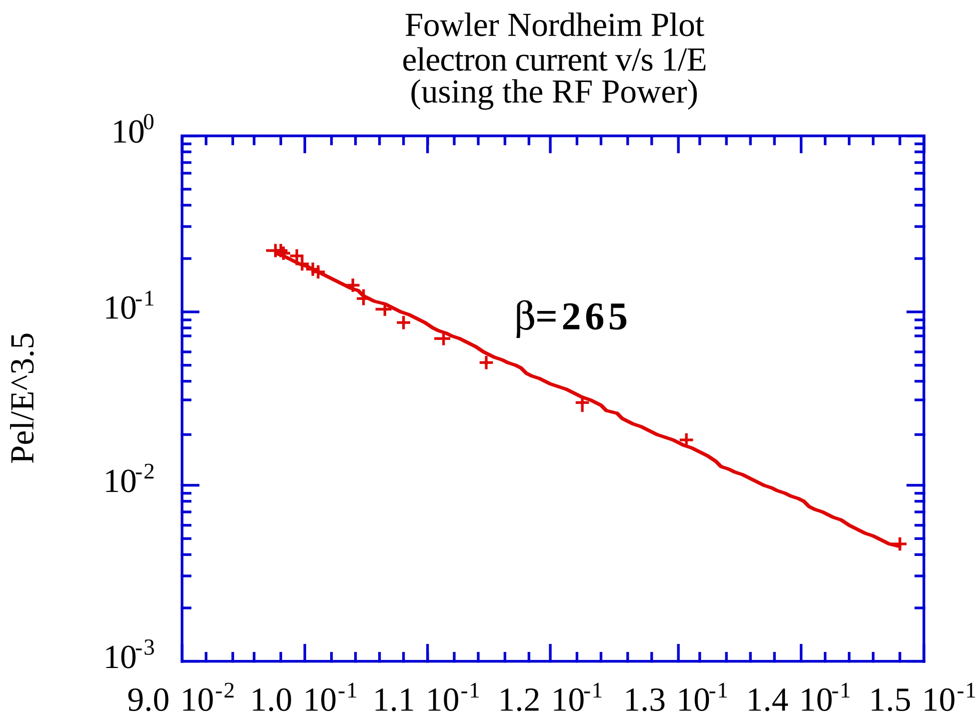

fig 4; Fowler-Nordheim Plot of the RF power dissipated by the electron current in the cavity showing a field enhancement of 265

Conclusions

From the experimental results the Niobium Titanium Nitride appears to be a very suitable material for accelerating cavity applications.

A suitable choice of the reaction parameters gives a uniform layer of the cubic phase With a 17 K T_c on the cavity surface as shown also by the AC susceptibility measurements performed in our lab (fig 5)

The Rf Behaviour of the Nitride cavities at 4.2 Kelvin is similar, for the Q_o value, to the behaviour at 1.8K of niobium cavities.

The Q versus field plot shows no Q_o degradation with the field up to the onset of a strong electron loading.

The field enhancement factor β=250 we measured is consistent with the surface roughness of the sample. This roughness is mainly due to the Lumps of δ-TiN found in the β–Nb_2N layer under the surface.

Using a Nb-Ti alloy with a content of titanium of 47% atomic (31% weight) greatly reduces the surface corrugation after the reaction, and gives an even sharper superconducting transition at 17.5 Kelvin

Last the quite high surface resistance should be induced by the not so high purity of the Starting niobium titanium alloy.

As reported we used a standard Nb-Ti "cable alloy" having by far a higher content in impurities and a worse homogeneity compared with the 3R Niobium specifications.

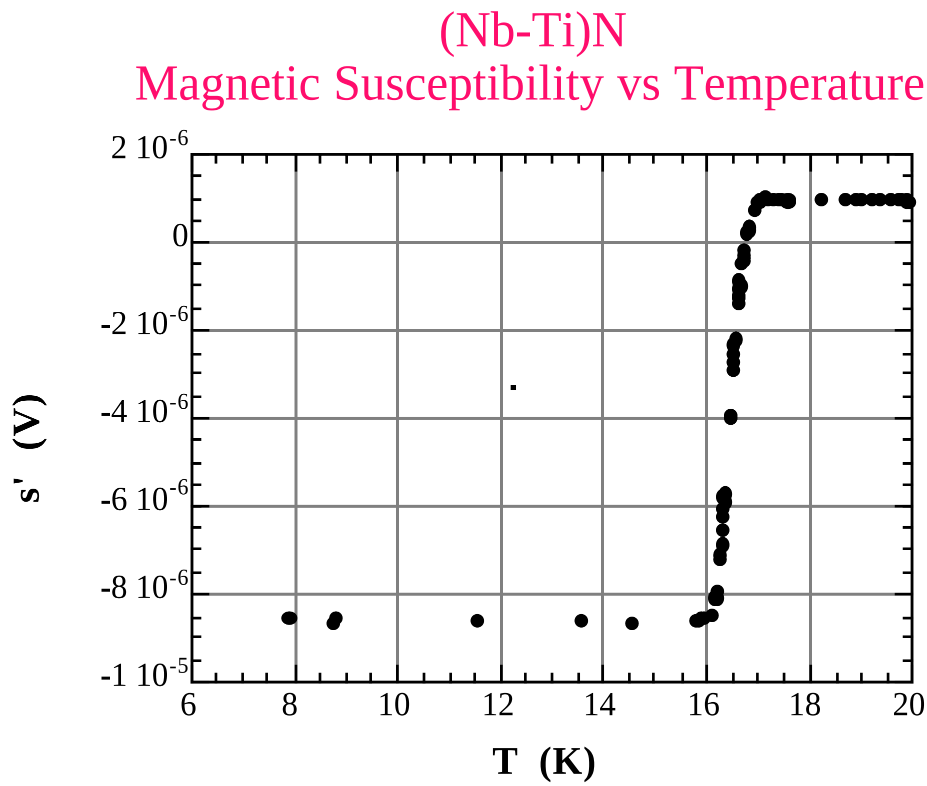

Fig. 5; AC susceptibility (real part) of a Nitride sample showing only a clean 17.2 K Tc phase on the sample surface.

References

[1] Teledyne Wa Chang ,Albany, Oregon

[2] ETTORE ZANON SpA Via Vicenza 18 Schio VICENZA