HIGH-TEMPERATURE SUPERCONDUCTING MICROSTRIP FILTERS WITH HIGH POWER-HANDLING CAPABILITY

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ABSTRACT

The performance of narrowband microstrip filters with low insertion loss and high power-handling capabilities made from $YBa_2Cu_3O_7$ (YBCO) high-temperature superconducting (HTS) films is presented. Results are shown for two different novel designs that were chosen to optimize the power-handling capabilities. Both have a 2-GHz center frequency and 5-poles that incorporate coupled resonators with 10-Ω internal impedances on 50-mm-diameter $LaAlO_3$ substrates. Both designs use parallel-coupled feed lines to avoid current crowding. The first design includes backward- and forward-coupled filters, has 1% bandwidth, and has handled over 25 watts of input power at 10 K with less than 0.25 dB compression. The second design has 1.2 % bandwidth and use only forward-coupled resonators. The minimum insertion loss is less than 0.2 dB at 45 K, it has a third-order intercept of 62 dBm. Another similar filter handled 36 watts of power at 45 K with less than 0.15 dB compression across the passband. We have developed a technique to visualize the power dissipation of the filter by observing the bubbles created by the filter when submerged in liquid helium, showing areas with local defects or where the current distribution is at its peak value.

I. INTRODUCTION

Filters with sharp skirts, low insertion loss and high power-handling capability are critical to enhance the performance of communication systems. Superconducting planar filters with very low insertion loss and high out-of-band rejection have been reported [1-3]. Most of these filters have relatively low power-handling capability limited by conduction non-linearities in the HTS film at higher current densities. Several high-power YBCO filters on 50-mm-diameter $LaAlO_3$ substrates have also been reported [4-5]. The filter we reported previously had a 0.7 % fractional bandwidth [4]. The input and output feed lines were directly tapped to the first and last resonators. This feed configuration limits the power the filter can handle due to the current crowding at the junction of the input feed line and the first resonator. In addition, the forward coupling between non-adjacent resonator lines affects the filter response and this effect increases with the increase of resonator width [5].

In this paper, we present two types of filters that are designed to avoid the above-mentioned current-carrying issues. The first type is a 5-pole filter that has a combination of the forward- and backward-coupled resonators with parallel-coupled input feed lines. The other is an all-forward-coupled filter with parallel-coupled feed lines. We have chosen a microstrip structure for our filters at the 2 GHz cellular communication frequency band. In the design of the filters, we place emphasis on increasing the power-handling capabilities by widening the lines. We also bond the wafer in a thermally matched package to maximize thermal contact to the cold head, which in turn minimize the heat localization on the YBCO film.

II. FILTER DESIGN

A) Backward- and Forward-Coupled Filter Design

We made a filter which combines forward- and backward-coupled resonators. Backward coupling is maximized when two coupled resonators have a one-quarter wavelength overlap and is minimized when two half-wavelength resonators are fully aligned. The forward coupling, on the other hand, results from the even- and odd-mode phase velocity difference and plays a dominant role when two half-wavelength resonators are fully aligned, because the backward-coupling is then minimized. By the combination of resonators with different dominant coupling, we achieve filters with narrow bandwidth and high power-handling capability. Fig. 1 shows the mask layout of this filter.

As shown in Fig. 1, the three center resonators are coupled together dominantly by forward coupling, while the first and last resonators are coupled mainly by backward coupling. This arrangement eliminates the non-adjacent coupling present in the filter reported earlier (see Fig. 1 in [4]). The input and output feed lines are parallel-coupled into the

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outermost resonators, eliminating the current crowding at the junction of the feed lines and those resonators.

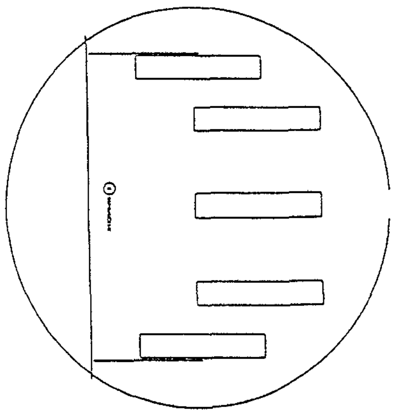

Fig. 1. A mask layout of a forward- and backward-coupled filter at 2 GHz. The filter has 1.2 % bandwidth and 10-Ω characteristic impedance.

B) Forward-Coupled Filter Design

Forward-coupled narrowband filters utilize coupling due to the even- and odd-mode velocity difference of coupled microstrip lines. In order to eliminate all backward coupling, the resonator elements are coupled over their full half-wavelength extent, instead of the conventional quarter wavelength. More detailed discussion on designs can be found in the literature [4-6]. Fig. 2 is the mask layout of the filter with 1.2 % fractional bandwidth on a 50-mm-diameter $LaAlO_3$ substrate.

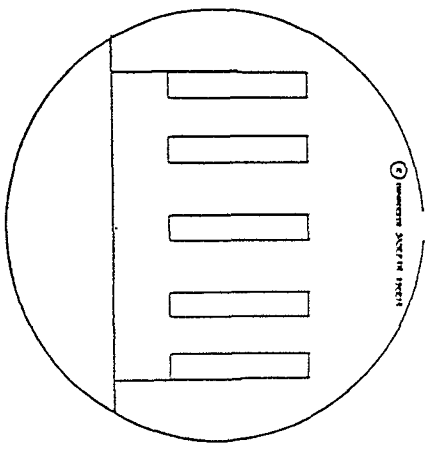

Fig. 2. A mask layout of a forward-coupled filter at 2 GHz. The filter has 1.2 % bandwidth and 10-Ω characteristic impedance.

III. FILM DEPOSITION, FILTER FABRICATION, AND PACKAGING

YBCO films were deposited on both sides of $LaAlO_3$ substrates by several techniques: cylindrical magnetron sputtering [7], off-axis sputtering, off-axis laser ablation and co-evaporation [8]. Processing of the high-power microstrip filters involves several steps: ground plane contact and protection layer deposition, patterning of the YBCO microstrip, and formation of ohmic contacts.

Filters were bonded to a thermally matched package that is bolted to the cryocooler head using indium foil to ensure a good thermal contact between the package and cryohead.

IV. FILTER PERFORMANCE

Filter power-handling measurements are done with a frequency synthesizer and a power amplifier. The third-order intercepts (TOI) are obtained by a standard two-tone intermodulation measurement in which two single-frequency tones ω_1 and ω_2 of equal amplitude are applied into the filter. Third-order mixing products, such as $2\omega_1$-ω_2, are obtained in a spectrum analyzer at the output.

A) "Bubble" Imaging Technique

In order to understand the current distribution and heat dissipation distribution issues, we have developed a technique for imaging the spatial distribution of heat dissipation in filter structures by immersing the filter in liquid helium and observing the boiling pattern around the filter elements. This procedure is used to identify the current distribution in the geometric structures in a particular design. A camera is mounted outside of the dewar to observe the boiling phenomena on the filter with different input power. As the power passing through the filter increases, the current increases correspondingly. The surface resistance of the film results in increased dissipation with increasing currents. This dissipation initially leads to nucleate and, eventually, to film boiling of the helium bath. Figure 3a shows the visualization of the bubbling. Figure 3b is the view as seen by the camera through the transparent window of the dewar. The rectangular area is the resonator, and the contours correspond to the perimeter of the He boiling region at different power levels; the larger the enclosed area in the contour, the higher the power. From the location and intensity of the bubbling we can identify the high dissipation areas. Also, by observing the bubbles at different operational conditions, we can identify how the current distribution changes with frequency in band, and how a plateau in dissipation in one area may lead to an onset of dissipation in another, indicating a redistribution of the currents.

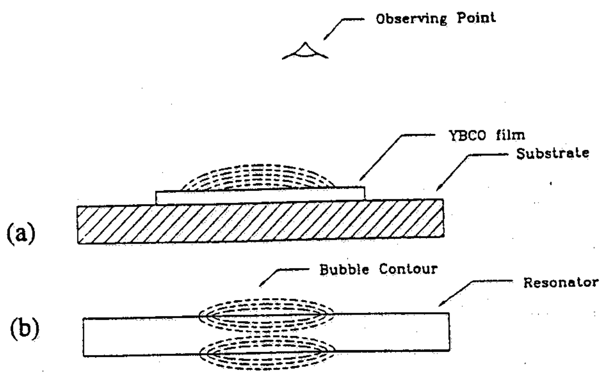

Fig. 3 Schematic diagram of helium bubbling on a YBCO thin-film filter resonator in an interdigital filter.

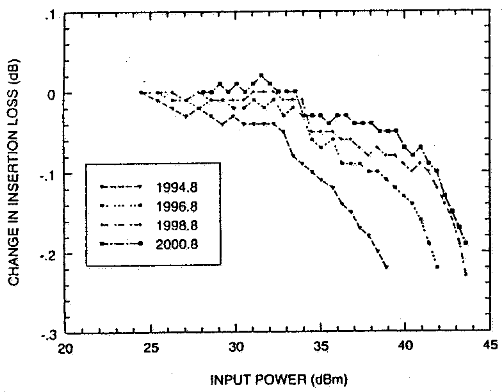

Fig. 4. Insertion loss increase of the filter shown in Fig. 1, different curves representing to different frequencies in MHz.

B) Backward- and Forward-Coupled Filter performance

Fig. 4 is the insertion loss variation of the filter shown in Fig. 1, as the input power is changed from a few mW to 25 watts (44 dBm). As can be seen, the relative change in insertion loss is less than 0.25 dB when the applied input power increases to 25 watts.

B) Forward-Coupled Filters performance

Fig. 5 shows the measured filter response at different input power levels at 50 K for the forward-coupled filter of Fig. 2 The wafer was bonded to a thermally matched package and was tested in a cryocooler. The dissipation loss at 45 K is less than 0.2 dB, and the return loss was better than 12 dB. We applied 10 watts to the filter at 50 K with 0.1 dB compression. Fig. 6 shows the intermodulation of the filter shown in Fig. 1 at 45 K. As can be seen, it is 62 dBm.

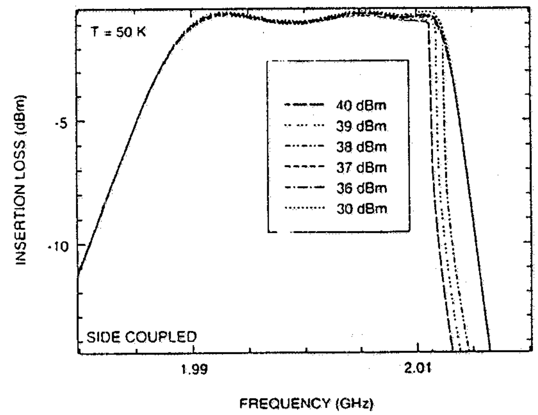

Fig. 5 Frequency response of the filter shown in Fig. 2 at 50 K with different input power.

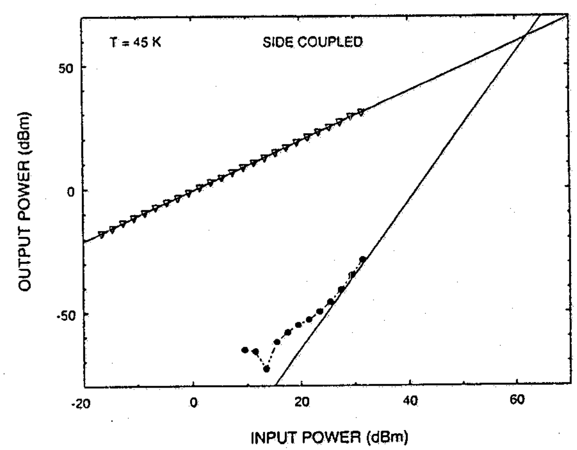

Fig. 6 Intermodulation measurement of the filter shown in Fig. 2 at 45 K. The TOI is 62 dBm with best linear fit. The upper curve is the fundamental mode output per tone, and the lower curve is the third-order output. All measured power are per tone.

Another forward-coupled filter handled 36 watts of power at 45 K with a maximum compression of 0.15 dB at the upper band edge, when the input power is changed from a few mW to 36 watts (45.6 dBm). Fig. 7 shows the relative insertion loss changes with respect to the input power. Figure 8 shows the third-order intercept at 77 K and with the linear curve fit (with a slope of 3) and a linear best fit of arbitrary slope (3.8). The TOI of the filter for two different fitting schemes are 57 dBm and 49 dBm.

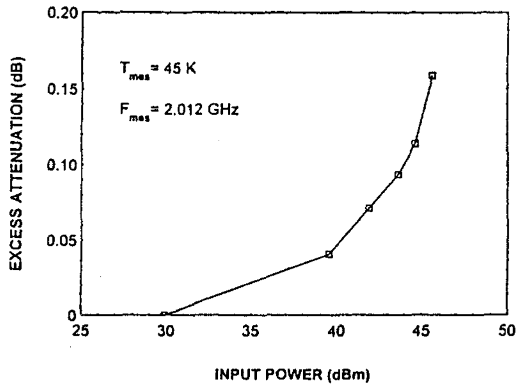

Fig. 7 Insertion loss increase of the filter in Fig. 2 at 45 K with the increase of the input power at the upper band edge (at 2.012 GHz).

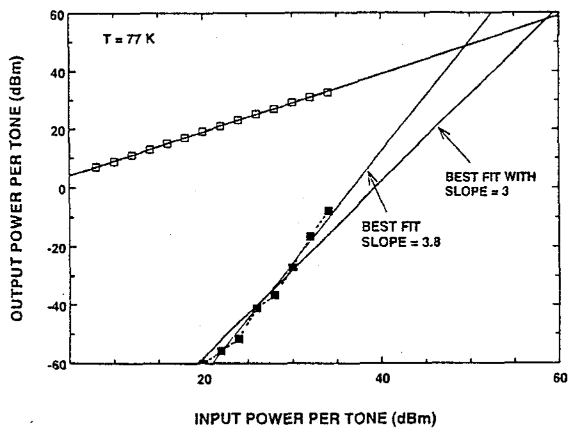

Fig. 8. Intermodulation measurement of the filter shown in Fig. 2 at 77 K. The TOI is 49 dBm with best linear fit and is 57 dBm with best fit of curve with a slope of 3.

V. CONCLUSIONS

We have discussed the design, fabrication, and testing of high-power HTS filters. We reported two type of filters with low internal characteristic impedances. One backward- and forward- coupled has handled over 25 watts at 10 K, another type of filter reported is forward-coupled filter, one of them has 1.2 % BW and 10-Ω internal impedance, handled more than 10 watts of power at 50 K. Another forward-coupled filter handled 36 watts of power at 45 K, with a maximum band edge compression of 0.15 dB. as the applied input power increases to 36 watts.

VI. ACKNOWLEDGMENT

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