A novel Si-YBaCuO intermixing technique has been developed for patterning YBaCuO superconducting thin films on both insulating oxide substrates (MgO) and semiconductor substrates (Si). The electrical, structural, and interfacial properties of the Si-YBaCuO intermixed system have been studied using resistivity, x-ray diffraction, scanning electron microscopy, x-ray photoelectron spectroscopy and Auger depth profiling measurements. The study showed that the reaction of Si with YBaCuO and formation of silicon oxides during a high temperature process destroyed superconductivity of the film and created an insulating film. On a MgO substrate, the patterning process was carried out by first patterning a silicon layer using photolithography or laser-direct-writing, followed by the deposition of YBaCuO film and annealing. For a silicon substrate, thin metal layers of Ag and Au were patterned as a buffer mask which defines the YBaCuO structures fabricated thereafter. Micron-sized (2–10 μm) superconducting structures with zero resistance temperature above 77 K have been demonstrated. This technique has been used to fabricate current controlled HTS switches and interconnects.

Key words: YBCO films, annealing, reactive patterning

INTRODUCTION

Over the last few years, significant progress has been made in the development of high Tc superconductor (HTS) electronics, such as SNS Josephson junctions, SQUIDs, bolometers, and microwave components. These devices have been fabricated on insulating oxide substrates. An important application of HTS is the development of superconductor-semiconductor hybrid devices and superconducting interconnects. This requires the formation of HTS structures on a semiconductor substrate. Technically, this is much more difficult to achieve than on an insulating oxide substrate. Most semiconductors except silicon cannot withstand the high temperature processing needed for making the YBaCuO films. For a silicon substrate, the interdiffusion and reaction at the Si-YBaCuO interface can destroy the superconductivity of the film and cause the film to become insulating.

One of the solutions to this interfacial reaction problem is the use of buffer layer materials, such as ZrO₂, MgO, Au₃Ru₂, BaTiO₃/MgAl₂O₄, and recently CoSi₂. These buffer layers have been proven to be effective to reduce the HTS film-substrate interface reaction. In this way, high quality YBCO films have been made on Si wafers.

The next step, which is more important towards the fabrications of HTS electronics, is the patterning of HTS thin films to be desired micron-sized device features over a large area. Currently, the techniques for patterning of HTS films still rely on conventional lithographic processes, such as lift-off, ion or electron beam irradiation, chemical etching. Most of them involve the removal of material using chemical solutions, which will degrade the superconductor surface. Another method is laser patterning including laser pyrolysis and laser ablation etching. This method is limited by the area of the localized laser beam.

In this work, we present studies of the structural and electrical properties of a Si-YBaCuO intermixed system. Experimental techniques including resistivity, x-ray diffraction, scanning electron microscopy, x-ray photoelectron spectroscopy and Auger depth profiling measurements have been used to characterize the materials. Based on the material properties, a Si-YBaCuO reactive patterning technique has been developed for patterning of YBCO films on both insulating (MgO) and semiconductor (Si) substrates. Micron-sized (2–10 μm) lines and large-scale (over cm in size) device features were demonstrated using this technique. The patterned structures showed zero resistance above 77 K. We have successfully made current controlled HTS switches using this technique. Compared with other patterning techniques, this method is a chemical contamination free and a rapid way of patterning HTS films. One major advantage of this technique is that the patterning can be performed by using well established Si planar device fabrication technology without attacking the HTS films. This may be benefit for processing of many HTS structures, especially for making HTS-semiconductor hybrid devices.
PROPERTIES OF Si-YBCO INTERMIXED SYSTEM

In order to know better the Si-YBaCuO reactive patterning method, one has to understand the material properties, particularly the interaction between YBaCuO and Si. Two subsystems have been investigated; one is a YBCO film intermixed with a Si film deposited on a MgO substrate, and another is a YBCO film deposited on a Si substrate directly. The first one was chosen such that one can easily characterize the properties of a Si-YBCO intermixed film with regard to that of a YBaCuO film on MgO.

a) Material Processing

The sample preparation for the first subsystem includes the evaporation of a silicon film, sequential deposition of Cu/BaO/Y\textsubscript{2}O\textsubscript{3} layered structures, and a rapid thermal annealing (RTA). The silicon films (500–1000\textsubscript{A}) were first deposited on a MgO (100) substrate by electron-beam evaporation in an ultra-high vacuum chamber at base pressure of 8 × 10\textsuperscript{-8} Torr. Three layer structure of Cu/BaO/Y\textsubscript{2}O\textsubscript{3} was then deposited on the samples with thicknesses of 1000, 2400, and 900\textsubscript{A} for Y\textsubscript{2}O\textsubscript{3}, BaO, and Cu, respectively, as illustrated in Fig. 1(a). The films were placed on a 4 inch silicon wafer inside a quartz chamber of a RTA processor and annealed at 980 °C for 30–90 sec. During the annealing, the Si wafer absorbed infrared radiation from high-intensity, tungsten-halogen lamps and was heated rapidly. A typical RTA process, as shown in Fig. 1 (b), consists of a 30 sec heating ramp, a constant high temperature period of 1–2 min, and a cooling down to 200 °C in 5–7 min. All RTA cycles were carried out in flowing helium or oxygen gas at atmospheric pressure. Details of the YBCO deposition and RTA processing have been described elsewhere.\textsuperscript{47–48}

After annealing, the Si-YBaCuO intermixed films appeared light gray and were slightly transparent. The resistivities of the films were at least five to six orders of magnitude higher than that of pure YBaCuO films. It was found that the electrical insulating property depends strongly on the thickness of the silicon layer. For a 200\textsubscript{A} silicon layer, the mixed film was conductive, but not superconducting. For the thickness of the Si layer reaches 800\textsubscript{A} (corresponds to a composition ratio of 1.2:123 for Si:YBaCu), the film contained mainly smaller white spots of a half micrometer in size, as indicated by the SEM micrograph of Fig. 2 (c). The crystalline structures were severely destroyed. These results were also confirmed by the x-ray diffraction measurement. Figure 3 (a) shows the x-ray diffraction pattern of a film with 500\textsubscript{A} silicon mixing. As seen from the figure, the peak intensities of the YBaCuO 123 phases were greatly reduced for the Si mixed film and many 123 phases turned to 211 phases. Other phases of Ba\textsubscript{2}SiO\textsubscript{4} and CuO have been reported by Cheung et al.\textsuperscript{49} in

![Diagram](a)

![Diagram](b)