HIGH T_c SUPERCONDUCTING COPLANAR DELAY LINE WITH LONG DELAY AND LOW INSERTION LOSS

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ABSTRACT

11-nanosecond coplanar delay lines have been fabricated from TlBaCaCuO (2212) and YBaCuO (123) high T_c superconducting thin films on 1"x1" $LaAlO_3$ substrate. This device exhibits the unique combination of long delay (11 ns), low insertion loss (<0.25 dB/ns up to 8 GHz), and low cross talk (< -50 dB). In terms of total delay and delay per unit area, to our knowledge, it is a record for high T_c superconductor delay lines. Test data are compared with theoretical values. Potential applications are discussed.

Introduction

Delay lines have important applications in radar and EW equipment, instruments such as sampling oscilloscopes, and analog signal processors such as chirp filters. The advantages of superconducting delay lines are: Less dispersion propagation, low insertion loss, compactness and light weight. These advantages have previously been demonstrated for low T_c superconductors such as niobium which operates at 4 K. We have fabricated high T_c superconducting delay lines operating at 77 K with performances sufficient for some real applications.

Design and Fabrication

Coplanar line was chosen as the transmission line for the delay line. The advantages of coplanar line are: (1) The characteristic impedance is mainly determined by the gap to line width ratio. Therefore, the line width can be selected according to other considerations such as rf loss and total delay. (2) The ground planes between adjacent line provide some shielding effect to reduce cross talk. (3) One layer structure simplifies the fabrication processing and assembly. The disadvantage of the coplanar line is more rf loss due to current concentration at the edges. But the high conductivity of the thin film high T_c superconductor may compensate for that.

11-ns high T_c superconducting coplanar delay lines were fabricated on one-inch square $LaAlO_3$ substrates (e_r=26) from both TlBaCaCuO (2212) and YBaCuO (123). The line width was 30 microns; the gap width was 70 microns and the line spacing was 0.5 mm. The substrate thickness was 0.504 mm. The circuit is shown in Figure 1. The TlBaCaCuO films were produced by co-sputtering of Ba, Ca and Cu oxides in oxygen followed by an ex-situ anneal in an atmosphere containing Tl_2O [1]. The YBaCuO films were produced by co-evaporation and co-sputtering of Y, Cu, and BaF_2 in oxygen followed by an ex-situ anneal in an atmosphere containing oxygen and water [2]. The patterning process utilized standard photolithographic techniques followed by an ion beam milling of the superconductor film.

Packaging for superconducting device is a non-trivial issue. It has to meet rf, mechanical, and thermal specifications. The delay line package was made of copper and gold plated for good electrical and thermal conductivity. The circuit was clamped down to the bottom of the case by beryllium copper springs for thermal stress release. The contacts on the center line and ground planes were gold ribbon bondings. Stress release K-connectors from Wiltron were used for rf input and output. The packaged circuit is shown in Figure 2.

Test Data and Discussions

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The delay lines were tested by the resonant method. Discontinuities were introduced at the input and the output of the delay line to form a resonator. The attenuation coefficient was calculated from the measured Q-values by using the following formula:

$$A=8.68 \frac{\pi}{Q_o\lambda'} \text{ dB/unit length} \qquad (1)$$

where Q_o is the unloaded Q-value and λ' is the wavelength in the line. Figure 3a shows the attenuation coefficient plotted versus frequency for a TlBaCaCuO (2212) delay line.

If the penetration depth of the superconductor is much less than the film thickness (0.8 μm), Wheeler's formula [3] can be used to calculate the attenuation coefficient due to conductor loss:

$$Ac=8.68\frac{\sqrt{\varepsilon_{eff}}Rs}{120\pi Z}\left[\frac{\partial Z}{\partial h}-\frac{\partial Z}{\partial w}-\frac{\partial Z}{\partial t}\right] \text{ dB/unit length (2)}$$

where ε_{eff} is the effective dielectric constant, R_s is the surface resistance, Z is the characteristic impedance and h,w, and t are the substrate thickness, line width, and line thickness, respectively. The loss tangent of $LaAlO_3$ was estimated from our high Q resonator test to be 0.00005 at 77 K. Radiation loss was not taken into account. Assuming a square law dependence of R_s versus frequency, the theoretical attenuation coefficient of the delay line is shown in Figure 3b.

The "zig-zaging" of the test data at high frequency is due to some film defects. The standing wave of the rf current under resonant test condition forms periodic peaks and nodes that change location as the frequency in swept. When the current peak is coincident with a defect spot, the attenuation test data at that frequency was exaggerated.

At low frequency, the test data shows some systematic deviation from the theoretical values. One possible explanation is that the penetration depth may be comparable to the film thickness and so Wheeler's formula (2) would no longer be applicable. But this seems not to be the case. Separate R_s measurements on 0.25 μm thick TlBaCaCuO (2212) films up to 90 K showed no rf penetration through the film. Therefore, the penetration depth should be much less than the 0.8 μm thickness of the film. Another explanation is based upon a finite residual resistance. At a low enough frequency, the surface resistance will become dominated by the residual resistance i.e., the resistivity of the defect or non-superconducting regions in the film. Therefore, the square-law dependence of R_s versus frequency of the two-fluid model is no longer valid. Other recent data on stripline resonators show similar behavior [3]. More test data is needed to confirm this speculation.

Numerical simulation using Hewlett Packard MDS software showed that the design has a very low cross talk (< -50 dB). Measurements are being made to confirm this.

Conclusions

High T_c superconducting coplanar delay lines with 11-ns delay were fabricated on an 1"x1" $LaAlO_3$ substrate. This device exhibits the unique combination of long delay (11 ns), low insertion loss (<0.25 dB/ns up to 8 GHz), and low cross talk (< -50 dB). The measured insertion loss is comparable to regular semi-rigid copper cable. We believe that this high T_c superconducting delay line could be used for some practical applications.

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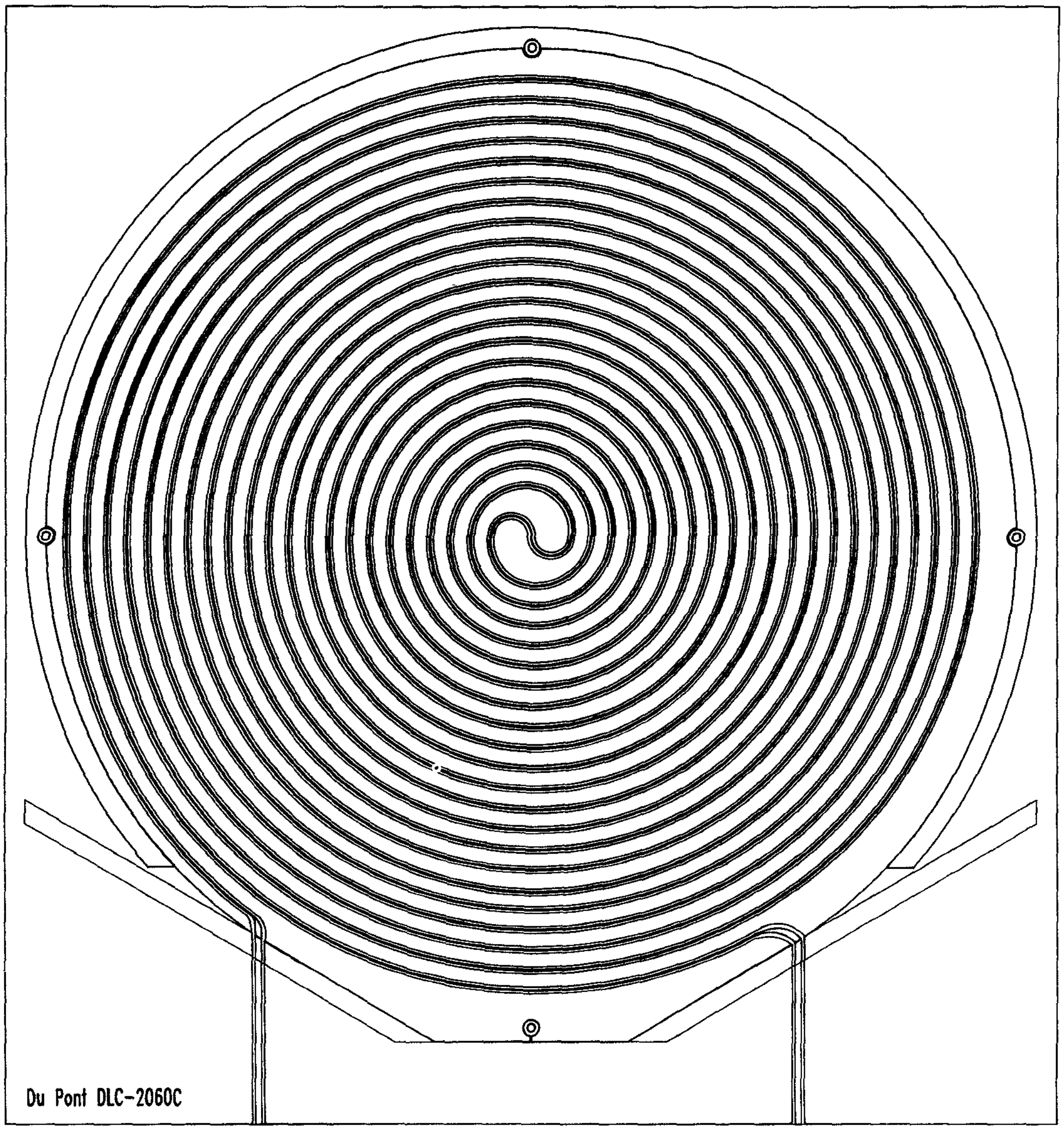

Figure 1: Lay out of the 11-nanosecond delay line circuit.

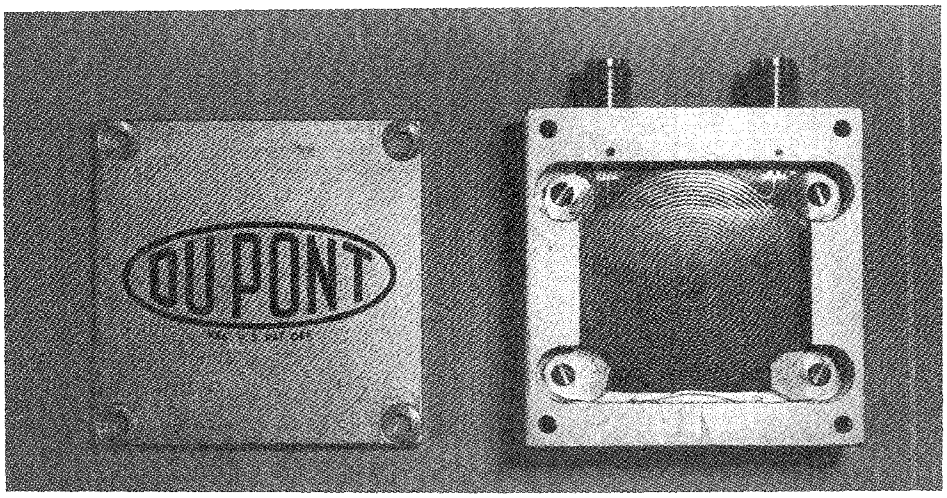

Figure 2: Packaged 11-nanosecond delay line with the lid open.

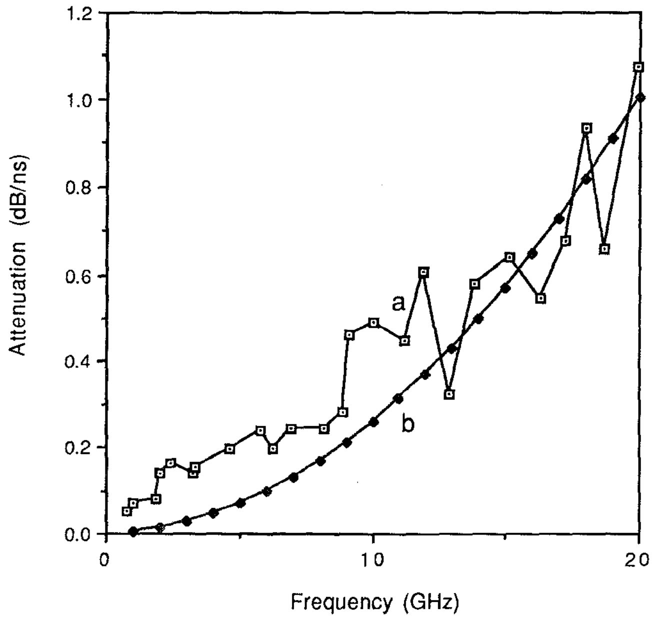

Figure 3: Attenuation coefficient versus frequency data for a 11-ns TlBaCaCuO coplanar delay line:

a- Test data at 77 K and -10 dBm input power;

b- Theoretical values for R_s=3 milli-ohms at 20 GHz and loss tangent=0.00005.