Adjustable Multilayer HTS Filters

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Abstract—An adjustable multilayer high-temperature superconductor (HTS) bandpass filter has been fabricated. Taped comb-line filters with multilayer structures were designed. $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) thin films deposited on LaAlO_3 were used to construct the packaged multilayer HTS filter. The electrical length of the resonators in the filter was smaller than a quarter-wave length. The frequency responses of the filter were measured at liquid nitrogen temperature 77 K. The insertion loss of the packaged filter was determined to be less than 0.5 dB. By mechanically adjusting the multilayer structure, the center frequencies of the filter changed from 1.78 to 1.92 GHz, and the variations of the bandwidth from 60 to 150 MHz were also obtained.

Index Terms—Adjustable, filter, high-temperature superconductors, multilayer structure.

I. INTRODUCTION

IN WIRELESS communications, high-temperature superconductor (HTS) filters, fitted in cryocoolers as front-end receivers, have been widely tested [1], [2]. It has been proved that HTS filters have extremely steep rejection skirts at the bandpass edge and a nearly flat response across the passband. With regard to the cryogenic environment for HTS filters, a large device size will cause heavy refrigeration loading. Therefore, developing HTS filters to a minimum size is important for reducing the cooling space and power consumption of the refrigeration system. Hairpin-comb filters [3] and hairpin-resonator filters [4] were previously proposed to minimize the configuration of HTS microstrip filters.

In this paper, we report the design and fabrication of a new adjustable multilayer HTS filter. It is based on a taped-comb-line filter with layered loading capacitors. The electrical length of the resonators can be dramatically decreased when the loading capacitors are greatly increased. The size of the filter is then reduced. By moving the position of the individual layer and changing the loading capacitors, the center frequency of the filter can be adjusted. The bandwidth can also be varied by mechanically adjusting the height of the gap between the filter patterns and the housing tip.

Fig. 1. The schematic of four HTS YBCO films stacked to form a multilayer HTS filter.

Fig. 2. Detailed filter patterns on the second and third layers. The dashed rectangle was the capacitor ground on the second layer.

II. EXPERIMENT

A packaged multilayer HTS filter composed of four $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (YBCO) films in a copper housing was designed. The dimensions of the package inner space were $30 \times 12 \times 7$ mm. Three conductor layers were stacked on the bottom surface and one layer was attached to the top surface of the package space. The schematic representation of the layered structure is shown in Fig. 1. The first conductor is used as the bottom ground, the second one as a capacitor ground, the third one contains resonator patterns, and the fourth one is the top ground. The detailed filter pattern, on the second and third conductor level, is described in Fig. 2. The dashed rectangle was the capacitor ground plane on the second layer. On the third layer, the 12-mm long and 0.6-mm wide of input-output microstrip lines were perpendicularly connected to the two resonator patterns, respectively. The top ends of the resonators were respectively connected to a long rectangular pattern having one end connected to the ground. In the vertical direction, there is an air gap between the third and the fourth conductor levels for frequency response tuning. The filter was simulated by using 2.5-D simulators contained in the software

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Fig. 3. Simulated frequency responses of a two-stage bandpass filter.

Fig. 4. Prototype of complete packaged adjustable multilayer HTS filters.

LINMIC+/N (by JANSEN Microwave GmbH, Germany). The designed filter was a two-stage Tchebyscheff bandpass with the center of frequency (f_0) at 1.86 GHz and bandwidth (BW) of 120 MHz. Fig. 3 shows the modeled frequency responses of the two-pole filter.

Commercial YBCO films deposited on 0.5-mm-thick LaAlO_3 substrates ($\epsilon_r = 24$) were used in this experiment. The specifications of the films are $T_c > 87$ K, $J_c \sim 2 \times 10^6$ A/cm² at 77 K, and $R_s \leq 0.6$ m Ω at 10 GHz and 77 K (from THEVA GmbH, Germany). The loss tangent ($\tan \delta$) of LaAlO_3 was reported to be smaller than 10^{-5} at 6.3 GHz and 77 K [5]. The usual photolithographic technique with wet etching method was employed to pattern the YBCO films. A surface profilometer was used to measure a post-etching strip with a designed width of 300 μm . The width was determined to be 295 μm and the thickness was about 0.83 μm . Four YBCO films were stacked in a copper housing to form a multilayer HTS filter. Gold films with 0.2 μm in thickness were deposited on the input–output of the filter patterns as the pattern contact points. Two SMA connectors were attached to the copper housing as the input–output terminals. In–Sn solder was used to connect the SMA pins and the input–output of the filter patterns. Ag-paint with contact resistivity $\rho \sim 1 \times 10^{-4}$ $\Omega\cdot\text{cm}$ was used to short HTS transmission lines to ground. Fig. 4 shows the photo of a complete multilayer HTS filter.

A Wiltron 360B vector network analyzer (VNA) was used to measure the (reverse) reflection coefficient (S_{22}) S_{11} and (re-

(a)

(b)

Fig. 5. (a) Frequency responses of the adjustable multilayer HTS filter, with $f_0 = 1.83$ GHz, BW = 60 MHz, and IL = 0.45 dB. (b) Varied frequency responses of the HTS filter, f_0 decreased from 1.83 to 1.78 GHz with BW = 60 MHz and IL = 0.59 dB.

verse) transmission coefficient (S_{12}) S_{21} . A pair of cryogenic measurement cables (+150 $^{\circ}\text{C}$ to -269 $^{\circ}\text{C}$) was connected to the input–output ends of VNA with each individual end. The other ends were, respectively, connected to the SMA connectors of the packaged HTS filter. The filter with connected cables was then immersed into liquid nitrogen (77 K) to do measurements.

III. RESULTS AND DISCUSSION

Fig. 5(a) represents a measurement of frequency response of the packaged multilayer HTS filter. The center of frequency was at 1.83 GHz, the bandwidth was 60 MHz, and the insertion loss (IL) was 0.45 dB at 1.86 GHz. For varying the loading capacitors of the designed comb-line filter, the superconducting patterns on the third layer were moved. Moving the two patterns on layer 2 and layer 3 closer to each other by 0.5 mm, the loading capacitors of the filter were increased, and the center of frequency was then decreased. Fig. 5(b) shows the frequency shifting. The

Fig. 6. (a) Varied frequency response of the HTS filter with $VD = 5$ mm, showing $BW = 110$ MHz, $f_0 = 1.78$ GHz, and $IL = 0.50$ dB. (b) Varied frequency response of the HTS filter with $VD = 6$ mm, showing $BW = 150$ MHz, $f_0 = 1.86$ GHz, and $IL = 0.52$ dB.

center frequency of the HTS filter was varied from 1.83 to 1.78 GHz with BW of 60 MHz. The center frequency can also be adjusted toward higher frequency by reducing the loading capacitors. In this experiment, we obtained a center frequency of 1.92 GHz with $IL = 0.56$ dB.

The bandwidth of the HTS filter has been adjusted by varying the vertical distance (VD, air gap) of the third and the fourth conducting levels. The bandwidth of the filter changed from 60 to 150 MHz. The frequency response shown in Fig. 5(b) corresponds to a filter with $VD = 4$ mm, having $BW = 60$ MHz. The bandwidth increased by increasing the vertical distance of the third and the fourth conducting levels.

Fig. 6(a) represents the frequency response of an HTS filter with vertical distance 5 mm, showing $BW = 110$ MHz and $f_0 = 1.78$ GHz. The bandwidth was increased to 150 MHz in a tested HTS filter with $VD = 6$ mm, shown in Fig. 6(b). Table I shows the summary of the tests of this adjustable multilayer HTS filter.

TABLE I
SUMMARY OF THE TESTS OF AN ADJUSTABLE MULTILAYER HTS FILTER

Test	Center Frequency f_0 (GHz)	Band Width BW (MHz)	Insertion Loss IL (dB)
1	1.78	60	0.59
2	1.78	110	0.50
3	1.83	60	0.45
4	1.88	150	0.52
5	1.92	80	0.80
6	1.92	110	0.56

The center of frequency from 1.78 to 1.92 GHz and bandwidth between 60 and 150 MHz were obtained.

Microstrip lines in this multilayer HTS filter were shorted to ground by using Ag-paint at the high-current point. This may decrease the unloaded Q of the packaged HTS filter, as discussed in [6]. Insertion losses of the filters in this experiment may be reduced, if the contact resistance of the ground contacts is decreased.

IV. CONCLUSION

An adjustable multilayer HTS bandpass filter has been designed and fabricated. Four YBCO thin films deposited on LaAlO_3 substrates were stacked and placed into a copper housing to form a packaged multilayer HTS filter. The center of frequency of the filter was varied from 1.78 to 1.92 GHz by moving the HTS films. The bandwidth of the filter was also adjusted by changing the vertical distance of the air gap in a copper housing. The variation of the bandwidth from 60 to 150 MHz was obtained.

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