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Fabrication of superconducting $YBa_2Cu_3O_{7-x}$ delay lines by a chemically modified sol-gel method

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Abstract

Utilizing the photosensitivity of $YBa_2Cu_3O_{7-x}$ (YBCO) gel films, superconducting YBCO delay lines were fabricated on 1 in. $LaAlO_3$ (LAO) single crystalline substrates by a chemically modified sol-gel process. Laser confocal scanning microscopy (LCSM) and X-ray diffraction (XRD) analyses of the prepared YBCO delay lines revealed a well-defined structure and a strong c-axis orientation. The superconductivity and delay properties were measured using a low-temperature superconducting tester and network analyzer, showing that the resulting delay lines have excellent superconductivity properties with a high critical transition temperature (T_c) of 91 K, a transition width (ΔT) of 1.2 K and a critical current density (J_c) of 1.4×10^6 A/cm^2 at 78 K, and the superconductivity properties were not affected by using the novel chemically modified sol-gel method. The measured delay time of the delay line was about 8.6 ns.

Keywords: Superconductor; Delay line; Photosensitivity; Sol-gel method; Chemical modification

1. Introduction

Delay lines have been widely used in signaling systems, computer communications and measurement systems. However, traditional delay lines exhibit several disadvantages, such as a high insertion loss and a large volume. YBCO, as a second generation high temperature superconducting materials [1–4], is considered to become a next generation delay line material because delay lines made of YBCO not only have a smaller size and show lower noise levels, but also possess a lower power consumption and higher sensitivity [5]. Due to the complicated structure of the delay line, the traditional methods for the micro-fabrication of YBCO are facing several challenges. For instance, lateral etching often occurs during wet etching techniques, thereby decreasing etching precision and potentially degrading the superconductivity of YBCO due to corrosion. On the other hand, dry etching processes, such as ion etching, are slower, and the superconductivity of YBCO could be degraded by the great heat generated during the etching process. Therefore, it is very important to develop a simple and effective micro-machining method which does not lead to a degradation of the superconductivity properties of the YBCO delay line.

In this paper, we propose a novel chemically modified sol-gel method to fabricate YBCO delay lines. The YBCO sol was modified by adding the chemical modifier benzoylacetone (BzAcH), resulting in a YBCO gel film with good ultraviolet (UV) photosensitivity. Subsequently, YBCO superconducting delay lines were successfully fabricated on 1 in. LAO substrates. The results indicate that the obtained YBCO superconducting delay lines have good superconductivity and delay characteristics.

2. YBCO delay line design

Typical YBCO superconducting delay lines are produced in a variety of structures, such as the microstrip structure, the coplanar structure and the banded structure. However, the microstrip structure, shown in Fig. 1, is the most commonly used structure, e.g. due to its convenient installation and low insertion loss, and was therefore also adopted for this study.

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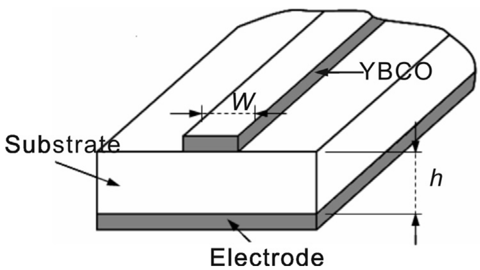

Fig. 1. Schematic diagram of the microstrip delay line structure.

For a successful preparation of a delay line, the following points need to be considered: the delay time, the characteristic impedance, the frequency range, and the insertion loss. As a large delay time and a low insertion loss are contradictory, it is necessary to balance these two parameters during delay line design. The delay characteristic of microstrip structure can be expressed by the following formula:

$$\tau = \frac{l}{c_0}\sqrt{\varepsilon_e} \quad (1)$$

Where τ is the delay time, l is the length of the delay line, c_0 is the speed of electromagnetic waves in vacuum, and ε_e is the effective dielectric constant, which can be calculated using formulas (2) and (3), where ε_r is the relative dielectric constant, q is the constant of proportionality, W is the width of the delay line, and h is the thickness of the substrate.

$$\varepsilon_e = 1 + q(\varepsilon_r - 1) \quad (2)$$

$$q = \frac{1}{2}\left[1 + \left(1 + \frac{10h}{W}\right)^{-1/2}\right] \quad (3)$$

Therefore, for the preparation of a delay line with a long delay time, it is necessary to increase the length and decrease the width of the delay line on a substrate of limited size. However, inter-line coupling is a major factor limiting the line length, since an increase in line length usually reduces line spacing due to the limited available surface area, resulting in strong coupling effects seriously affecting the delay line properties if line spacing is too small. By using a double-spiral meander-line structure, a large length delay line can not only be prepared in the limited surface area of the LAO substrate, but also the inter-line coupling can be reduced.

The characteristic impedance of a YBCO delay line is determined by the width of the delay line, the thickness of the substrate and the permittivity of the substrate. A common characteristic impedance of typical delay lines is 50 Ω. The characteristic impedance was calculated using formulas (4) and (5):

$$Z_0 = \frac{Z_{01}}{\sqrt{\varepsilon_e}} \quad (4)$$

$$Z_{01} = 60 \ln\left(\frac{8h}{W} + \frac{W}{4h}\right) \quad (W/h \le 1) \quad (5)$$

Where Z_0 is the characteristic impedance, Z_{01} is the characteristic impedance in vacuum. For this study, LAO substrates with a thickness of 0.5 mm and a permittivity of 23.6 were used. The characteristic impedance of the YBCO delay line was 50 Ω, and the width was calculated to 0.165 mm at 3 GHz.

Several issues need to be considered during the design process: (1) The characteristic impedance of the meander line structure is slightly lower than the impedance of the linear structure, (2) the inter-line coupling will increase the equivalent width of the delay line, and (3) in a low temperature environment, the dielectric constant of LAO will be slightly reduced. Based on these considerations, a delay line with a width of 0.16 mm and a hyperbolic spiral structure with a w_1:w_2 ratio of 1:1 and r=3.5 mm were adopted for this study [6]. The input terminal and the output terminal used gradient design, the specific parameters and structure are shown in Fig. 2, and the theoretical latency delay is calculated about 9.0 ns by the above formula.

3. Experimental details

3.1. Delay line fabrication

A flow chart of the fabrication process is illustrated in Fig. 3. Using yttrium acetate, barium acetate and cupric acetate as

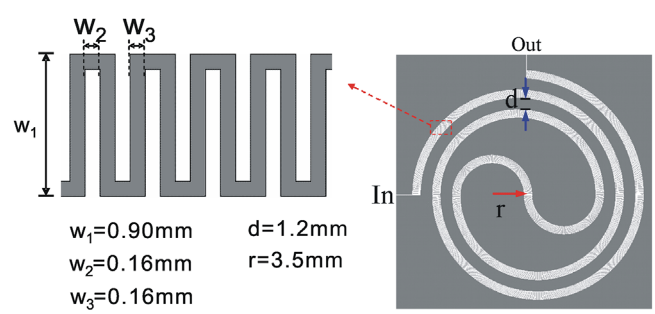

Fig. 2. Structural parameters of the fabricated YBCO superconducting delay line.

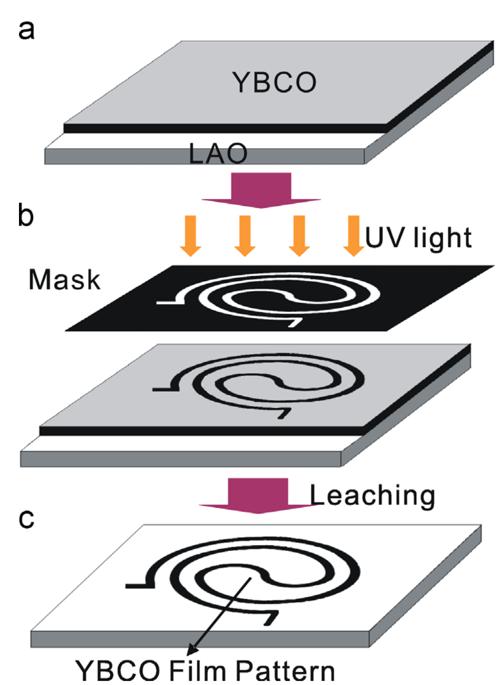

Fig. 3. Schematic illustration of the individual steps of the fabrication process of a superconducting YBCO delay line.