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Title: **High-Temperature Superconducting Thin-Film-Based Electronic Devices**

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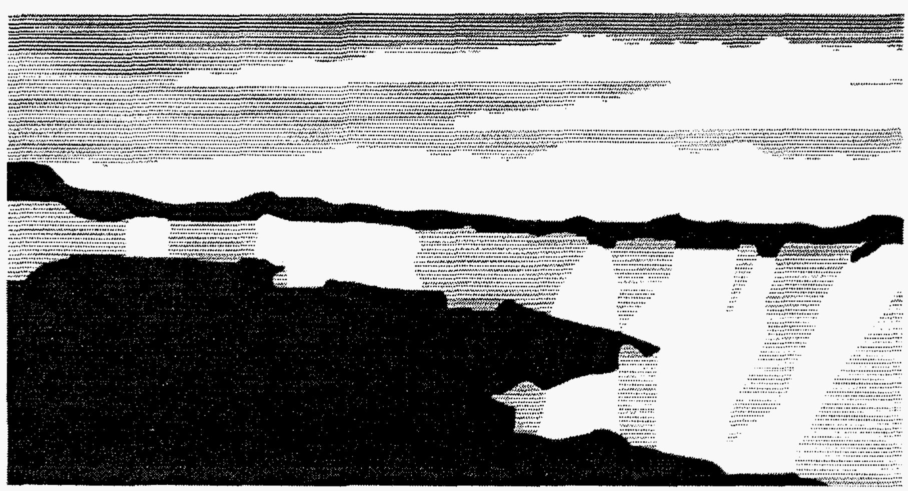

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High-Temperature Superconducting Thin-Film-Based Electronic Devices

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Abstract

This is the final report of a one-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). The project involved optimization of processing of Y123 and Tl-2212 thin films deposited on novel substrates for advanced electronic devices. The Y123 films are the basis for development of Josephson Junctions to be utilized in magnetic sensors. Microwave cavities based on the Tl-2212 films are the basis for subsequent applications as communication antennas and transmitters in satellites.

1. Background and Research Objectives

In the past few years, tremendous progress has been made in preparation of high-T_c thin films and thin-film-based devices. These devices include microwave components for communications for radar, Josephson junctions for extreme small-magnetic-field sensing, and infrared detectors that offer a high sensitivity at long wavelengths. Though many processing steps from device patterning to metallization need to be optimized, thin-film material improvement is still necessary to meet the device requirements. Our work was to focus on development of Josephson junctions and microwave devices, since it should require the least time to bring these high-T_c devices to military or commercial uses.

High-T_c Josephson junctions are the basic element of superconducting quantum interference devices (SQUIDs), which are the most sensitive of magnetic field sensing devices. Applications of high-T_c SQUIDs are not limited to simply measuring magnetic fields. SQUIDs can also be used to measure underground structures, corrosions (weapons), cracks (airplane wings), biomagnetism (e.g. magnetoencephalography), measurement of current distribution in integrated circuits, and a variety of other areas where measurements of weak magnetic fields can be used for microscopic current sensing or field-distortion detection.

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Microwave devices including cavities are useful in both communication and particle accelerator applications. Use of high-T_c devices enables operation with liquid nitrogen cooling. In space, with radiation shielding, operation with no additional cooling is possible due to high transition temperatures of the superconductors.

2. Importance to LANL's Science and Technology Base and National R&D Needs

This project supports Los Alamos core competencies in nuclear and advanced materials as well as complex experimentation and measurement. This project is important, not only for Los Alamos to enhance the capabilities of material processing and device fabrication further, but also for the United States to have a competitive position with respect to foreign countries.

3. Scientific Approach and Results to Date

Josephson junctions (JJs) can be used as magnetic sensors by both the military and medical communities. At present, only a few approaches have been used to make these high-T_c devices. One method used to make JJs is to use the natural grain boundaries as weak links so that JJs can be formed across the boundaries. The other method is to make artificial grain boundaries. Since the high-T_c superconductors are a new class of materials, and controlling the materials properties in thin-film form is already not very easy, one can imagine the difficulties in manipulating the boundaries. In order to fabricate the world's most sensitive magnetic sensing device, two identical JJs would be required. Our device design is based on superconductor-normal metal-superconductor (SNS) edge junctions, which have advantages of easy placing of the devices anywhere on a substrate, performance controlling by the N-layer thickness, and easy integration for circuits.

For microwave devices, we focused on tunable microwave devices. We utilized the tunable dielectric properties of $SrTiO_3$ or $(Sr,Ba)TiO_3$ under an electric field to fabricate tunable high-T_c microwave filters, which are needed for switching as well as for fine tuning. Fabricating Tl-2212 thin films was also performed for applications in microwave cavities.

We have fabricated SQUID-based, SNS-edge junctions on $LaAlO_3$, yttria-stabilized zirconia (YSZ) and MgO substrates. We used $YBa_2Cu_3O_{7-d}$ (YBCO) and $GaBa_2Cu_3O_{7-d}$ (GBCO) as the electrode material, and Pr-doped $YBa_2Cu_3O_{7-d}$ (Pr:YBCO) as a barrier layer to fabricate SNS junctions and SQUIDs. Pulsed-laser deposition or off-axis sputtering techniques were used to deposit both top- and bottom-superconducting electrodes, N-layer Pr:YBCO, and insulating-layer CeO_2. A bottom-superconducting electrode and an insulating-

CeO_2 were deposited first. Conventional photolithography was used to pattern the films and ion milling with 250-eV Ar ions was used to etch the films and form the edge. The angle between the edge and the substrate surface was controlled to a range of 15° ± 3°. The N layer and the top-superconducting electrode were deposited after stripping off the photoresist and cleaning the edge surface. Edge cleaning before N-layer deposition is very important in controlling the interface. The cleaning was done by ion milling with 200-eV Ar ions. After the second deposition, the films were patterned again by ion milling to form SNS junctions. Then gold contacts were sputtered on the devices by a lift-off process. Before the final packaging, the samples were post-annealed in flowing oxygen at 450 °C for 1 hr.

Using an optimal Pr:YBCO-layer thickness of 10-500 nm yield I-V characteristics consistent with the resistively shunted junction (RSJ) model. Temperature-dependent critical current measurements on SNS junctions or SQUIDs revealed that the critical current varies with temperature as $(1-T/T_c)^2$ for temperatures near T_c. The temperature dependence relationship has been developed from conventional SNS proximity theory. A voltage modulation of 49 μV, corresponding to a differential voltage modulation of over 150 $\mu V/\Phi_0$, at 75 K has been achieved on these SQUIDs. This value is believed to be the highest reported so far for this type of SQUID. Noise tests give a flux noise of 30-40 $\mu\Phi_0 Hz^{-1/2}$ with direct current bias at a frequency of 1 Hz and at a temperature of 75 K.

We have also demonstrated electrically tunable microwave resonators incorporating superconducting YBCO and paraelectric $SrTiO_3$ (STO) layer on $LaAlO_3$ substrates. The top YBCO layer for each sample was patterned into a 8-mm long coplanar transmission line with a 40-μm gap and a 20-μm center line width. The microwave transmission through the coplanar transmission line exhibits resonances corresponding to standing microwaves along the co-planar transmission line. There resonances are modulated by applying a bias voltage between the center line and the ground planes. Samples with a 0.5-μm thick (2-μm thick) bottom STO layer show, for a resonance at around 8 GHz (5 GHz), a frequency modulation of about 4% (24%) and a quality factor Q of about 200 (50) under 1000 V bias at 80 K.

Publications

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