Proceedings of the Korean Superconductivity Society Meeting 2000
(KSS 2000), YongPyung, Kangwondo, Korea, Aug. 16-18, 2000

High-temperature superconducting filter and filter subsystem for mobile telecommunication

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Received 22 July 2000

Abstract

Large-area high-temperature superconducting (HTS) films, filter design and damage-free processing technique have been developed to fabricate low insertion loss and sharp skirt filters. Further, long life cryocooler, low temperature low noise amplifier (LNA) and cryocable have been developed to assemble HTS filter subsystem for IS-95 and IMT-2000 mobile telecommunication. The surface resistance of the films was about 0.2 milli-ohm at 70 K, 12 GHz. An 11-pole HTS filter for IS-95 telecommunication system and a 16-pole HTS filter for IMT-2000 telecommunication system were designed and fabricated using 60 x 50 mm^2 and one half of 3-inch diameter YBCO films on a 0.5-mm-thick MgO substrate, respectively. We have assembled the filter and low temperature LNA in a dewar with the cryocooler. Ultra low-noise (noise figure: 0.5 dB at 70 K) and ultra sharp-skirt (40 dB/1.5 MHz) performance was presented by the IS-95 filter subsystem and the IMT-2000 filter subsystem, respectively.

Keywords : HTS filter, IMT-2000 subsystem

I. Introduction

Since the discovery of high-temperature superconductor (HTS) in 1986, the widespread application of HTS in various new fields has been anticipated. In particular, for microwave application, HTS is useful for antennas, filters and mixers, because of its very low surface resistance. HTS filters have a high unloaded quality factor Q_u, and consequently they have low insertion loss and sharp skirt characteristics. Q_u on the order of 40,000 has been demonstrated in the planar HTS microstrip line configuration at 77 K [1].

Mobile telecommunication systems have been rapidly popularized over the last few years. Large volumes of data are required to be transmitted correctly and efficiently in the multi-media mobile telecommunication systems and for that purpose, the performance of the rf front-end of the base station is very critical. We have been developing the HTS filters in order to realize high-performance mobile telecommunication systems.

In this paper, we describe the HTS filter and demonstrate the complete filter subsystem that can be used for the receiver front-end of a practical mobile telecommunication system.

II. HTS Thin Films

We have adopted YBCO for the application because the plotted curve of surface resistance Rs of YBCO versus rf magnetic field is relatively flat and YBCO can handle more power than Tl-Ba-Ca-Cu-O when the temperature is at or below 70 K [2]. Chemical compatibility between HTS films and substrates is very important. Substrate-film reactions, crystalline perfection, environmental stability, mechanical properties, thermal expansion match with HTS materials, availability over a large area and cost are important issues to be considered for the substrate selection[3]. We use MgO for the substrates. The frequency of mobile telecommunication is in the sub-microwave band that is from 800 MHz to 3 GHz. The required substrate size is several-cm square or diameter when we fabricate a multiple HTS filter that has sharp skirt.

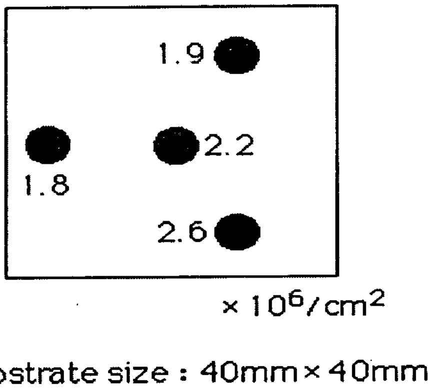

Fig. 1 The distribution of the critical current density J_c measured by J_c -T_c measurement tester. The tester has four probes whose positions are shown in this figure.

HTS thin films can be prepared by several methods. In this study, we used a dc sputtering method to deposit YBCO thin films on MgO substrates.The deposited YBCO films were confirmed to be c-axis-oriented from the results of X-ray diffraction (XRD) analysis. The uniformity of the

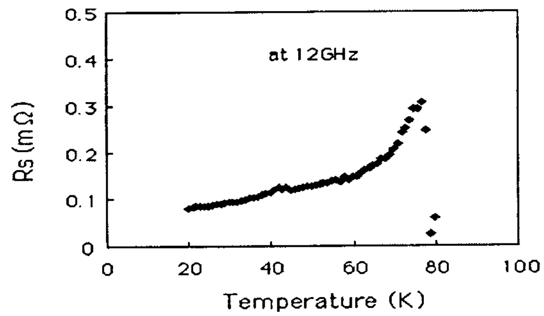

Fig. 2 Temperature dependence of surface resistance Rs of YBCO measured by Kobayashi Lab. of Saitama University.

film characteristics was also investigated. The deposited film thickness was about 500 nm and the standard deviation 3 sigma of the thickness distribution was less than 3% in the 30-mm-diameter circle. The average T_c value was about 85 K and the standard deviation 3 sigma was less than 4%. The distribution of the critical current density J_c was measured by the inductive method, as shown in Fig. 1 [4]. The obtained J_c values were favorable, about 2×10^6 *A/cm²* at 77 K within the 30-mm-diameter circle. Double-sided HTS thin films on a substrate are essential to fabricate a microstrip line filter, so the YBCO films were grown on both sides of the substrates. After deposition was completed on one side, the YBCO film was deposited on the other side. To prevent contamination from the heater on the heater-side plane, noncontact heating by radiation using a cover plate was employed. The measurement of the Rs of the films was performed by the dielectric resonator method [5] using a cylindrical sapphire rod (diameter: 11.8 *mm*, height: 5.49 *mm* and 16.47 *mm*) resonators. The results of R_s measurement are shown in Fig. 2. R_s was less than 0.2 $m\Omega$ when the measurement temperature was below 70 K.

III. HTS filters

An 11-pole Chebyshev filter for IS-95 was designed using parameters of both the YBCO film and the MgO substrate. The YBCO film was assumed to be the perfect conductor. The thickness and the relative

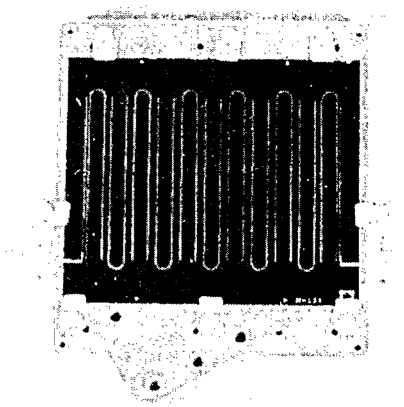

Fig. 3 Photograph of the 11-pole HTS bandpass filter mounted on the base housing. The substrate size 50 x 60 *mm²*.

dielectric constant of the MgO substrate were 0.5 *mm* and 9.7, respectively. The size of the filter was 60 x 50 mm². The passband frequency was from 824 MHz to 849 MHz, which was used for the IS-95

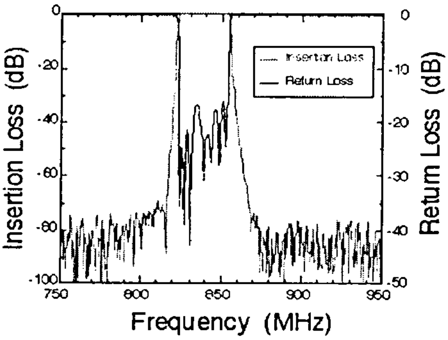

Fig. 4 Frequency response of the 11-pole HTS bandpass filter measured at 70 K. The insertion loss in passband is less than 0.1dB, and the ripple is about 0.1dB. The incident power is 0 dBm.

system. The filter pattern was designed using a linear simulator (HP Microwave and RF Design Systems) and the characteristics of the filter were estimated and optimized using the electromagnetic simulator (HP Momentum). The optimization was carried out with the consideration of the coupling between the non-adjacent resonators. The ripple of the insertion loss was less than 0.05 dB. The passband frequency

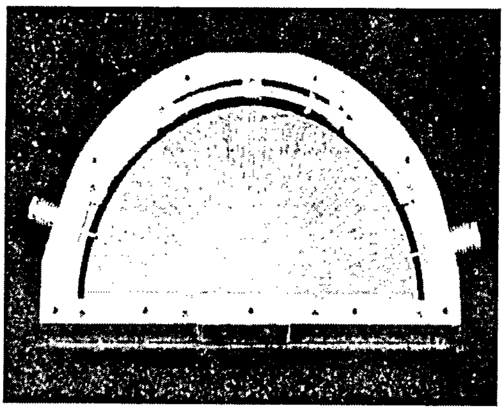

Fig. 5 Photograph of the 16-pole HTS bandpass filter mounted on the base housing.

was from 824 MHz to 852 MHz, with considering the fluctuation of the operating temperature and the deviation of the thickness and the relative dielectric constant of the substrates.

The HTS filters were fabricated using conventional semiconductor fabrication processes. The YBCO films were patterned using a photolithography and argon ion milling. During the argon ion milling, the substrate was cooled in order to prevent the desorption of oxygen from the YBCO pattern edges. Contact pads for wire bonding were made with Au/Ni/Ti films. After the fabrication processes, the HTS filter was mounted on the metallic base housing with low radiation loss. The 11-pole filter mounted on the metallic housing is shown in Fig. 3. The frequency response measured at 70 K and 0 dBm of the incident power is shown in Fig. 4. The net insertion loss of the filter was calculated by subtracting the insertion loss of the semi-rigid cable in the vacuum chamber from the total insertion loss. The insertion loss in passband was less than 0.1 dB, and the ripple was about 0.1 dB.

Similarly, a 16-pole Chebyshev filter for IMT-2000 was designed and fabricated. The photograph of the 16-pole Chebyshev filter is shown in Fig. 5.

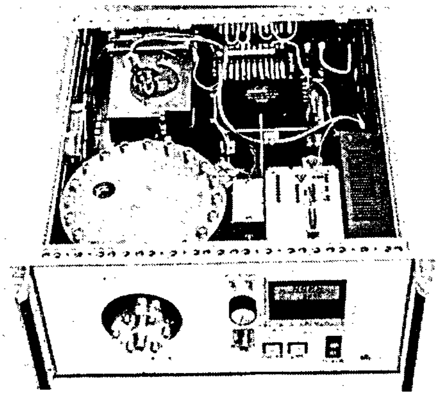

Fig. 6 Photograph of the HTS receiving filter subsystem for IS-95 wireless system. There are a dewar that contains a HTS filter moudle and a first stage LNA, a starling cycle cryocooler, a second stage LNA with an attenuator, a thermal controller, and power moudles.

IV. HTS Filter Subsystems

We assembled the HTS filter module and a low noise amplifier (LNA) in a dewar with a cryocooler in order to form a cryogenic receiver. Figure 6 shows the photograph of the HTS receiving filter subsystem for IS-95. Much attention was paid to reducing thermal radiation from the dewar to the filter module

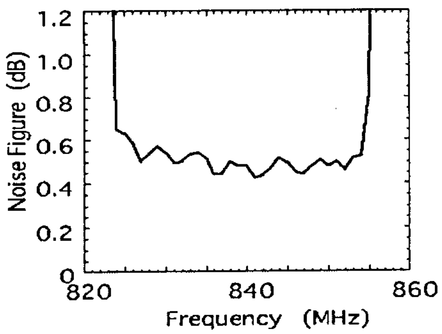

Fig. 7 Noise figure of the HTS filter subsystem shown in Fig. 6 including the loss of the low heat-load RF cryocable measured by Y-factor method at

and the LNA. For example, the housing of the filters and the LNA were gold-plated, and some radiation shields were used over the filter module. Low heat-load cryocables were developed and used to connect the filter module and the LNA to the ambient temperature side of the vacuum insulated dewar [6]. After evacuation through a pump port and baking out of the dewar, the pump port was pinched off and welded for a permanent seal. There is an active getter

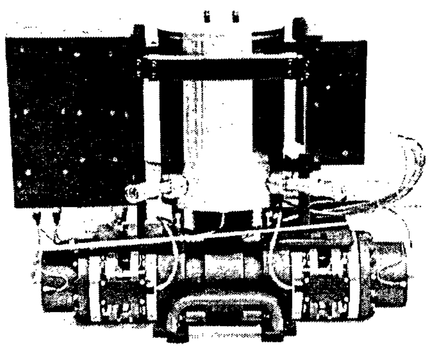

Fig. 8 Photograph of the HTS receiving filter subsystem for IMT-2000 wireless system.

in order to evacuate the residual and out gas in the dewar. The second-stage LNA input in the ambient temperature side is connected to the output of the first stage LNA in the dewar. The total gain of the LNAs can be varied from 21 dB to 30 dB. The operating temperature of the subsystem is controlled at 70 K. Figure 7 shows the measured noise figure (NF) of the filter subsystem including the loss of the low heat-load cryocable. The NF was measured by means of Y-factor method, where the frequency width of the detection was 30 kHz [7]. The NF at the passband frequency range was about 0.5 dB, which was a few dB lower than that of the conventional filter subsystem [8].

Figure 8 shows the photograph of the HTS receiving filter subsystem for IMT-2000. The filter module and LNA were cooled by the pulse tube

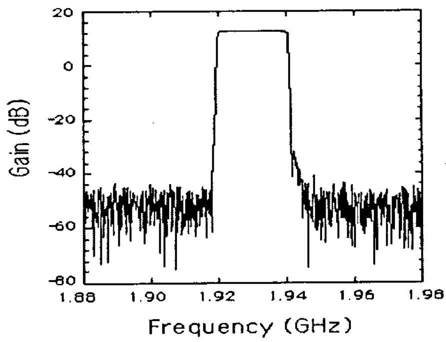

Fig. 9 Frequency response of the HTS filter subsystem shown in Fig. 8.

cryocooler whose cooling capacity at 70 K was about 6 watts. Figure 9 shows the frequency response. The center frequency was 1930 MHz and the pass band width was 20 MHz. The gain in pass band was about 14 dB. The skirt characteristics at the edge of the pass band was 40 dB/1.5 MHz.

V. Conclusion

We have described the HTS film, filter design and fabrication. We have also demonstrated an 11-pole bandpass filter subsystem of 800 MHz band for the IS-95 wireless system and a 16-pole bandpass filter subsystem of 2 GHz band for the IMT-2000 wireless system. A very low noise figure of 0.5 dB was obtained by using 800 MHz band HTS filter subsystem and a extremely sharp skirt characteristics of 40 dB/1.5 MHz was observed by using 2 GHz band HTS filter subsystem.

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