CEA Saclay Laboratory report

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Abstract

The first part of this paper reviews the R&D activities made at Saclay these last two years on RF Superconductivity. The second part presents the projects in which our group is committed.

1. R & D activities

1.1. High gradients

As described in reference [1] the large increase of the performances of niobium cavities obtained these last two years is mainly the fruit of the work done to increase field emission and quench field thresholds.

Saclay activities on field emission and the collaboration with IPN Orsay, are presented in detail by M. Luong in the paper reference [2]. Our interest has been concentrated on geometric defects and conductive particles, and on the understanding of the field emission mechanism in DC and RF regimes. Most of our work was made on metallic protrusions which have the same behaviour and are more stable under high fields than unattached conductive particles. The β and A_e parameters of the Fowler-Nordheim's law were determined on the same emitter in DC and RF regimes. Their values were found identical. Experimental results are consistent with the explanation that high field enhancement factors β result from a multiplicative effect of a geometrical superposition of nanometer size protrusions with micrometer size ones. Also in favour of this argument is the observation that smoothing slightly protrusions by electron beam or high pressure water strongly reduces field emission.

Field emission used to be one the main limitations for achieving high gradients in superconducting cavities before high pressure rinsing showed its potentialities on a Nb/Cu cavity [3]. Now this treatment seems to be inescapable to reach high accelerating fields. We developed our own system working in a class 100 clean room which proved to be quite efficient. At present, field emission is generally suppressed by high pressure rinsing up to accelerating fields of 30 MV/m.

An other major effort was to optimise the thermal treatments for the purification of the cavities niobium walls by Ti gettering. We heat first at 1300°C for 4 hours, then at temperature slowly decreasing to 900°C for about 40 hours [4] in order to increase the thermal conductivity of the niobium at low temperature [5], and therefore the quench field threshold. RRR values as high as 430 can be obtained starting from a RRR 150 bulk cavity. Accelerating fields up to 30 MV/m are often obtained.

We have also tested the purification treatment on the half cells only, and others heat treatments at lower temperatures and of shorter time ; the results are encouraging (fig.1).

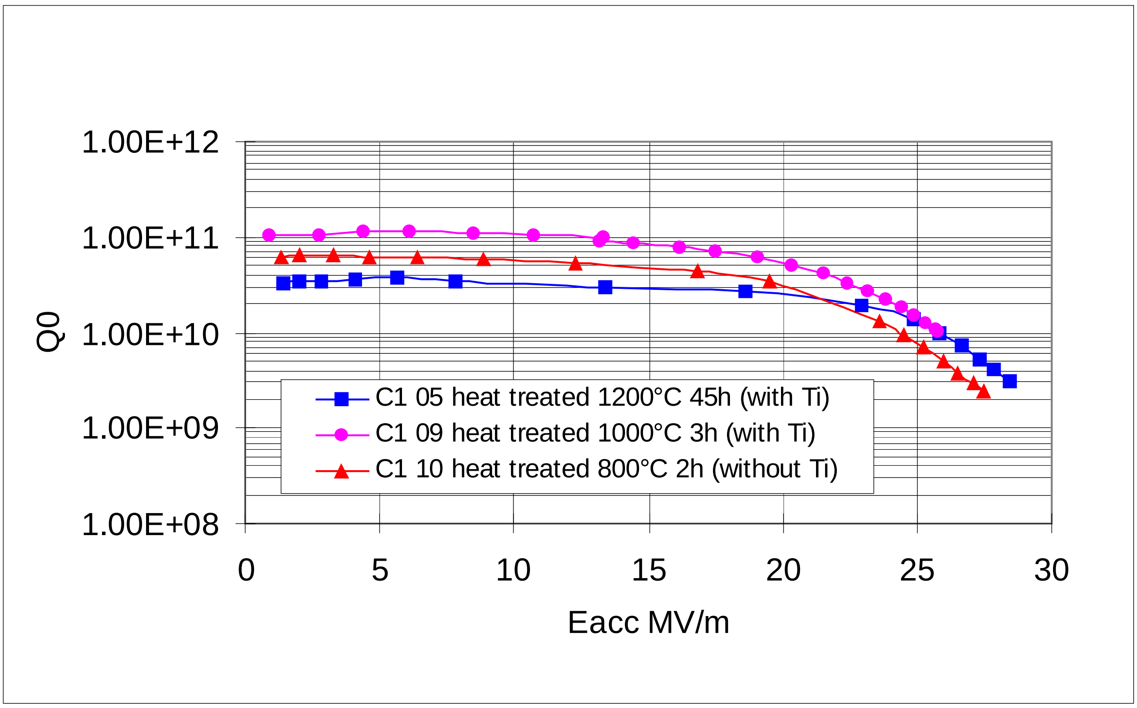

Fig. 1 : RF performances of cavities after different heat treatments

However, for fields higher than 17 MV/m, most cavities exhibit a strong decreasing slope in Q with increasing field though no field emission is detected (fig.1), revealing an ununderstood phenomenon. Temperature mappings made in collaboration with IPN Orsay show an almost homogeneous heating of the cavity. We will continue experiments in order to understand and overcome this limitation.

A collaboration has been undertaken with KEK to compare and understand the RF performances obtained with cavities in the 2 laboratories [6]. Three 1.3 GHz single-cell cavities, previously measured at KEK, have been tested at Saclay. Two cavities made from Tokyo Denkai niobium were fabricated by CERCA and also tested at Saclay following our usual procedure. The above mentioned Q degradation is systematic for cavities prepared and tested at Saclay, and not systematic at KEK.

1.2. Residual resistance

The Niobium high purity we have reached has allowed to reduce the residual resistance. In addition, by improving the magnetic shielding and taking care of the dissipation in the end tubes, we have obtained, for the 1.3 GHz single-cell cavities C1-01 and C1-09, a surface resistance at 1.5 K as low as 3 nΩ, i.e. Q_0 as high as 10^{11}.

1.3. Local RRR measurements

We have developed an non-destructive magnetometric method for measuring the electrical conductivity and applied it to the RRR mapping of niobium cavities [7]. The sensors are composed of two coupled coils placed close to the niobium surface. Their mutual inductance is modified by the conductivity of the material. They are fixed to a movable arm rotating around the cavity thus permitting the RRR mapping. The local measurements are consistent with the results obtained by the destructive DC method within 10 %.

1.4 Thin Films

R&D on thin films has been continued on pure niobium coatings deposited on copper substrates (Nb/Cu). Our major effort has been to find a chemical polishing treatment for 1.5 GHz copper cavities. This study is still going on.

Two sputtering set-ups are available for depositing on samples and on 1.5 GHz cavities. A TE011 cylindrical cavity working at 4 GHz (and 5.7 GHz in the TE012 mode) is used to measure the surface resistance at 4.2 and 1.6 K of samples Φ126 mm in diameter (fig.2). The limit of these measurements is reached if the samples have a lower surface resistance than the bulk niobium of the rest of the cavity. An alternative method, using thermometers under vacuum, is being developed to determine after modelisation the surface resistance from the temperature rise on the disc.

The optimisation of the Nb deposition parameters is under way (RRR > 65 have already been obtained with Nb coatings deposited on SiO_2 substrates), and the influence of the heat treatment temperature on the copper substrate diffusion into the Nb films has been studied on samples. No significant pollution of the Nb coatings by the copper substrate occurs up to a temperature of 800 °C applied during one hour [8].

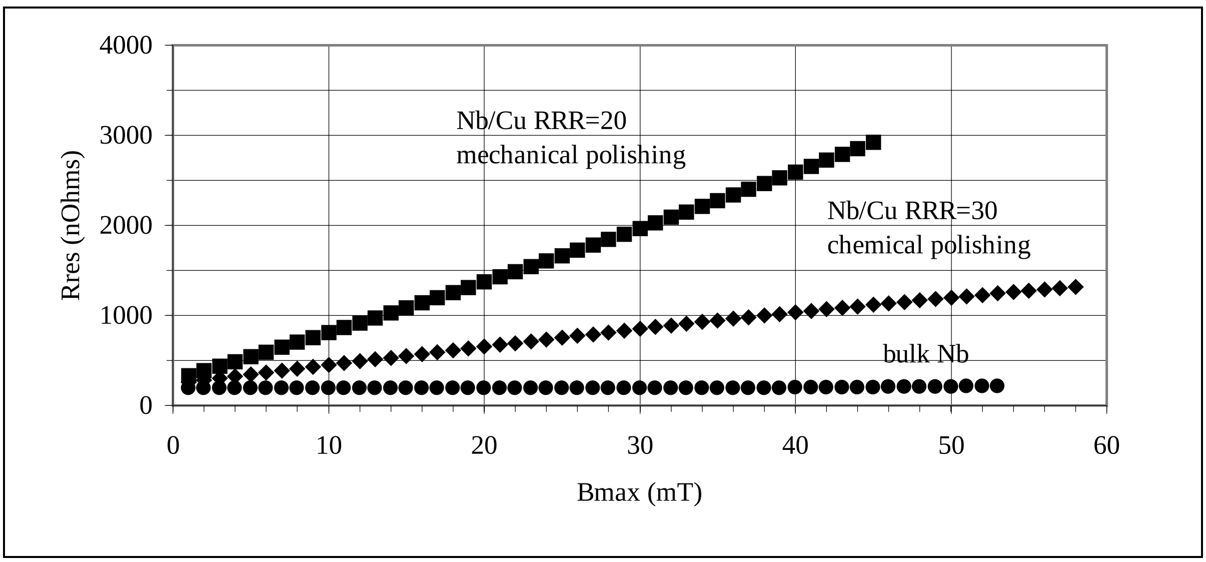

Fig.2 :Residual surface resistance of two different Nb coatings deposited on copper determined from RF measurements on TE012 mode at 5.7 GHz and T=1.7 K.

1.5. Hydroforming of 1.3 GHz Nb cavities

This work is presented with more details in reference [9]. The hydroforming programme is made in collaboration with different institutes and industries : the extruded tubes (RRR 20 and 200) follow a fabrication scheme developed by Forges de Bologne, hydroforming itself is performed at Bourgogne Hydro, and the modelisation with the code FORGE2 was developed by CEMEF.

The calculations, which can predict the radius and the thickness within 3 % accuracy, also predict that the shape could be obtained in 2 steps (only one annealing) in using RRR200 niobium tubes. The hydroforming of copper cavities was successful in two to three steps, depending on initial tube radius. However the hydroforming of a niobium cavity led to a breaking not far from the final deformation (fig.3).

The major cause for the breaking is the heterogeneity of the Nb tubes which were used : their grain size varied from 30 to 120 µm , and the crystallographic texture (orientation of the crystallites) may not favour the maximum possible strain. Other causes for the breaking are that some laws such as friction were not included in the first calculations, and that the path chosen for the deformation was not yet optimum.

Fig.3 : The maximum deformation obtained for 1.3 GHz cavity hydroforming

1.6. Copper plasma deposition on Nb cavities outside surface

This technique is being studied with the Orsay LAL and IPN for stiffening the cavities and reducing their cost due to thinner Nb wall needed [10]. The first test was made in June 1995, on the 1.3 GHz C1-02 single cell cavity fabricated with half cells 2mm thick made out of niobium purified by heat treatment. After copper plasma deposition the cavity did not show any Q_0 degradation and only a small reduction in E_{acc} from 30 MV/m to 27.6 MV/m.

1.7. Input coupler test stand

As described in reference [11], we built in collaboration with LAL and IPN Orsay an input coupler test stand that allows to test new coupler design for TESLA. This stand is made of a 1.3 GHz klystron able to deliver up to 1.2 MW of RF peak power during a 0.8 ms pulse at a repetition rate of 0.1 Hz. The coupler (or piece of coupler) is tested. under travelling wave condition if the waveguide is terminated with a load, or under standing wave condition if the waveguide is shorted, the position of the electric field maxima being displaced in this last case by varying the operating frequency (+ or - 25 MHz).

The diagnostic systems used to follow the behaviour of the element under test are the following : vacuum levels, electron pick-ups and photomultipliers. All the data are acquired for each RF shot, and the system is run automatically 24 hours a day by a LABVIEW program. This program can do the RF processing, by ramping the power and scanning the frequency. If vacuum or electron or light levels exceed user given limits, the power level is decreased until signals are again within limits.

The test stand has been operational since the summer 1997. We first tested element such as waveguide window, doorknob waveguide to coaxial transition and FERMILAB conical window used in TTF couplers.

New coaxial windows are under construction ($\lambda/2$ and travelling wave type) and will be tested during the first semester of 1998. A 70 K cryostat is also under construction to test the windows under cold conditions. in early 1998.The first new design of the prototype coupler will be tested in the second semester of 1998.

2. Projects

2.1 TTF

One of the main goals of these last two years was the design and the commissioning of the low charge per bunch injector for the TTF project. In collaboration with LAL and IPN Orsay, we have built the electron injector for the TESLA Test Facility, and installed it at the DESY site. It comprises a 250 keV electron gun, a 216 MHz subharmonic buncher, a β=1 standard 9-cell superconducting capture cavity sitting in a separate cryostat (CRYOCAP), powered by an independent 250 kW klystron, followed by analysing and matching beam lines.

The capture cavity C19 has been fabricated by CERCA. It reached 18 MV/m in vertical tests but was not operated above the level of 14 MV/m during beam tests because of field emission. The commissioning of all the assembly took place during the early month of 1997. The specified beam conditions of 800 μs pulses, 8 mA peak, at energies in the 10 to 12 MeV range were easily obtained. It may have been the first superconducting cavity ever operated with beam and pulsed RF. The most satisfactory achievement is that, in these conditions, stabilities of 0.3° in phase and 5.10^{-4} in amplitude are reliably obtained. The injector is now in permanent operation and is said to work as a turnkey machine.

In addition to the building of the injector, Saclay ordered one spare cavity for the injector, and 6 other nine-cell cavities to CERCA for the TTF cryostats. The cavities were fabricated under Saclay specifications. Up to now, only four of them have been measured and show very good performances. The results are presented on fig.4. The maximum field of 28 MV/m has been obtained with the cavity C21.

Saclay also delivered 9 cold tuning systems, and 30 dismountable type HOM couplers.

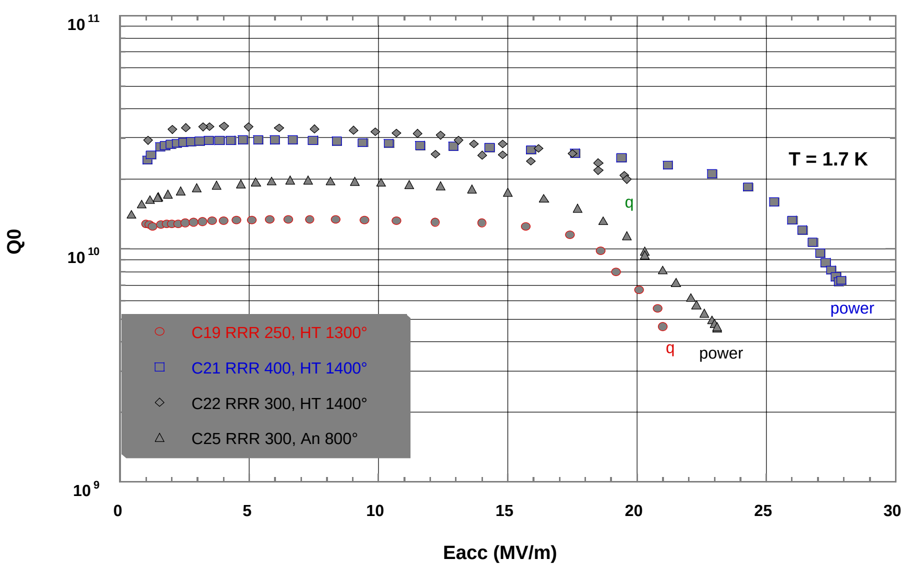

Fig.4 : Q0-Eacc curves of four 9-cell TTF cavities ordered by Saclay to CERCA

2.2. Superconducting RF system for SOLEIL

SOLEIL is a synchrotron light source project aiming at covering the spectral range between 10 eV to 10 keV (VUV-X Rays). Its storage ring is about 100 m in diameter, the linac and the booster are located inside. The storage ring beam intensity is 500 mA, its energy is 2.5 GeV, the bunch length is about 4 mm.

The 4 MV acceleration in the storage ring is provided by a superconducting RF structure that we are developing in collaboration with CERN [12]. Saclay is in charge of the design of the cryomodule containing 2 cavities, the HOM couplers, and the tuning system. CERN will fabricate the sputter coated Nb/Cu 352 MHz cavities and provide the two 200 kW main couplers. The assembling in clean room, the RF tests in vertical cryostats, the high power RF tests and the cryogenic tests will be made at CERN.

The accelerating system is mainly constituted by two superconducting cavities connected by a large beam pipe, and terminated by smaller ones. The strong coupling of the HOMs, and the weak coupling for the accelerating mode, allow the use of coaxial superconducting HOM couplers [13] located on the large tube, where the standing wave HOM fields have a large amplitude. Modes of frequencies higher than 1 GHz will be damped in the tapers on each side of the cryostat.

2.3. High Power Accelerators

The development of superconducting cavities for high intensity protons accelerators is just beginning. We made a preliminary test consisting in the irradiation at LNS Saclay, at room temperature, of the 1.3 GHz single cell cavity C1-01 the Nb of witch had been purified by heat treatment. 1.510^{6} protons of 1.3 GeV on a 1.6 cm^{2} area were delivered. The cavity did not show any degradation neither in Q_0 nor in E_{acc} max. We noticed an RRR degradation measured on samples irradiated with the cavity[14]. An R&D program of 700 MHz cavities is envisaged. Two bulk niobium cavities are going to be ordered.

Acknowledgements

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