STATUS ON RF SUPERCONDUCTIVITY AT THE INSTITUTE FOR HIGH ENERGY PHYSICS

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Abstract

The development of SC cavities started at the Institute for High Energy Physics in September 1980 when the group of technology and study of SC cavities of the Research Institute of Nuclear Physics at Tomsk Polytechnic Institute moved there. At first the group worked at the Linear Accelerator Division, then later, in March 1993 the Federate Problem Laboratory for Technology and Study of the superconducting cavities of the Russian Atomic Ministry was founded at IHEP .

The main goal of the SC cavity investigation is to study and develop the suppression methods for emission effects and conditions for thermomagnetic breakdown creation to increase the accelerating fields at SC cavities ; also developing the experimental equipment to answer this goal.

In this report the following items are enlightened in short:

1. Study and development of methods to suppress emission effects in SC cavities;
2. Study and development of methods to increase the threshold of the thermomagnetic breakdown.
3. Study of new materials and technologies.
4. SVAAP (SC accelerator for the applied purposes) project development

1. STUDY AND DEVELOPMENT OF METHODS TO SUPPRESS THE EMISSION EFFECTS

According to some laboratories we could see that mainly the emission effects serve to reduce the accelerating field, since RF losses due to field emission grow by the exponential law and they dominate at the high power level.

We studied the influence of some factors on the Nb emission properties, НБР make, by GIREDMET firm:

- Crystallographic orientation of the SC cavity working surface;
- Micro roughness of the SC cavity surface;
- Content of impurities;
- $Nb_2 O_5$ oxide films.

1.1 Crystallographic orientation influence of the SC cavity working surface

Crystallographic orientation influence on the SC cavity emission properties and accelerating fields have been studied both experimentally and by computation. Six cylindrical SC cavities have been made from monocrystal Nb with the orientation of <111>, <110> and <100> [1,2]. Computation has been made according to the programs of the Institute of crystallography of RAS. Computation of the integral work function to the SC cavity working surface resulted in the following: cavities with the orientation of <111> have φ=4.461 eV, and with that of <110> have φ=4.14 eV and with orientation of <100> have φ=4.08 eV (for polycrystal φ = 4.08 eV) This means that we profited – 0.43 eV [1] in the work of the electron output with the cavity axial orientation <111>.

Since the face of this cavity with the maximum work function was only 57 %, three monosided cavities with the plane orientation of {110} [2] have been additionally investigated and the profit obtained appeared to 0.7 eV.

As you may know even a small profit in the work function allows a considerable increase of both the surface and accelerating fields in SC cavity[3].

Draft calculations and experiments showed that in many-sided cavities the surface electric field increases from 30 MB/m to 76 MB/m while in mono-sided cavities it increases from 76 MB/m till 93.4 MB/m.

These investigations were based in the development method of the express-control of SC cavity made of Nb bars and sheets [4].

1.2 Suppression of emission effects due to smoothing micro roughness

As one can see above, the possibility the increase of Eacc is possible the expense of the work function. As is well known, this can also be done by decreasing the field emission factor. β [3]. Practically, the value β can vary from some tens to several hundreds and even thousands dependent on the surface quality processing. That is why the efficient way to suppress the field emission is electropolishing since β is determined by the geometry and micro roughness sizes on the SC cavity working surface.

We have developed two EP methods [5,6]:

- method of continuous electropolishing with alternating voltage control;
- method of finishing electropolishing with the control by the current oscillation «pockets» described by a strange attractor.

1.2.1. Method of continuous electropolishing with alternating voltage control

In the course of the EP method study with the alternating voltage in the 50-1000 Hz frequency range we could uncover basic regularities and develop a method of a forced removal of metal from the SC cavity working surface (3 microns per minute). In this case there is no need in electrolyte stirring, because a pulse of a reversed polarity does that job, and one should keep in mind that the ratio change of cathode and anode current component is equivalent to the change of rotation speed of an electrode in the course of EP Besides, a component that is dangerous for a human being is removed from the electrolyte [5].

1.2.2. Method of electropolishing with control by the current oscillation «pockets» described by a strange attractor

This technological process has been worked out on the base of the very interesting phenomenon – excitation of low frequency current oscillations at the direct voltage superposition [3]. Oscillations start at the area of volt-ampere curve with the negative differential resistance.

In Fig.1 you can see that oscillation packets with the different time out between them. They have quite definite envelope and filling frequency.

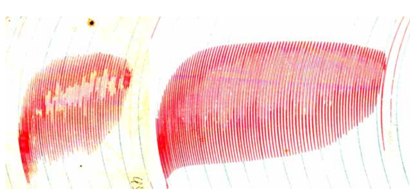

Fig.1. Oscillation packs at EP SCC

It is rather important that it is possible to have three places of negative differential resistance per a volt-ampere curve. It practically means a possibility to remove metal on three levels at 0.01μm, 0.1μ m and 0.87 μm per one packet [6].

In Fig.2 one can see packs to be used at automatic EP.

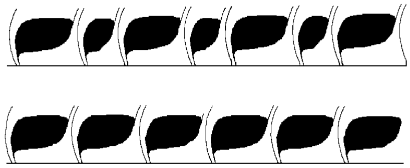

Fig.2. Oscillation packs at EP of the SC cavity

1.3 Study and development of the method to suppress impurity emission centers

As shown by the experiments of different laboratories, carbon, oxygen and sulfur are the most active emitters th t can be removed in the course of annealing in vacuum 10^{-7} Па. Carbon can only be removed from Niobium when its volatile compounds with oxygen, fluorine or hydrogen are formed The effective method of carbon removal due to the anode oxidation before annealing was developed on the base of studying the annealing kinetics using the Auger -electron spectroscopy and backward scattering of alpha particles [7]. At the temperature above 900° C one can observe the oxide film decay following the scheme Nb_2O_5 - Nb O_2 – NbO. The Auger–spectra pointed to the peak of oxygen growth and reducing carbon peak while mass-spectrometric data confirmed removal of carbon in the form of CO and CO_2 oxides. According to the experiments, the carbon removal efficiency grows with that of the film thickness, but at d> 2550 Å the film is loose and the cleaning efficiency reduces. A single repetition of such a process can yield the reducing the carbon concentration from 0.05% to 0.012% [7].

1.4 Study and development of a method of emission suppression by means of putting oxide films

One of the ways to solve the task of the SC cavity Eacc rise is to suppress the field emission by means of putting special covering We have developed a method of covering oxide films on the Nb working surface and studied their influence on the emission properties[8].

The calculation program includes the following:

1- calculation of the tunnel currents on the border of the phases Nb-Nb_2O_5-vacuum;
2- calculation of the emission loading;
3- calculation of losses in the dielectric volume;
4- calculation of losses in the SC cavity walls;
5- calculation without dielectric but with emission loading.

In fig.3 the one can see the SC cavity estimation results for SVAAP for Eacc 10 MV/m and 20 MB/m.

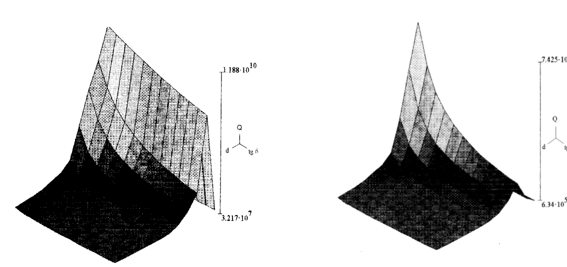

Fig.3. Q =f (d, tg δ) at E acc=10 MV/m and 20 MV/m.

In all the cases the best results were obtained when having the oxide film width of 480-520 Å if some special conditions for oxidation were kept.. All the results as given in [8] witness that there is a suppression effect in the field emission when a special oxide film is used.

As a result of all methods we developed to suppress the field emission we have got β= 10.8 – 13.5 [6].

1.5 The equipment used to study the emission

While working at the suppression methods of the field emission the following equipment has been designed, fabricated and commissioned to measure the emission.

- A stand of the field emission measurements with a device to measure at cryogenic temperatures;
- A stand to measure parameters of the secondary emission;
- A stand to measure exoelectron emission

2. STUDY AND DEVELOPMENT METHODS OF INCREASING THE THRESHOLD THERMOMAGNETIC QUENCH

As said above, the accelerating field in the SC cavity is restricted by two phenomena: field emission and thermomagnetic quench. Thermomagnetic quench in the 0.1-10 GHz frequency range is caused by heating the defects on the working surface.

We deal with this problem in two ways

- Developing methods of the quench threshold rise;
- Theoretical study of SC cavity working stability on the base of Nb and Nb/Cu at the high level power.

2.1. Development of methods to increase the quench threshold

As known, a quench threshold depends on RRR of the cavity material and the size of the defect on the cavity working surface. According to calculations, a quench slow growth can be seen at big RRR We also know, that Ta has much influence on RRR. It is Ta that determines the obtained value of heat conductivity. However, Ta is difficult to remove from Nb as it has relative physical and chemical properties.

Taking this into account a new cleaning method to remove Ta impurities from the SC cavity working surface was proposed [9,10]. On the base of a well-known method of electric transfer the oxide layer method was chosen (a particular case of the deep metal cleaning with electric transfer through oxide). It is to be convenient to join the method oxidation by combination drive [10]. Later this oxide is to dissolve in hydrofluoric acid.

While working at the cleaning method the nuclear-physical methods of analysis have been used to analyse the impurity composition. Besides, the SIMS method has been also used to study the Ta presence both in the oxide film and in the upper metal layer after it was removed. One can find more details about this in [11].

This method allows to reduce the Ta content as much as 6 to 10 times per 8-10 μm depth that is much deeper than by a high frequency field into a superconductor.

In Fig.4 one an see the Ta distribution in the depth of the upper Nb layer [12]

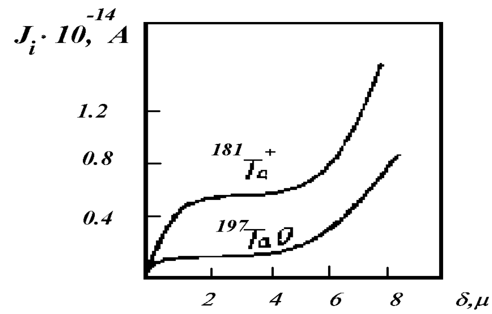

Fig.2. Nb cleaning effect from Ta impurity .

This method allows to raise Eacc from 8 MV/m to 30 MV/m and have the results obtained on the cavity of a cheaper Nb with RRR=100 equivalent to a cavity of Nb with RRR=500 [12].

2.2 Theoretical study of reliable operation of the SC cavity on the base of Nb/Cu

Theoretical calculations of the reliable operation of SC cavity on the base of Nb/Cu have been discussed in detail in the PH001 report [13].

3. STUDY OF NEW MATERIALS AND TECHNOLOGIES

Pure Nb specially created for SC cavities is known to be an expensive material and its cost depends on how big the RRR is. To build big accelerators many tons of that Nb will be required. If we recall that the Nb resource is limited we will think of developing the cheaper saving technologies.

The purpose of developing new technologies is to reduce the SC cavity cost, to raise their reliability with the respect to the quench, and to study the possibility to cover the Nb films , N2V alloy, HTC ceramics on the surface of copper shells.

3.1.Galvanoplastic shaping technique of the copper shells for SC cavities

Our Laboratory has developed a method of galvanoplastic formation of copper shells [14] that does not require an expensive equipment to obtain them but if a very pure electrolyte is available it allows to get copper shells that do not yield to those made of oxygen-free copper.

Fig.5 shows the possibilities of this technology. In the picture you can see a copper shell of the accelerating cavity SVAAP having 9 cells for the frequency 3 GHz, a copper shell of the groupping cavity for SVAAP having three cells for the frequency of 3 GHz, a copper shell of the cavity for five cells for the ESAR accelerator for the frequency of 2.45 GHz and a shell of the cavity of TJNAF-shape having one cell for the frequency 1.3 GHz.

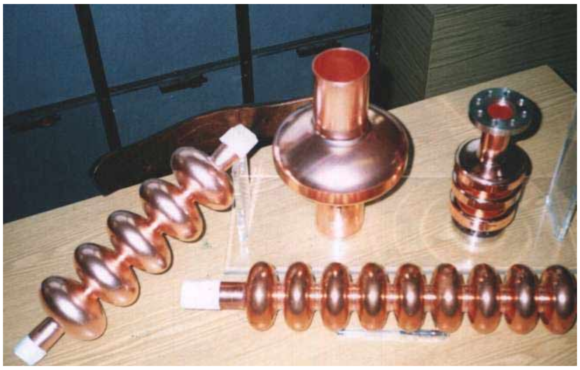

Fig.5. The copper shells manufactured in the Lab.

In Fig.6 you can see the equipment designed for this technology.

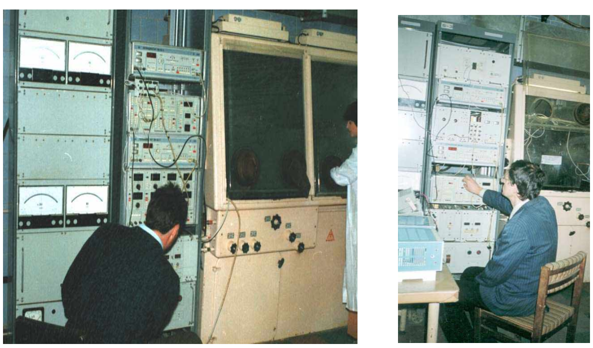

Fig.6. The equipment for manufacturing the SCC copper shells

The equipment comprises [14]::

- an automated power supply
- whole-metal box with galvanic bathes, rotation, stirring, filtering and electrolyte thermostatic devices placed in it.

3.2 Magnetron sputtering

We felt it necessary to manufacture the accelerating SHF cavities of different geometry for frequencies of 2.45 GHz, 3 GHz and 1.3 GHz and also the SC cavities for stabilising SHF generators by the SC cavities with 9 GHz frequency; we decided to develop and use two set-ups: for axial magnetron spattering and for planar magnetron spattering [15].

In Fig.7 one can see a set-up for the axial magnetron sputtering and in Table 1 there are its main parameters.

Fig..7. The set-up for axial magnetron sputtering

Table 1 [15]

№	Stand parameters	Value
1.	The size of the working chamber	length 650 мм Diameter 160
2.	Cathode and nozzle	
3.	material	removable
4	Cathode voltage	up to 950 V
5.	Rotation speed	1 rot./ min.
6.	Working gas	Argon
7.	Finish vacuum before covering	$5x10^{-7}$ Pa
8.	Cathode diameter	8-30 мм
9.	Cooling	N, H_2O
10	The mandrel temperature	50-150 °C

To obtain good superconducting coverings from Nb, alloy of N2V and High TC material a set of removable cathode devices and nozzles has been made.

The first results for the cavities on the base of H2B/Cu and HTC/Cu [15] were promising for adhesion, uniformity of the layer and Tc. However, some technological difficulties do not allow to get the characteristics necessary for SC cavities.

4. RESEARCHES MADE FOR DEVELOPING THE SVAAP PROJECT

The results of the study of the technology and SC cavities were for the first time used in the linear accelerator project for the electron accelerator at the energy of 5 MeV with the RF structures on the base of Nb/Cu [17].

Currently the SVAAP accelerator project at the energy of 7.5 MeV and the beam current of 10 μA designated for HTC ceramics exposure is under development The accelerator scheme, calculation of particle dynamics, injection energy choose and the accelerating RF structure geometry are described in detail in [18-20].

In Fig.9 and Fig.10 you can see the exterior of the experimental SC grupping cavity (3 cells), accelerating cavity (9 cells) and RF structure for the SVAAP accelerator on the base of Nb/Cu that consists of a groupping section (3 cells), and an accelerating section (nine cells) [21].

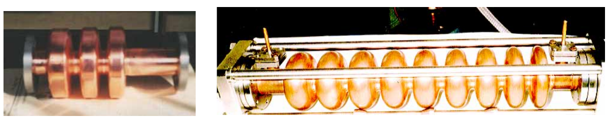

Fig.9. SC cavities (the grupping cavity for SVAA and the accelerating cavity for experimental research)

Fig.10. Superconducting RF -structures for SVAAP designed at the Lab

In Fig.11 [21] the best results for the last 8 years are shown that were obtained at SC cavities at the frequency of 2.45-3 GHz (between curves of 1-3), and for SC cavities at 1.3 GHz. (between curves of 4-5).

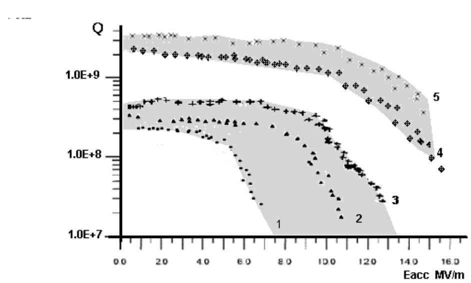

Fig.11. Dependence Q =f (Eacc)

The lower results for the range of 2.45-3 GHz can be explained by the technological difficulties that arise when one applies the axial magnetron sputtering, related to the small size of diaphragm. We hope that the use of this new set-up of complex magnetron sputtering will allow us to change the situation.

5. ACKNOWLEDGEMENTS

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