FABRICATION AND TESTING OF L-BAND NIOBIUM COATED COPPER CAVITIES

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Abstract

L-band niobium coated copper cavities have been developed for the application to TeV linear colliders and FEL drivers. Single cell copper cavities were made by electroforming. Niobium films were deposited by the RF magnetron sputtering method. After the sputtering conditions were optimized, the 1.5GHz single cell coated cavity attained a Q_0 of $2x10^9$ at 1.8K at low fields. The 1.3GHz single cell coated cavity has achieved a maximum accelerating field gradient of more than 10MV/m without any field emission or thermal instability.

Introduction

Superconducting cavities made of niobium sheets are expected theoretically to attain a maximum accelerating field of 60MV/m. It is however limited to 20~30MV/m by thermal breakdown induced either by electron loading or by enhanced RF losses due to surface defects. Replacing niobium with a higher thermal conducting material like copper should considerably improve the stability against thermal breakdown. A superconducting niobium film, 1 μm thick, is sufficient because the Meissner effect limits the RF field penetration in a superconductor to a very thin superficial layer.

The techniques of coating a copper cavity with a niobium film have been studied at CERN since 1980. 352MHz coated four-cell cavities have been installed in LEP to upgrade energy above 55GeV [1]. 1.5GHz coated single cell cavities have been developed recently at CERN/CEN Saclay. The Q-value at 1.8K was 10^{10} at low fields and decreased rapidly to $4.5x10^8$ at the maximum accelerating field of 5.5MV/m [2].

This problem could be caused by poor adhesion of niobium films to copper cavities, because it leads to an insufficient thermal contact which prevents heat from dissipating. To overcome this, we have fabricated copper cavities by electroforming and deposited niobium films to the inner surface by using the sputtering technique [3]. These methods have the advantage of eliminating the welding procedure in the fabrication of copper cavities, and producing a smooth inner surface without any defects.

Fabrication of cavities

The main steps of fabrication are as follows :
1) Fabrication of an aluminum core
2) Electroforming of copper
3) Resolution of the aluminum core
4) Joining of flanges
5) Electropolishing
6) Coating of a niobium film

The electroformed copper cavity had about a 3mm thick wall. Stainless steel flanges (ϕ152 conflat flanges) were joined to cut-off tubes of the cavity by electron beam welding. There was no vacuum leak in superfluid helium after several thermal cycles. The finished surface of the copper cavity proved to have a roughness of below 0.5μmRz in the sample tests.

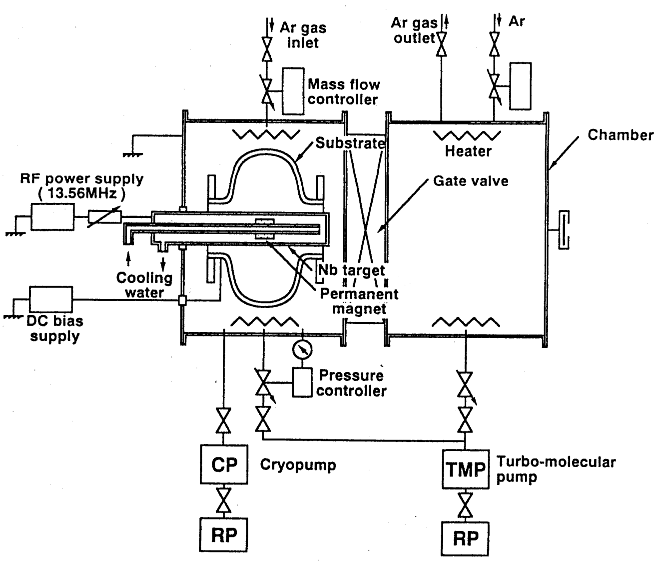

Fig.1 RF magnetron sputtering system

Sputtering of niobium films

Figure 1 shows the schematic view of the RF magnetron sputtering system. The system was evacuated by the turbo-molecular pump and the cryopump. A pressure of 3×10^{-6}Pa can be reached in the sputtering chamber after baking at 150°C for 24 hours. A pure argon gas (>99.99995%) was used during sputtering. The permanent magnets were placed inside a cylindrical cathode surrounded by niobium pipe (RRR~100) which was cooled by water. This produced a magnetic field of about 200 gauss near the surface of niobium cathode, increasing the deposition rate considerably. The RF generator (13.56MHz) supplied power to produce a glow discharge.

The typical coating sequences are as follows :

1) Rinsing the copper cavity with ultra-pure water
2) Baking the copper cavity at 300°C for 8 hours in the load-rock chamber
3) Pre-sputtering for 1 hour
4) Sputtering at 1500W, 0.4Pa, 300°C for 1 hour

Figure 2 shows the thickness of niobium film on the copper plates mounted on a 1.5GHz copper cavity. The maximum was 4.0μm and the minimum was 1.2μm. Niobium films on several 1.5GHz half cell copper cavities didn't peel off after 10 thermal cycles between the room temperature and the liquid nitrogen temperature. The cavities were kept in dried atmosphere for 90 days. Following this, no peeling was found during the thermal cycles.

The critical temperature (Tc) and the residual resistance ratio (RRR) of niobium films deposited on sapphire substrates were measured by the four-probe method. The critical temperatures of niobium films were 9.4~9.8±0.2K. The maximum value of the residual resistance ratio was 16. Auger electron spectroscopies revealed that the impurity contents in the niobium films sputtered on copper (OFHC) substrates were below 1at.%. The impurities of O,C,N appeared at the surface of niobium film because the films were exposed to air.

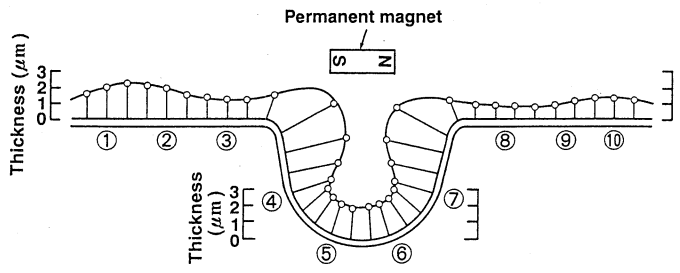

Fig.2 Thickness of niobium film on 1.5GHz single cell cavity

RF performances of cavities

The Q-values were measured by using the transient method [4]. Fig.3 shows the schematic diagram of the measurement circuit. The input signal and the reflected signal observed by the oscilloscope are shown in Fig.4. The unloaded Q (Q_0) is related to the loaded Q (Q_L) and the coupling coefficient (β_1, β_2) as the expression $Q_0=Q_L(1+\beta_1+\beta_2)$. The loaded Q was determined from the decay time of the emitted power . The coupling coefficient was obtained from the incident power, the reflected power, and transmitted power.

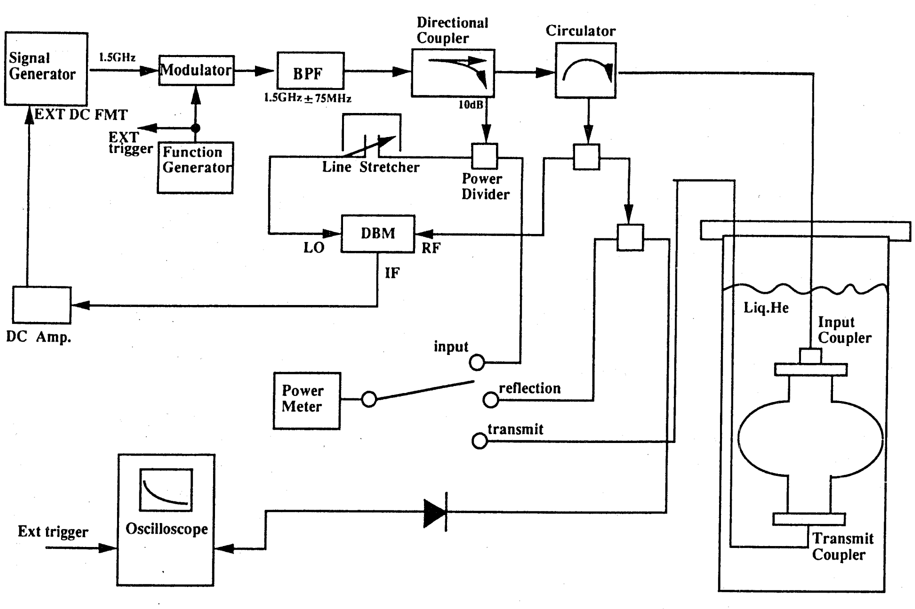

Fig.3 Measurement circuit of Q-values

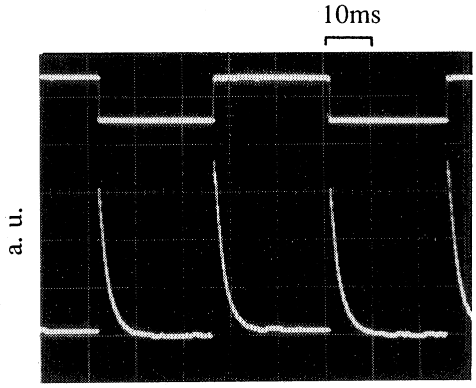

Fig.4 Input signal (upper) and reflected signal (lower)

The surface resistance (Rs) can be split into two terms, the theoretical resistance (R_{BCS}) and the residual resistance (Rres). The residual resistance is practically independent of temperature and strongly depends on the surface conditions. The surface resistance is obtained by the relation $Rs=G/Q_0$, where the G indicates geometrical factor (G=269Ω in our cavities).

The 1.5GHz single cell coated cavities were tested at low power. The Q_0 at 4.2K were below $4x10^7$ in the initial stage. After the sputtering conditions were optimized, the Q_0 at 4.2K was improved to $5.4x10^8$, which was better than those of niobium sheet cavities. The Q_0 at 1.8K was $2.2x10^9$. Fig.5 shows the dependence of the surface resistance on the temperature. The surface resistances decreased with the decrease of the cavity temperature and became almost constant below 2.5K because of the high residual resistances. The residual resistance of the cavity sputtered at a deposition rate of 2Å/sec was about 270nΩ (F8-1). When the cavity was sputtered at

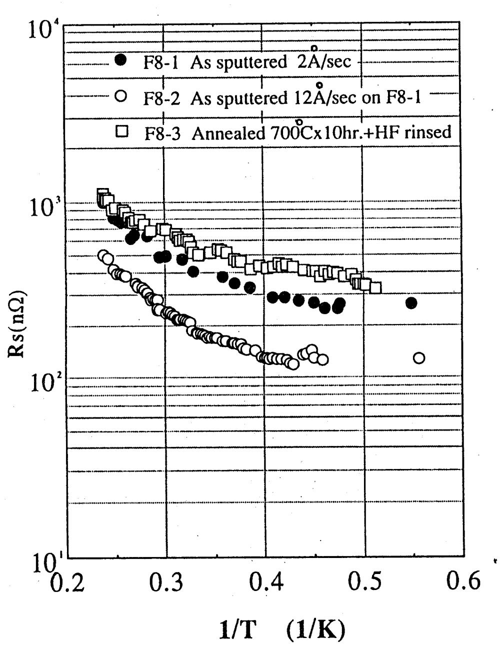

Fig.5 Dependence of surface resistance (Rs) on temperature [1.5GHz]

12Å/sec, it was improved to about 130nΩ (F8-2). It appears that impurities introduced during the film growth decrease when the deposition rate increases. Annealing at 700°C in the vacuum of $\sim10^{-4}$Pa caused the increase of residual resistance (F8-3). This could be caused by contamination due to the diffusion of Cu or to the adsorption of residual gases.

Figure 6 shows the relations between the Q-values and the accelerating fields of the 1.3GHz single cell coated cavity. The cavity achieved the maximum accelerating field gradient of more than 10MV/m without any field emission or thermal instability. The Q_0 at 2.1K at low fields was $4.5x10^8$ (H3-1). After the niobium film was coated on this cavity, the Q_0 at 2.1K at low fields was improved to $1.0x10^9$. However, the accelerating field was limited at 7MV/m because of the field emission.

Conclusion

L-band niobium coated copper cavities have been developed. Niobium films were deposited by the RF magnetron sputtering method on the electroformed copper cavities. The Q_0 of the 1.5GHz single cell coated cavity has reached $2x10^9$ at 1.8K at low power. There is still a problem of high residual resistance but the 1.3GHz single cell coated cavity has achieved the maximum accelerating field gradient of more than 10MV/m without any field emission or thermal instability.

References

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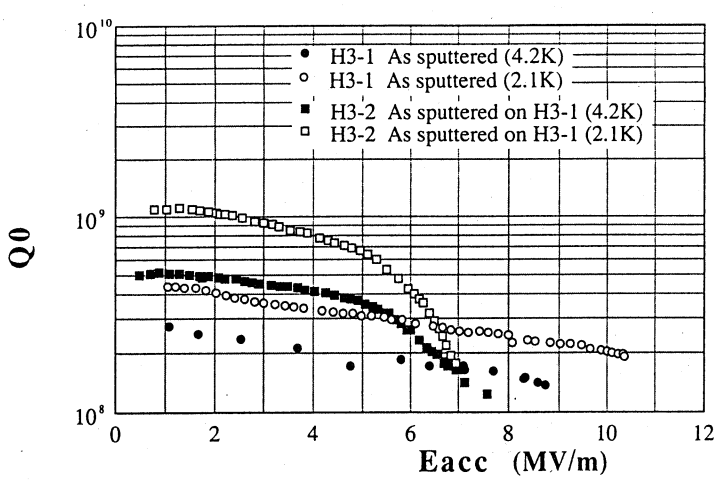

Fig.6 Q-values vs accelerating fields (Eacc) [1.3GHz]