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YBCO film properties for 2GHz band receivers with HTS filters and the filter characteristics

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ABSTRACT
We have developed YBCO high-temperature superconducting films for use in filters of 2GHz band receivers. Four Different crystalline YBCO films were prepared by pulse laser ablation deposition on both sides of MgO(100) substrate. 15-section band-pass filters composed of double-spiral patterned resonators, which are much smaller than the conventional hairpin patterned resonators, were then fabricated with each film. The comparison of the measured filter characteristics and film crystallinity suggested that the longer c-axis length of YBCO crystal unit cell increases the insertion loss at pass-band of filters. In addition, weak-link properties of the grain boundaries of the films influenced the filter characteristics. Therefore, YBCO films with higher crystallinity gave high performance 15-section band-pass filters. Furthermore, we developed a trial compact receiver subsystem for 2GHz band including a cryocooler and low-noise amplifiers (LNAs), in conjunction with two 15-section band-pass filters shielded by an Al package that generates lower thermal stress and possess higher thermal conduction when cryocooled compared with the Fe alloy packages. This subsystem was designed for employing in the open-air under the antenna on top of towers or buildings, where the base stations of 3G mobile communications are installed.
Key words: YBCO films, HTS filters, 2GHz band, crystallinity, double-spiral pattern, receiving subsystem

1. INTRODUCTION

It is believed that there will be a frequency resource shortage in the wireless communications systems such as cellular phones in the near future, as the number of users increases. If the interference of a RF signal by other signals of adjacent frequency channels can be controlled by selecting the signal frequency effectively, where the guard band between the channels can be decreased, the frequency resource can be used efficiently [1].

On the other hand, it is known that Cu-oxide high-temperature superconductors (HTS) of YBCO and the like have the possibility to reduce the surface resistance in microwave region of the mobile wireless communications by 2-3 order, as compared with the high conductivity metal conductors such as copper and silver [2]. It means that HTS is expected to show much higher Q factor, so that both lower insertion loss and higher frequency-selective filters can be obtained when applying HTS to the RF filters by which the signal frequency is selected at the wireless base stations. Moreover, the operation at low temperatures of tens of K level, which HTS filers are usually cooled down to, can exhibit a higher sensitivity. This can contribute to save the battery power of the potable phones or to expand the cell area serviced by base stations.

Therefore, research and development on HTS materials, design and fabrication of HTS filters, and filter subsystems with cryo-coolers, for the wireless base stations, have been in progress worldwide [3].

HTS films certainly have the advantage of miniaturizing filters because these films enable to utilize planar-type circuits in filters. However, poor quality of the HTS films causes the decrease in the Q factor, thus giving weak filtering characteristics. Therefore, it is essential to improve the quality of HTS filters. Thus, it is necessary to understand the relationship between the RF properties of the HTS films and their structural properties such as cystallinity. Moreover, methodology of making high quality HTS films with low surface resistance needs to be developed.

Previously, we examined the relationship between the RF properties of the YBCO double-sided films on MgO(100) substrates prepared by the pulsed laser ablation method and their film structural properties, using $\Lambda/2$ type hairpin-patterned resonator of 2 GHz, where Λ is the wavelength of the electromagnetic wave. It was found that the Q factor varied with the quality of the YBCO [4-6] films. In addition, from our results it was found that weak-link properties of the grain boundaries of the films affect the RF properties strongly [5, 6].

Based on the above observations, we have developed YBCO films and filters for receiving subsystems for the 2GHz band that is used for the third generation (3G) mobile communication systems.

In this paper, we report the film properties of YBCO films for 2GHz band receivers, filter characteristics of newly designed HTS filters [7-9] with YBCO films, and an application of HTS receiving filters to a subsystem [8, 9] for 2GHz band.

2. EXPERIMENTAL

2.1 Sample preparation of YBCO films

In this study, four different crystalline YBCO films were prepared. These YBCO films were grown on the both sides of MgO (100) substrates using a pulsed laser deposition (PLD) method [4]. The crystal structure, impurity and orientation of the grown films were analyzed by θ/2θ X-ray diffraction (XRD). The films mainly exhibited c-axis orientation perpendicular to the surface of the MgO substrates as shown in Fig.1. The degree of the c-axis orientation and in-plane orientation were checked by ω-rocking XRD and ϕ-scanning XRD, respectively. Table I summarized the cystallinity of the YBCO film samples. In Table I, the relative intensity I(200)/[I(200)+I(006)] corresponds to the ratio of the a-axis oriented grains in the film. Δω referees to the full width at half-maximum of the (005) rocking-curve, which shows the degree of c-axis orientation.

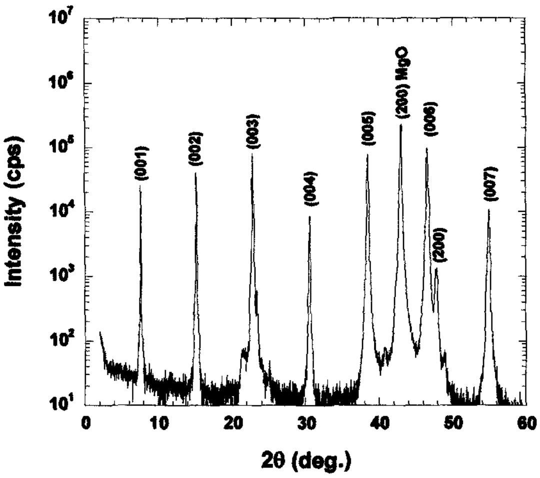


Fig.1 XRD pattern profile of YBCO film, FH.

In addition, the relative intensity I(45°)/[I(45°)+I(90°)] calculated from the ϕ scanning of (103) planes, as shown in Figure 2, indicates the ratio of the 45° tilted grains in the film. Δϕ referees to the full width at half-maximum of each peak, which shows the degree of in-plane orientation.

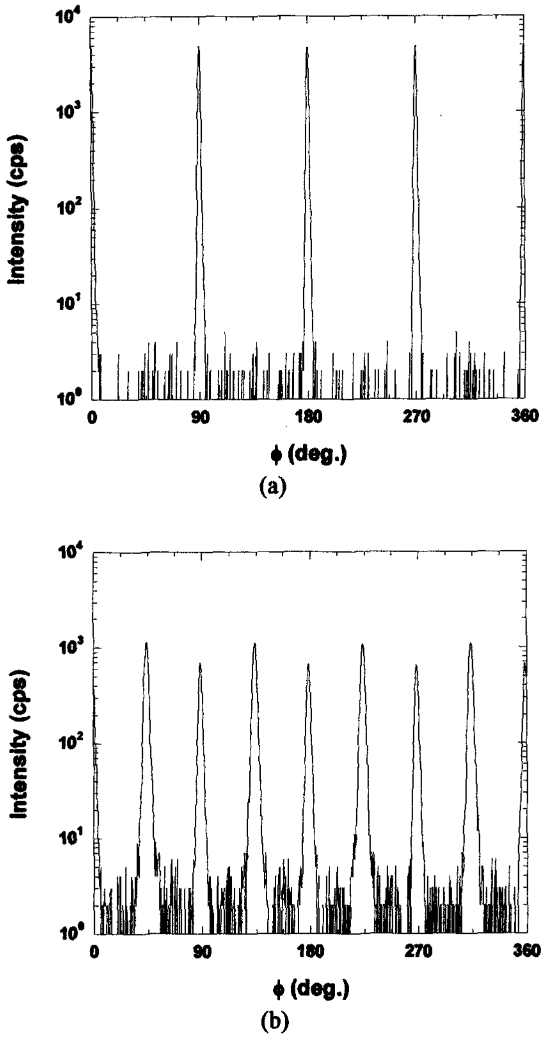


Fig.2 ϕ-scanning XRD pattern profile of YBCO film, (a) FH film, (b) FB film.

The ϕ scanning pattern of (110) planes of the MgO substrate showed the same four-folded symmetry at every 90 degree as in Figure 2 (a). The <100> direction of the films were mainly aligned parallel to the <100> direction of the substrates, which is called the cube-on-cube.

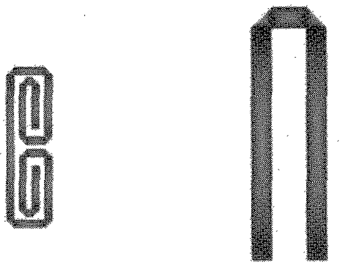
Table I Crystallinity of the films for filters.

Film#	C-axis length (nm)	I(200)/[I(200)+I(006)] (%)	Δω (°)	I(45°)/[I(45°)+I(90°)] (%)	Δϕ (°)
FH	1.1695	1.36	0.91	0	2.0
FM	1.1701	0.23	1.02	0	1.9
FL	1.1711	0.56	0.99	0.44	1.8
FB	1.1725	2.30	1.49	62	2.8

2.2 Filter design and fabrication

The miniaturization of HTS filters leads to the smaller area films and lighter loaded cryocooler, thus resulting cost reduction. In order to get a smaller HTS filter, each resonator-element in the filter was downsized. For this purpose, Λ/2 type MSL (microstrip line) resonator was proposed.

As shown in Fig.3 (b), hairpin type pattern was often used in MSL bandpass filters. We proposed a pattern called double spiral pattern as shown in Fig.3 (a), and then optimized the pattern shape and size using an electromagnetic simulator by the moment method [7]. From the simulation result, it was understood that the surface area of the new resonator is smaller than the hairpin type resonator, as depicted in Fig. 3.



(a) Double spiral type (b) Ordinary hairpin type

Fig.3 Comparison of resonators: (a) the double spiral type, (b) ordinary hairpin type; both resonators were composed of the same materials and were designed to operate at the same resonant frequency. The specific dielectric constant (εr) and thickness of the substrate are designed as 9.7 and 0.5mm of MgO(100), respectively [7-9].

The samples for transmission characteristic tests were designed to have a passband center-frequency around 2 GHz with bandwidth about 20 MHz and frequency response of Chebyshev type [7-9], which is equal ripple type in passband. One side of the film of each sample was patterned by photolithography. The other side of each sample was used as the ground layer.

Usually, the HTS filters are operated in a dewar. Therefore, in order to have the HTS filter with low heat capacity and low thermal radiation from the dewar wall under the environmental temperatures, aluminum-based small cryo-packaging was designed.

The major reason to use Al package in place of the traditional Fe(-Ni) based alloy (Invar, Kovar, etc.) package is to improve the heat capacity and thermal conduction. However, when Al package was applied, defects would generate at the I/O interconnects because of the thermal stress accumulation owing to the thermal expansion difference between the package and substrate, during the temperature cycling between the room temperature and operating cryogenic temperatures. To solve this problem, high reliability interconnects between the coaxial connector and the YBCO films are made with the Indium solder on the electrodes made from 3 metal layers for the filter. The metal layers are consisted of Ag /Pd /adhesion layer.

The package volume of the newly designed double-spiral type HTS filter [7-9] is estimated to have about 50% of the hairpin type filter with the same sections and the same frequency band. Fig.4 illustrated a photograph of a 15-section HTS filter sample with the double-sided YBCO films on MgO(100) substrate by the technique of the double-spiral resonator shielded with the Al package having indium junctions for I/O interconnects.

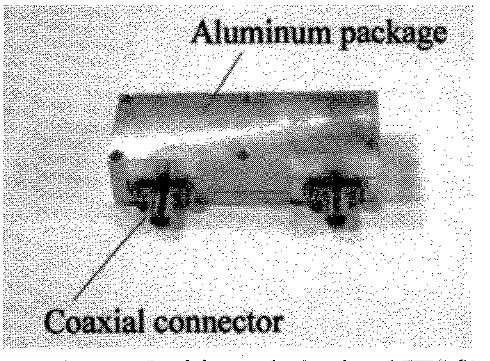


Fig.4 A photograph of the newly developed HTS filter sample.

2.3 Filter characteristics measurement

Each aluminum-packaged filter sample was mounted on the cold plate of a cryocooler. Then, the input and output cables were connected with the coaxial connector as shown in Fig.4. Next, the chamber with the package and the cables inside was vacuumed and cooled down to the temperature of 70 K. The temperature of the package was monitored and controlled by a sensor, which was inserted into the package. A network analyzing system was used to measure the S-parameters of the filter samples at lower temperatures than 100 K. The calibration was made at the measured operating-temperatures of filter samples, based on full two-port calibration.

3. RESULTS AND DISCUSSION

3.1 Filter characteristics

Fig.5 shows an example of the measured frequency responses of the HTS filter sample using FH film shown Table I. The filter sample with promising YBCO-film characteristics such as crystallinity would give frequency responses corresponding to the low surface resistance of the YBCO films at 2 GHz.

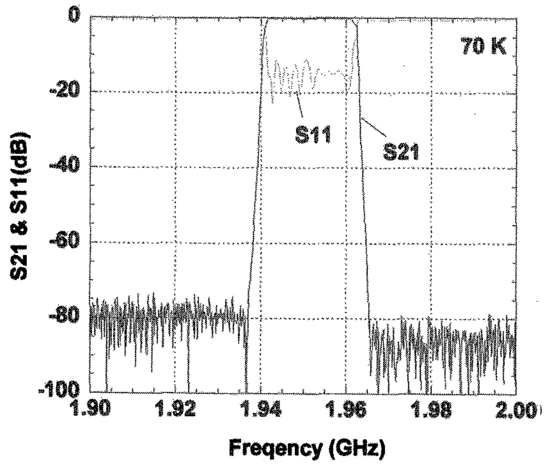


Fig. 5 Measured frequency response of the FH filter with good quality YBCO films at 70 K.

On the other hand, the HTS filter sample with the FL film showed larger loss compared to the FH filter. Fig.6 shows the comparison of the measured transmission responses (magnitude of S-parameter S21) of FH, FM, and FH filters at 70 K. The insertion loss of the FH filter is about 0.12 dB. However, it increases up to 0.95 dB when FL filter is used. Moreover, the filter curve of the FB filter did not appear beyond the instrumental noise at low temperatures down to 40 K.

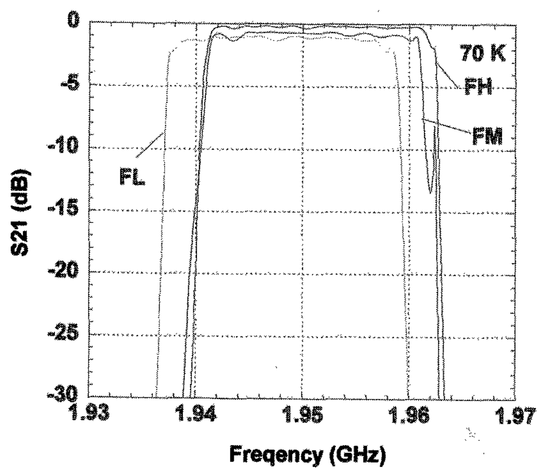


Fig.6 Comparison of the measured transmission responses of FH, FM, and FL filters at 70 K.

From the measured filter characteristics and crystallinity of the YBCO film sample shown in Table I, it is considered that the c-axis length of YBCO crystal unit cell would affect the filter characteristics. The c-axis length of the YBCO crystal unit cell relates to the oxygen deficiency and/or distortion of the films. The c-axis length of the FH film is close to that of the bulk material. However, even after oxygen annealing around 500℃ for hours, this type films with longer c-axis length didn't change the crystallinity. Hence, the distortion of the films results in the longer c-axis length. Moreover, in the case of the FB film, weak-link properties at the grain boundaries would adversely affect the filter characteristics, as well. From these results, we realized that it is very important to control the film cystallinity, especially for multi-section filters with compact patterned resonators.

3.2 Subsystem

Outlines of the development of the trial HTS subsystem, for 3G base stations (2GHz band), designed to operate under the open-air conditions using the newly developed small and high performance filter were given [1,8,9]. The subsystem provides a function of receiving diversity, which means that there should be two units at the receiving front-end circuit that consists of cryo-LNAs, HTS filters and so on. The weight and volume of the sub-system in Fig. 7 are about 19kg and 15L (W27cm x D15cm x H37cm), respectively, without projections of the interface connectors and so on. The volume and the functions of the subsystem were found to be comparable to those of the subsystem with no HTS filters. The HTS filters in the dewar in this subsystem can be exchanged for the other HTS filters, similar to the newly developed 15 section filter of Fig. 4.

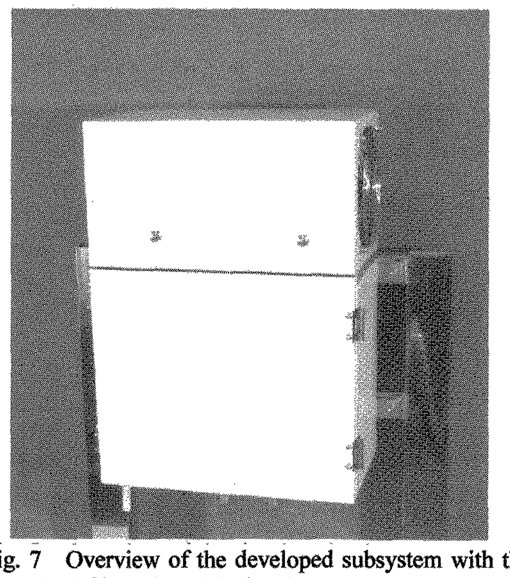


Fig. 7 Overview of the developed subsystem with the HTS filters for 2GHz band.

4. SUMMARY

We have examined the relationship between the crystallinity of YBCO films, on both sides of MgO(100) substrates prepared by the pulsed laser ablation technique, and the filter characteristics. The filters designed for the band pass around 2GHz were made using c-axis oriented YBCO films on both sides of MgO (100) substrates with the new resonator structure called double-spiral resonator, which is much smaller than the conventional hairpin structure. This would result higher-crystallinity YBCO films with superior filter performance and very low loss at pass-band. However, the films with longer c-axis length which relates to the distortion of films show larger loss.

Moreover, Al packages of these filters with In junctions were developed in order to get lower heat capacity than that of the Fe alloy packages.

Finally, we developed a 19kg, 15L cryogenic subsystem for 3G mobile communications, using the new miniaturized filter structure. A subsystem was designed for the use in the open-air under the antenna on top of towers or buildings

REFERENCES

[1] Yutaka Yasui, Yoshinori Tanaka, Yasuyuki Ohishi, Kazunori Yamanaka, FUJITSU, 54, 4, Sep., P323-330 (2003), in Japanese.
[2] N. Newman et al., J. Supercond., 6, 119 (1993).
[3] Balam A. Willemsen, "HTS Filter Subsystems for Wireless Telecommunications", IEEE, trans. on Appl. Supercond., VOL. **11**, NO. 1, MARCH, 60-67(2001).
[4] A. Akasegawa et al. : Film-thickness dependence of the microwave properties of YBCO films. *Physica*, **C341-348**, p.2681-2682 (2000).
[5] A. Akasegawa, K. Yamanaka, T. Nakanishi, M. Kai, Fujitsu Scientific J., vol.**38**, No.1, 31-37(2002).
[6] K. Yamanaka, Akihiko Akasegawa, and Teru Nakanishi, "Effect of YBCO film characteristics on RF properties of MSL resonators with these films", 2000 MRS Fall Meeting at Boston, Proc.Vol.**659**, II6.2., (2000)
[7] Manabu Kai, Teru Nakanishi, Akihiko Akasegwa, Kazunori Yamanaka, IEICE, trans. on Electron., to be published.
[8] http://pr.fujitsu.com/jp/news/2002/09/20.html
[9] K. Yamanaka, Manabu Kai, Teru Nakanishi, and Akihiko Akasegawa, "HTS filters with YBCO films for 2 GHz band receivers". ISS 2002, FD-9, Nov., (2002).

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