SUPERCONDUCTING RF ACTIVITIES AT FEDERATE PROBLEM LAB FOR TECHNOLOGY AND STUDY OF THE SC CAVITIES OF THE MINISTRY OF THE RUSSIAN FEDERATION FOR ATOMIC ENERGY AT THE INSTIUTE FOR HIGH EHERGY PHYSICS

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Abstract

The Federate Problem Lab now has some groups working on the technology and study of the superconducting cavities for accelerators. This report covers the activities of Federate Problem Lab for the period with 1991 to 2001. The purpose of this report is to discuss different aspects of our work

1. Development of the Technology and study technological possibilities for manufacturing SC acceleration cavities on the base of Nb and Nb/Cu and also on the base HTC films on the copper shells by using the resource saving technology.
2. Development of the equipment for realization of these technologies.
3. Development and construction of SVAAP stand for irradiation of the HTC ceramics with the goal to stabilize of the stoichiometry composition of them.
4. RF power transfers to the long distances with use the SC waweguides on the base of HTC films on the copper shells.

1. ELECTROCHEMICAL POLISHING METHODS

1.1. EP method of Nb with current oscillation «pockets» control, described by strange attractor.

The technological process of EP for Nb SC cavities has been developed from a very interesting phenomenon – excitation of low frequency current oscillations by constant voltage [1] Practically, we have the possibility to conduct the EP process on the three level with metal removal that varies in thickness [2, 3]
(see Fig.1)

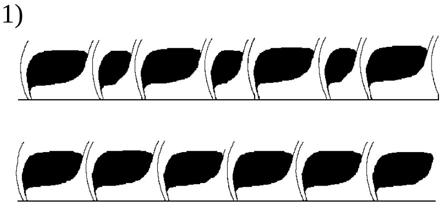

Fig.1. Pocket oscillation under EP for Nb.

"Pockets" (upper) correspond to 0.1μm of metal removal per pocket and to 0.01μm.

1.2. Method of continuous EP with alternating current control

A very important factor during large scale production of SC cavities is reduction rate, especially when it is necessary to remove 50-100 μm from the working surface of cavity. The most productive methods have been developed at KEK, WU, and IHEP. Among them are horizontal rotation EP with current density control, EP with potential control method and alternating current EP [3]. They all are continuous methods used for the preliminary treatment. Our method hasn't a component of high corrosion in the solution (HF), that reduces corrosion degradation of the ventilation ducts and there is no need to agitate the solution. Metal removal is 3μm /min.

So, the EP technique is presently getting more popular among the people working with SC cavities. The results allow to hope that we can improve the working surface of cavity and raise the E_{acc} for RF structure.

2. ELECTROCHEMICAL CLEANING TECHNOLOGY

The Nb price is determined by RRR value, while Ta is a limit impurity specifying this price [4]. If there is the possibility to clean the working surface of SC cavity to depth of RF field penetration, we can use a cheaper material to manufacture the SC cavity.

New cleaning method of the working surface of Nb cavity from Ta impurity is being proposed [5]. It is based on the well-known method of electric transfer, in particular, on its special case of the deep cleaning by means of electric transfer of an impurity through oxide barrier, and a layer of purified metal is kept behind the oxide barrier [6].

We have found it suitable to combine this method with the anode oxidation in joint method [4] when diffusion and electric transfer of Ta impurity takes place. Multy iteration of the technique, called oxipolishing, provides an efficient cleaning of upper Nb layer 10 μm deep. The mechanical stresses in oxide film are the cause of cracks in dielectric coating on the cavity surface. Especially they occur during temperature drop from 300 K to the operating temperature of cavity. However, as it turned out, the effect that is negative for one case may be positive for another. The analysis of experimental data on mechanical stresses in anode oxide films and their dependence on the oxidation current density (Fig.2) suggests the idea of developing the max mechanical stresses in Nb_2O_5 film. [4].

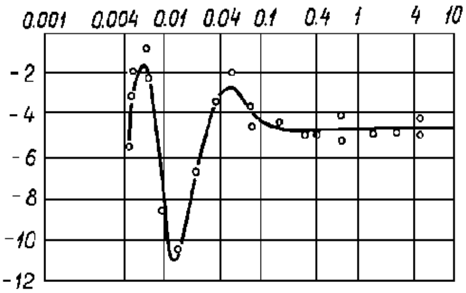

Fig.2. Mechanical stresses in anode film versus the anode oxidation current density

As the figure shows, the max mechanical stresses are observed in current region the 0.01-0.02 mA/cm ^{2}.

Fig.3 shows the effect of cleaning the working surface of Nb from Ta impurity [15].

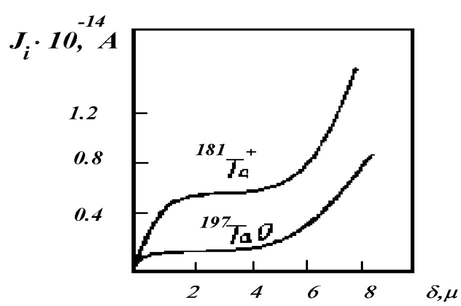

Fig.3. Effect of cleaning the Nb surface.

The figure shows that in this case the Ta impurity in the surface Nb layer is distributed almost uniformly at the depth of 5 µm whereas in deeper layers an exponential growth is observed at a depth of 6.5µm followed by flattop. All results presented here point to the existence of the Nb purification effects from Ta through the oxide layer. It gives us the possibility to receive E acc. from 8 MeV/m to 30 MeV/m for SC cavities prepared from a more cheaper Nb with RRR=100, that is equivalent to value of Nb RRR=500.

3. INFLUENCE OF THE SPECIALLY CREATED OXIDE FILMS ON THE EMISSION PROPERTIES

One of the ways of solving the problem of increasing E acc. in SC cavities is to suppress the field emission effects. We develop a method and studied the influence of oxide films on Nb surface, specially made to decrease the field emission, and also studied their influence on the electrodynamics parameters of SC cavity [7]. In the result of optimization of Nb anode oxidation aimed at obtaining the minimum field emission currents we have received an optimal block of parameters. Using it, we study influence of different conditions at emission dark currents of Nb with oxide films of 200 to 1000 Å thickness. As one can see from [7] the minimum emission dark current exists at the thickness of 480-520 Å.

Calculation program of influence of the Nb_2O_5 covering at the factor Q of SC cavities includes as follows: 1- the RF tunnel current calculation on the boundary phase Nb-Nb_2O_5-vacuum; 2- emission load calculation; 3-losses calculated in the dielectric film volume; 4-the energy dissipation in the cavity walls; 5-calculation of factor Q of the cavity without dielectric layer but with emission load.

Calculation results of SVAAP cavity Q-factor with dielectric layer depending on the oxide film thickness are given in Fig.4 at the accelerating fields 10 MV/m and 20 MV/m and Fig.5. (of taking into account the emission load).

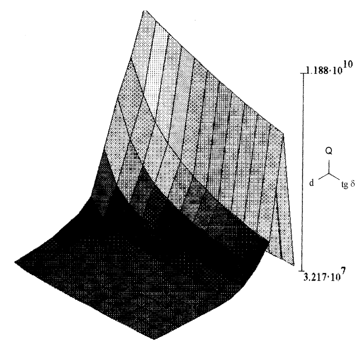

Fig.4. The factor Q of the SC cavity with Nb_2O_5 thin film versus the thickness and tgδ at Eacc = 10 MV/m.[7].

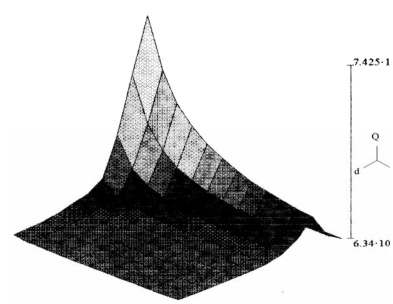

Fig.5. The factor Q of the SC cavity with Nb_2O_5 thin film versus the thickness and tgδ at Eacc = 10 MV/m. [7]

In all cases the best results have been obtained when thickness range was 480-520 A, if the specific conditions of oxidation are provided. So, all results presented here show the existence of suppression effect for field emission when we have used Nb with Nb_2O_5 films.

4. GALVANOPLASTIC TECHNIQUE

SC cavities on the base of Nb/Cu make it possible to reduce the cost of SC RF structure. They have a higher stability during operation at the cryogenic temperatures, do not require special magnetic shields and allow one to apply not only Nb, but also other SC materials on copper shells. Since the technological process is complicated and it can be successful only with a certain combination parameters (current density, voltage value and type, composition, concentration and temperature of electrolyte, rotation rate, type of mixing, preliminary treatment) [8] optimization is needed.

A copper layer is formed electrochemically on a rotating Al mandrel taking the form of cathode, that later will be the working surface of the copper shell of SC cavity. Unfortunately an intricate configuration of cavity results in different distances between the anode and the cathode and therefore there is in different thickness of copper shell walls. We have solved this problem by means of optimization all parameters of the technological process and of development special setup for it. On Fig, 9 you can see setups to realize of this technology.

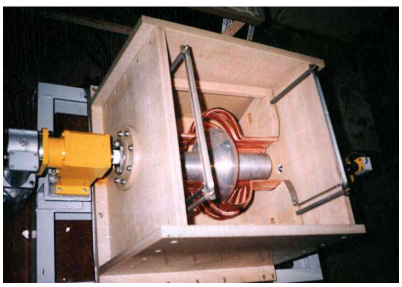

Fig. 6. Setup of the galvanoplastic shaping technique for TJNAF-shape cavity

After copper shells has been made making it is necessary to have EP on the setup (Fig.7) with the subsequent very slowly annealing in special stand (Fig. 8) for removing gases (especially H_2).

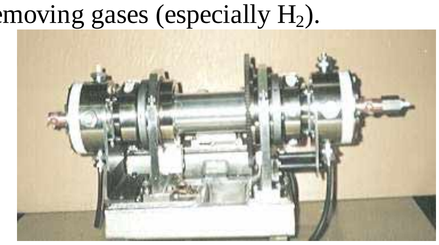

Fig.7. Setup of the EP of the copper shells for TJNAF-shape cavity

Fig.8. Stand for annealing cavity and copper shells.

This technology for weldless copper shells RF cavities and SC accelerating structures with complicated configuration allows us to make copper and SC cavities showed in Fig. 9 and Fig.10.

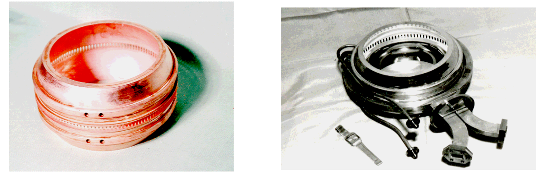

Fig.9. The copper cavity for VLEPP [8]

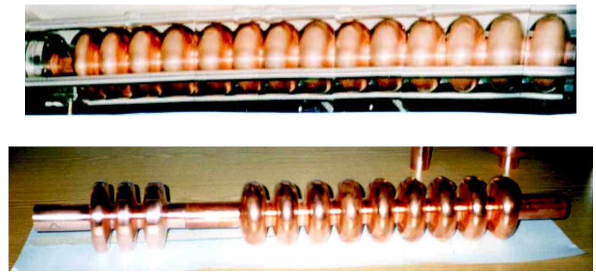

Fig. 10. Copper shells for SC cavities from 14 and 3 +9 cells for SVAAP [9]

All copper shells demonstrated the promising features of this technology.

5. MAGNETRON SPUTTERING TECHNOLOGY

The tendency to develop the cheap source saving technologies, including the creation of SC accelerating cavities on the base of film materials is now interesting. The peculiarities of magnetron sputtering of SC materials and copper as an accompanying material is being studied. The current voltage characteristics and the curves of magnetron discharge ignition in planar and axial geometry are studied in our Lab. [10]. The geometry of electrode system and the working gas (argon) pressure are optimized. We are studying now the peculiarities of magnetron sputtering of SC materials on the copper shells of the different methods: axial and planar magnetron sputtering. Depending on kind of SC coatings (Nb, allow «H2B»or HTC) and the frequency band we use different setups and stands.

Fig. 11 and Fig.12 show equipment for axial and planar magnetron sputtering.

Fig.11. The setup for axial magnetron sputtering.

Besides of Nb, High Tc material on the YBaCuO base is perspective for the high accelerating field problem. On the seminar on future prospects for high energy physics and the SRF conferences the question about the opportunity to obtain Eacc. of order of 400 MV/m with use of the YBaCuO film was discussed long ago. We have a lot of difficulties with this question now. To deposit a film of required quality at the working of copper shell surface it is necessary to solve the problem to guarantee of the YBaCuO film stability with 3-10 micron thickness. The problem is to conjugate crystallographic structures of High Tc and copper.

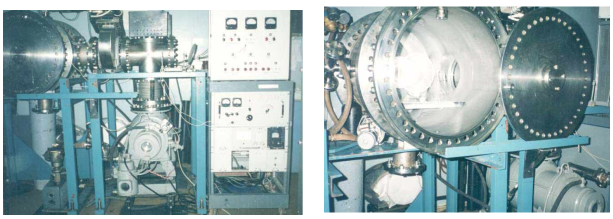

Fig.12. Planar magnetron sputtering setup in MIPhI

According to that the conjugation possibility increases if Cu lattice parameters start increasing and approach to the lattice parameters of YBaCuO. There are many opinions of different firms on buffer layers between copper and YBaCuO. Using them different buffer layers have been tested, and the best preliminary results have been got for buffer layer from solid solution of Al-Cu [10]. The Fig.13 shows our setup for solid state diffusion in high vacuum to obtain the buffer layer.

Fig.13. The setup for solid state diffusion.

The possibilities to make cavities of complicated configuration using the wasteless resource–saving technology with good adhesion and uniformity can be found in [10]. But we couldn't receive needed SC parameters up to now. Now we are developing new setup for complex magnetron sputtering with sample temperature 600- 650 °C and we hopes improve our results in future.

Fig.14 shows the SC cavities for SVAAP on the base of Nb/Cu, received by means of method galvanoplastic forming technique and magnetron sputtering.

Fig.14. One of SC RF structure for SVAAP.

The manufacturing technology of RF structure elements on the base of Nb or High Tc, sputtered on the copper shells, is under development.

6. SC RF STRUCTURE FOR SVAAP

At the Federate Problem Lab at IHEP the project of the **S**C vertical **a**ccelerator for **a**pplied **p**urpose (SVAAP) is under development. SVAAP is needed for irradiation HTC superconducting materials. The basic characteristics of SVAAP are given in table 1.

Table 1.

N	Parameter		Value
1	Electron energy	MeV	7.5
2	Power disorder of particles	%	0.5
3	Injection energy	keV	80
4	Current of particles	μA	10
5	Working frequency f	GHz	2.950

This project is developed within the frames of agreement with Atomic Ministry of Russian Federation together with the department «Electrophysical Facilities» of Moscow Engineering and Physical Institute.

The particular attention is paid to the choice of geometry and superconducting RF cavity technology [11]. We have studied the influence of injection energy in the range of 40-250 keV at accelerating RF structure geometry [12] and also the electron beam dynamics for horizontal and vertical accelerator channels, including beam phase portraits in different accelerator cross-sections, emmittance, acceptance, particles trajectories etc. On the base of these investigations the injection energy and geometry of accelerating structure of 14 cells at the frequency of 3 GHz, that provides the beam energy 7.5 MeV, have been chosen. Now RF structure consists from of the capture cavity and accelerating cavity.

6.1. Geometry of accelerating RF structure

The determination of SC cavity geometrical sizes and its basic electrodynamic characteristics has been carried out on the base of the particle movement computer simulation. The preliminary variant has been chosen as a result of this study. The SC accelerating RF structure was calculated for different injection energies in the range of 50÷250 keV, because the SC accelerating structure with the injection energy 40 keV chosen earlier was found more difficult to manufacture due to very narrow first three cavity cells [12]. Finally has been chosen injection energy 80 keV. Basic RF characteristic cavity is shown in table 2.

Table 2.

N	Parameter		Value
1	Accelerating field	MV/m	10-12
2	Q-factor		10^9
3	Injection energy	keV	80
4	Frequency	GHz	2.950
5	Number 0f cells: grouping cavity accelerating cavity		3 9

On the Figs.15 you can see RF structure, which consists of capture cavity of three cells with β = 0.74, 0.78 and 0.9 accordingly. The accelerating cavity consists of nine cells with β = 1.0 and uniform distribution of accelerating field to axes.

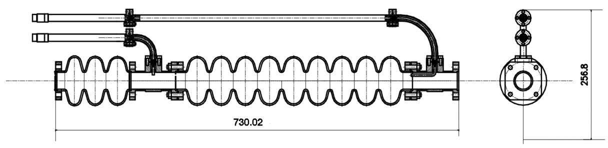

Fig.15. Superconducting RF structure for SVAAP.

Study of the thermomagnetic instability for SVAAP RF structure on the base of Nb/Cu you can find in [13].

6.2. HOM calculations

Study of the HOM for SVAAP RF structure on the base of Nb/Cu you can find in [14]. For this purpose it is need to study not only working, but also the HOM type of fluctuations in SC cavities in a range frequency up to 3 f_0 .The numerical analysis of SC cavities is made with program URMEL and . URMEL -T. The dispersive characteristic of the accelerating cavity is shown [14].

6.3. Mechanical stresses

As SC accelerating structure is placed down in vertical cryostat deformation of cells by means of gravity occurs. Change of geometrical form of cells leads to the change of f_0 and of field distribution on an axis. We have estimated this deformation. The analysis of deformation influence on electrophysical parameters is shown more detail in [14]

6.4. Q-factor and accelerating fields for Nb/Cu cavities at 3 and 1.3 GHz.

Figs.16 shows the dependence for Q =f(E acc) of the SVAAP-shape cavity (1) and TJNAF-shape cavity (2) on the base of Nb/Cu, manufactured according to our technology.

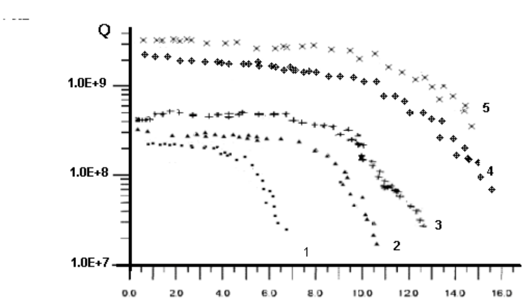

Fig.16. Dependence for Q =f(E acc) of the SVAAP-shape cavity (1,3) for 3 GHz, 2-for 2.45 GHz and TJNAF-shape cavity (5) for 1.3 GHz.

Figure shows, that best results are received for cavity at f=1.3 GHz. Lower results for cavity at 3 GHz be can explain by technological difficulties at use of magnetron sputtering (axial) due to of the small sizes. We hope, that use of new setup for complex magnetron sputtering (together axial and planar) will allow us to improve this situation

7. ACKNOWLEDGEMENTS

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