Coplanar Transmission Lines with Meandering Center Conductors in Y-Ba-Cu-O/Au Bilayers

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Abstract—We have investigated both conventional and meandering coplanar microwave transmission lines patterned in Y-Ba-Cu-O/Au bilayers on yttria-stabilized zirconia and sapphire substrates. Within the meandering waveguides, the center conductor was deformed from a straight line to a meander. Such a layout could be useful for metrological High-T_c Superconductor arrays, which are based on series arrays of shunted YBCO bicrystal junctions. The microwave properties of the lines were measured in the range 0 – 40 GHz at 76 K, using on-chip through-reflect-line calibrations. We discuss the measured attenuation in terms of conductor losses in the bilayers and show to what extent the disturbance of the line geometry affects the microwave properties.

I. INTRODUCTION

Shunted Y-Ba-Cu-O (YBCO) bicrystal junctions on yttria-stabilized zirconia (YSZ) substrates may be suitable for metrological applications because of their small spreads in critical current I_c and normal resistance R_n. In particular, they provide a large I_cR_n product at temperatures unattainable by low-T_c junctions [1]. However, the demand of placing all junctions in the form of a meander along the straight grain boundary is a strong restriction on the array design. A homogeneous microwave power distribution, which is crucial to the phase locking of the array, is difficult to achieve under these circumstances.

As an alternative to the High-T_c Superconductor (HTS) arrays that have been realized so far, we have developed a new concept with a meander line being the center conductor of a coplanar waveguide (CPW). Such a layout would be close to already existing layouts in low-T_c voltage standards and has the advantage of fewer patterning steps.

In this work we focus on the extent that the microwave properties are influenced by the disturbance of the ideal straight CPW geometry. To be close to the metrological application mentioned above, we realized our test structures in YBCO/Au bilayers on single crystal substrates of YSZ and sapphire.

II. DESCRIPTION OF THE TRANSMISSION LINES

Four different variations of CPWs with meandering center conductor were designed. Each of these four types was investigated using a set of lines with an increasing number of meander turns per length, ranging from an undisturbed CPW to a CPW with a center conductor having a maximum number of turns. As an example, Fig. 1 shows three CPWs from the set of type 1 and three from the set of type 2. Within one set, all CPW dimensions were kept constant. The distance d between the turns is used to distinguish the lines within one set (see Fig. 1).

Among the four types, two characteristics were varied: The shape of the meander and the CPW center and gap dimensions. These parameters are characterized in Table I.

Characteristic of type 1 is the rectangular meander (crossing the center vertically). It is also the type with the smallest dimensions, a 6 μm wide center conductor and a 10 μm gap between the center and the grounds. Within types 2, 3, and 4, the center conductor turns are more slightly sloped (45°) and the width is 12 μm. Except for type 3, the inner edges of the grounds were formed to follow the center conductor to maintain the gap distance. In case of type 1, this adjustment of the grounds was only possible to a certain distance between the meander turns (compare the second and third image of type 1 in Fig. 1).

All four sets were equipped with their own lines needed for the through-reflect-line (TRL) calibration. Details of this multiline method are described in [2]. The TRL lines had the same lateral dimensions as the CPWs of each set and were not meandered. The straight CPWs of each set were part of the TRL lines. All microwave properties of the CPWs were calibrated in respect to the TRL structures of the same set.

Fig. 1 also contains images of the end pieces of two CPWs, showing the launching pads for the microprobes and the exponential transitions connecting the pads to the CPWs.

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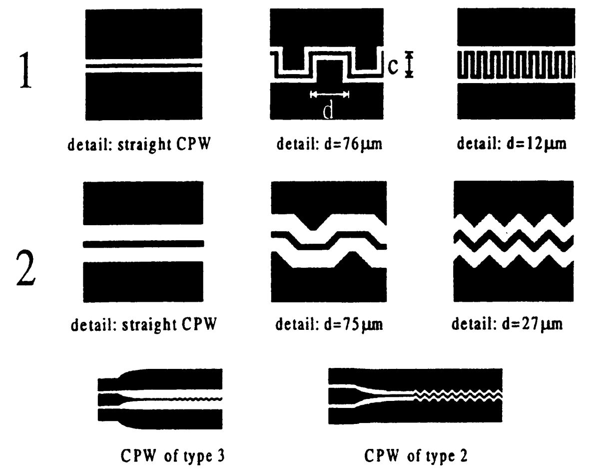

Fig. 1: Diagrams of some of the CPWs of types 1, 2, and 3. The meander detail pictures do not show the grounds in complete width. Values for the lateral extension of the meander, span c, are given in Table I.

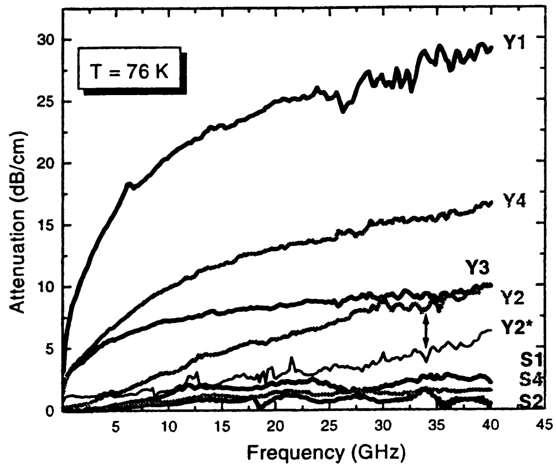

Fig. 2: Attenuation data for the undisturbed CPWs on YSZ and sapphire.

Each set of CPWs was patterned in YBCO/Au bilayers on YSZ by means of standard ultraviolet lithography and Ar-ion milling, resulting in the four samples Y1 to Y4. The bilayers consisted of 300 nm YBCO (by pulsed-laser deposition) and an *ex situ* sputtered 100 nm Au cap layer. Another three samples were fabricated on sapphire, with 330 nm thermal coevaporated YBCO (buffered with 10 nm CeO_2) followed by 300 nm *in situ* sputtered Au. These samples are called S1, S2, and S4 (the set of type 3 was skipped). All substrates were 10 mm x 10 mm. Resistive T_c measurements showed a transition temperature of 88-89 K for films on both substrates.

Due to the different layouts, the characteristic impedances of the four types ranged from 40 Ω to70 Ω on YSZ and 60 Ω to 110 Ω on sapphire (calculated for the undisturbed CPWs using the standard models for coplanar lines).

III. ATTENUATION OF THE UNDISTURBED CPW-LINES

Fig. 2 displays the attenuation versus frequency data obtained from the TRL calibration at 76 K. The straight CPWs on YSZ show much higher attenuation than their counterparts on sapphire. In addition, the four types are more widely separated, and the shape of the curves is square-root like. Sample Y2 was measured a second time, after removal of the Au-layer by ion milling, shown as Y2*. Removal of the normal metal reduced the attenuation considerably.

TABLE I

THE FOUR DIFFERENT TYPES OF TRANSMISSION LINES

Type	Dimensions (μm) (center, gap, span c)	Slope of Crossings	Shape of Grounds
1	6, 10, 44	vertical	Follow/Straight
2	12, 32, 25	45°	Follow
3	12, 94, 25	45°	Straight
4	12, 14, 25	45°	Follow

Longitudinal loss components must be considered to qualitatively explain the loss data. The square-root like shape of the YSZ samples differs from the quadratic dependence usually obtained for superconducting transmission lines [3]. In [3] the quadratic dependence was caused by the conductor losses of the superconductor, which is a longitudinal loss component. The reduced loss after removal of the Au layer in Y2* suggests that the normal metal dominates the conductor loss in the YSZ sample.

Using a program for the calculation of the conductor losses [3], we simulated the losses for the YBCO and the Au separately. We used a 300 nm thick, pure YBCO CPW on YSZ and a 100 nm thick, pure Au CPW on YSZ. The results obtained for the normal metal alone closely reproduced the measured results for the samples on YSZ. Simulations also confirmed a strong decrease in attenuation for an increase of the Au thickness up to 300 nm. Since the normal metal appears to dominate the bilayer attenuation, the lower loss in the sapphire specimen is partially due to the three times thicker Au compared to the YSZ samples. We also removed the Au from S2, S2* being roughly 2 times smaller in attenuation. So even without Au, a comparison between S2* and Y2* shows a considerably lower attenuation for sapphire. This difference is probably due to smaller longitudinal losses in the sapphire films (10 % thicker films than on YSZ and possibly different film quality). The attenuation component due to dielectric losses of the substrates ($\tan\delta > 6\cdot10^{-4}$ (YSZ), $\tan\delta = 10^{-8}$ (sapphire) at 10 GHz, [4]) was calculated to be much smaller than the observed attenuation values.

IV. COMPARISON WITH THE DISTURBED CPW-LINES

To evaluate the effect of the meandering on the microwave propagation, we measured the scattering parameters of all CPWs. For each sample the S parameters were determined by referring to the line impedance obtained for the straight CPWs by the TRL multiline method.

Fig. 3(a) displays the S_{12} parameters for all CPWs of set 2 on YSZ and sapphire. The CPWs on YSZ show a strong decrease in transmission as the turn density increases. The lines on sapphire show a better transmission and only small dependence on the turn density.

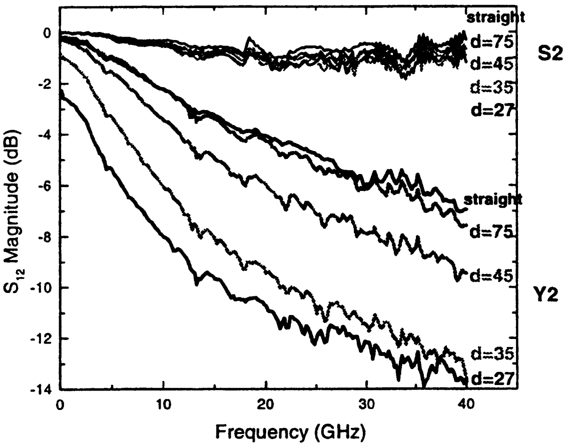

Fig.3(a): Comparison of all CPWs of type 2 on YSZ and sapphire (d in µm). The S parameters refer to the line impedance determined for the straight lines using the TRL multiline method.

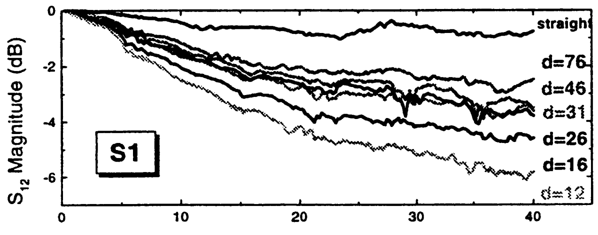

Fig. 3(b): On sapphire, even the worst design, type1, gives considerable results (d in µm).

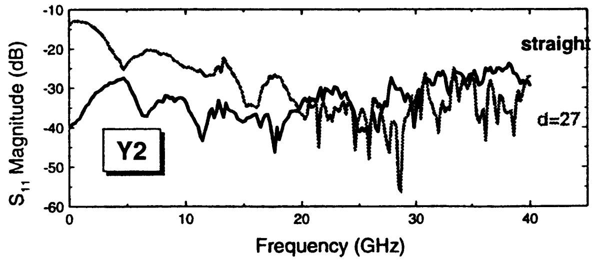

Fig. 3(c): Comparison of the most strongly disturbed CPW and thestraight one of type 2 on YSZ (d in µm).

In accordance with the strong increase of attenuation from type 2 to type 4 to type 1, which was obtained for the straight CPWs on YSZ (Fig. 2), the transmission data get also worse and the dependence on the turn density increases for type 4 and type 1. The three sapphire samples show the same behavior, but less extensively. Even for the worst design, type 1, the transmission values are considerable, as can be seen in Fig. 3(b).

Looking at the reflection of the CPWs, we found no larger mismatch between the undisturbed lines and the disturbed CPWs, showing that the meanders do not change the characteristics of the lines significantly. As an example, Fig. 3(c) displays the S_{11} parameters of the straight and the most disturbed CPW of Y2.

V. CONCLUSION

The microwave properties of our lines are ruled mainly by the normal metal losses. The disturbance of the CPW geometry by a change of the center conductor into a meander does not strongly influence the microwave characteristics, as could be seen on the sapphire samples. However, the increased length of the meander resulted in significant higher losses on YSZ because of the high longitudinal losses there. An improvement of the attenuation data seems possible by either removing the Au layer, or by thickening it. The latter approach would be of double advantage for metrological applications: It would improve the shunting of the junctions (suppression of R_n spread) and reduce the junctions resistance, an additional source of attenuation.

The considerable difference between the losses on sapphire and YSZ suggests differences in the film quality.

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