FABRICATION AND RF PROPERTIES OF HIGH-Tc SUPERCONDUCTING MICROWAVE PASSIVE ELEMENTS

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After the discovery[1] of the newly-developed metal oxide superconductors with higher transition temperatures in late 1986 raised the possibility of a new class of superconducting microwave devices operating well above liquid He and below liquid nitrogen temperature, the feasibility study for the superconductor devices at microwave, and millimeter-wave frequencies, i.e., cavity resonator, transmission lines, waveguide, and antenna, was started at JAERI(Japan Atomic Energy Research Institute), Tokai in April 1987. The successful fabrication and microwave properties of the superconducting TM_{010} cavity[2] were previously reported to be resonant at 7 GHz with the quality (Q) factor of 10^4-10^5. In the present work, it would be reported that the new bonding method utilizing low- and high-temperature brazing agents could be successfully applied to make the s-band cavities larger than the previous ones, and microwave properties of the cavities were much improved to have the quality factor scattered around 10^6. The fabrication technology utilized in the cavities have potential applications for any kinds of passive microwave elements, i.e., particle accelerators[3], resonant filters[4], ultrastable clocks[5], transmission lines and so on.

The body of the cavity was made out of the single-phased and bulk $YBa_2Cu_3O_{7-\delta}$ material with a transition temperature of about 92 °K. The Q factor of the cavity was measured as a function of temperature from 300 °K to 30 °K. Starting from a value of Q= several hundreds - a thousand from 300 °K to about 100 °K, the Q increased by a factor of thousands to Q=>10^6 at 15 °K-30°K and upon further conditioning of the cavity and the RF coupler, to about several x 10^6 at the same temperature. The temperature dependence of the Q factor was observed to be consistent with independent measurements of the ac Meissner effect and the surface resistance for the $YBa_2Cu_3O_{7-\delta}$ samples[3,6] , and the Q factor of the 7GHz cavity resonator[2].

High-purity Y-, Ba-, and Cu- oxides were mixed as fine powdered materials, and reacted at 900 °C for about 5 hours. The Cu-oxide powder used here was specially prepared to have the powder particle finer than the commercially-available powder. The mixture was repeatedly pulverized, reground, and sintered at 900 °C for about 10 hours. The resultant black powder was then cold-pressed into solid and disc forms, using an isostatic press at pressure of 300-400 kg/cm^2, and then mechanically machined into flat disc and ring forms. Before and after the final machining and polishing, the ring and discs were sintered at 920 °C in dry air for about 7 hours.

Characterization of the samples by four-point dc resistance, ac Meissner measurements and the others indicated a Tc onset of 92 °K with a transition width of less than 2 °K, and the density was measured to be about 75 % - 95 % of the theoretical value in average. X ray diffraction patterns taken in each process step showed that the discs and rings had the single-phased , the slightly ab-plane aligned structure parallel to the surface, no other structures than the $YBa_2Cu_3O_{7-\delta}$ and no impurities within the statistical error.

The high Tc superconducting cavities were designed and made to be resonant in the TM_{010} mode at 2.856GHz because RF measuring instruments, elements and power supplies of the frequency were available in JAERI linac laboratory, and very popular in small size linear accelerator facilities for research, industrial and medical applications. Because of the immature bonding technique at the first assembling of the cavity, the resonant frequency for the assembled cavities was shifted to be 2.43 GHz. Because the technique was improved after measurement of the first cavity, the second cavity could be successfully assembled and measured to be exactly resonant at the designed frequency of 2.856GHz. The resonances of the other TM_{0n0} modes with n=2,3,4,5 and 6 were observed at the calculated resonance frequencies from the fundamental frequency of the TM_{010} mode.

The cavities were made from the two identical $YBa_2Cu_3O_{7-\delta}$ discs, and the ring as shown in Fig.1. Each of the discs has dimensions of 110 mm outer diameter x 8 mm thickness which contains a coupling hole of diameter 4 mm at the center. The ring has dimensions of 110 mm outer diameter, 80 mm inner diameter x 5 mm and 8 mm thicknesses. The cold-pressed disc could be machined, and polished smoothly without any special care to avoid some damage to the disc. Finally surface roughness of the discs and ring were estimated to be less than about 10 microns. No coolant or lubricant was used to avoid contamination during machining. These two discs and the ring were sintered in dry air, and were assembled in the form of a cavity by welding mainly with a low-temperature indium-based brazing agent and a high-temperature silver oxide-based brazing agent.

The 7 GHz cavity in the previous report was assembled by the low temperature brazing agent only. The surface was not polished after the final machining, and the roughness was estimated to be around several tens microns.

The resonant frequency measured for the first cavity with TM_{010} mode was around 2.43 GHz between 300 °K and 30°K. The lower resonance frequency measured in the cavity than the designed showed that the cavity should have the inner diameter larger than the ring's one effectively. The lower resonance frequency than the expected one mainly came from the bad contact between the ring and discs, and imperfect diffusion of the brazing agents, and roughness of the bonding surface around the inner edge of the ring.

For a particular mode of a cavity, the $Q_{unloaded}$ is related to the surface resistance of the walls of the cavity by the relation

$$Q_{unloaded}=G/Rs, \quad \text{---------------------------(1)}$$

where G is a geometrical factor of the mode. The Q_{loaded} of the cavity was measured by so-called transmission and reflection methods, in which the input frequency was scanned, and the half-power bandwidth(df) of the resonance curve was observed by utilizing a commercially-available vector network analyzer system. The half-power bandwidth of the resonance is related to the equation of f(resonance frequency) and df

$$Q_{loaded} = f/df. \quad \text{----------------------------(2)}$$

$$Q_{unloaded}=Q_{loaded}(1+beta) \quad \text{----------------(3)}$$

where beta is a coupling parameter of the cavity. The coupling parameter for the cavity was estimated for calculation of the unloaded Q factor ($Q_{unloaded}$) by measuring the insertion loss and the reflected power by the cavity in the transmission and reflection methods, respectively.

Experimental set up used in the present work is illustrated in fig.2. The set up consists of a large cryostat, a He-gas closed loop refrigerator, a magnetic-suspended turbomolecular pumping system, and the vector network analyzer system. Q_{loaded} was measured with RF couplers critically adjusted at each temperature. $Q_{unloaded}$ was found to be nearly independent on input RF power less than 0.01 mW. $Q_{unloaded}$ is small and weakly temperature dependent between 300 °K and 100 °K, attaining a value of about a thousand around 100 °K. A sharp increase is observed as the cavity is cooled down below 92 °K.

The $Q_{unloaded}$ increase appears to slow down at lower temperatures, below 70 °K. The $Q_{unloaded}$ reached just around a few 10^6 at 15°K-30 °K.

RF measurements for single crystal $YBa_2Cu_3O_{7-\delta}$ samples[3] showed that the surface resistances were slightly better than, or nearly the same as the Nb ones at 4.2 °K. Although we should expect the Q factor of 10^{10} or even more from the theoretical consideration applying a conventional BCS theory, the Q factors for the single-phased and bulk $YBa_2Cu_3O_{7-\delta}$ cavity of the several orders of magnitude less than the expected could be obtained in the present work. The lesser Q factors than the theoretical consideration are thought to have some origins in the weak links of the grain boundary, the brazing agents, the bonding method, surface roughness, impurities and so on. And, we could not point out here what the major origins are for the large Q factor difference. The Q factor of the cavity may be increased by improving materials processing, assembling methods, brazing agents and so on because the lesser Q factor is thought not to be inherent in $YBa_2Cu_3O_{7-\delta}$ materials[3].

Concerning about the RF power level, the sintered $YBa_2Cu_3O_{7-\delta}$ samples show the larger increases in RF losses at the higher RF field, the crystal samples show the relatively smaller increases[3]. In order to make clear the applicability for the higher RF power applications, the RF power dependence measurements of the surface resistance are now under way at JAERI .

The authors would like to thank Drs. N. Shikazono, Y. Kawarasaki and Y. Kazumata of Physics, JAERI for their continuous encouragement and interests in this work.

References

1) J. G. Bednorz and K. A. Muller : Z. Phys. B64(1986)189.
2) E. Minehara, R. Nagai, and M. Takeuchi : Jpn. J. Appl. Phys. Vol.28, No.1, January, 1989, pp. L100-L101.
3) H. Padamsee, K. Green, J. Gruschus, J. Kirchgessner, D. Moffat, D. L. Rubin, J. Sears, Q. S. Shu, R. Buhman, D. Lathrop, T. W. Noh, S. Russek, and A. Sievers: CLNS 88/835 (Cornel University, Ithaca, 1988), and also Proc. Conference on Superconductivity and

Applications, Buffalo, NY 14620, April 18-20, 1988, (to be published).
4) J. J. Bautista and S. M. Petty: IEEE Trans. Magn. MAGN-21(1985)640.
5) S. Thakur, D. M. Strayer, G. J. Dick, and J. E. Mercereau: J. Appl. Phys. 59(1986)854.
6) E. Minehara : Proc. 6th Symp. on Accelerator Science and Technology, Tokyo(IONICS Publishing Co. Ltd., Tokyo1987)p.178.

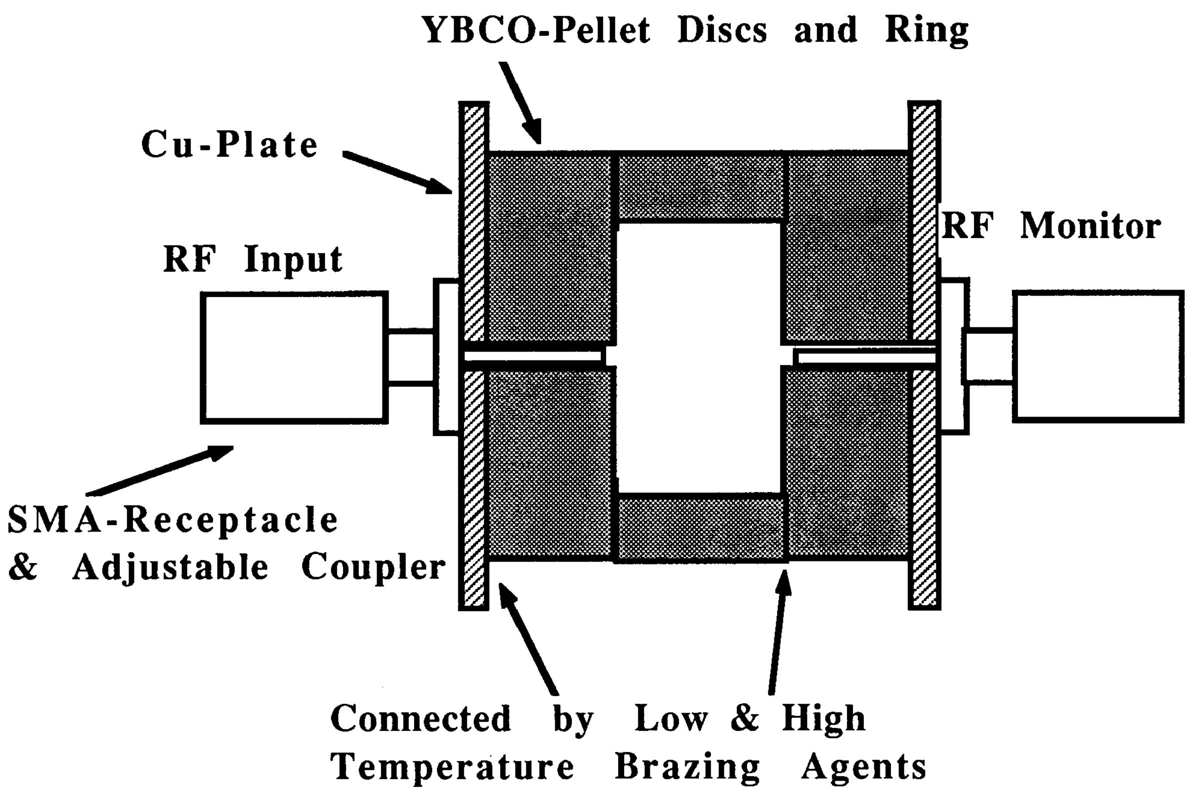

Fig. 1. Schematic of the $YBa_2Cu_3O_{7-\delta}$ cavity.

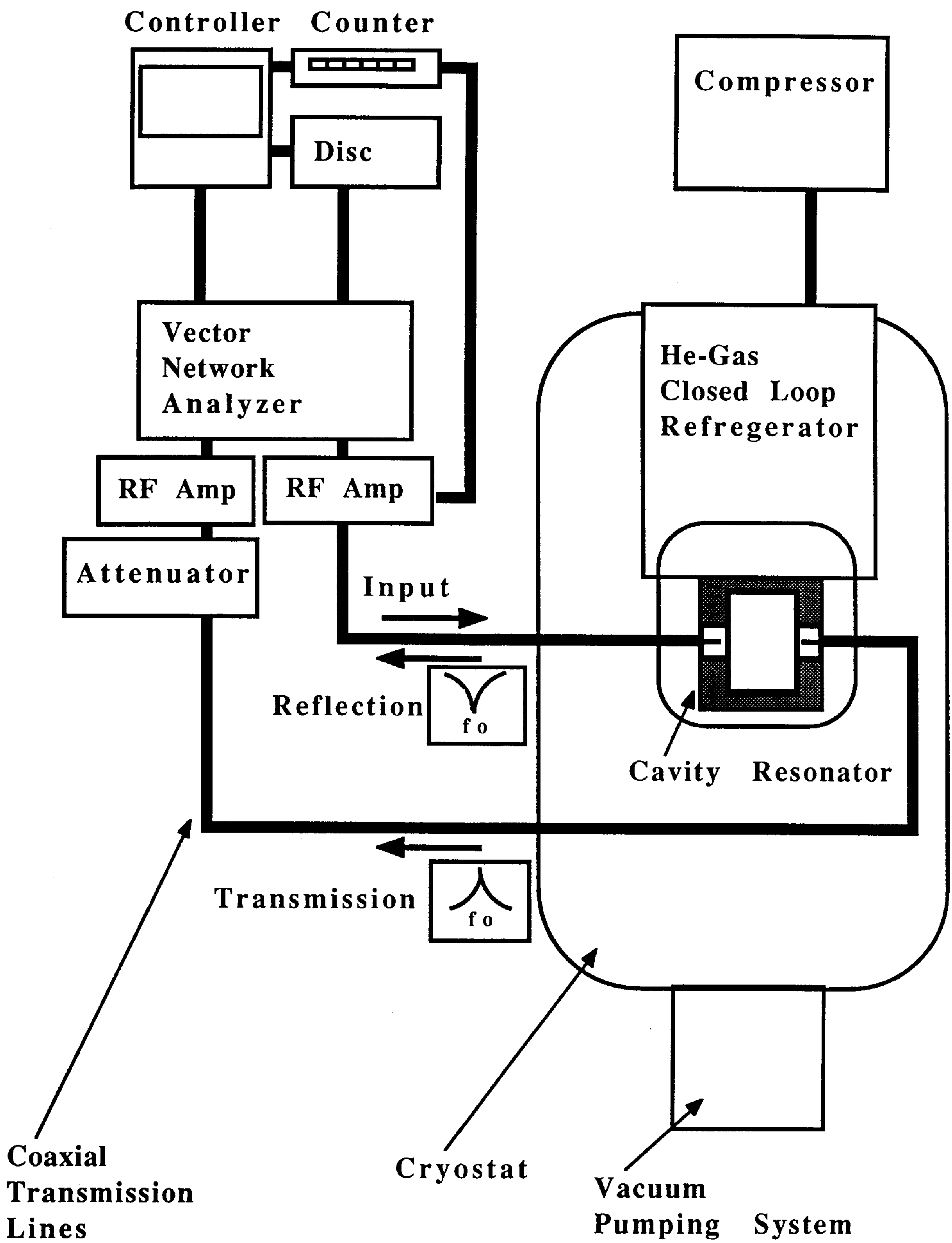

Fig. 2. Experimental set up.