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High-Temperature Oxide Superconductor Thick Films

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INTRODUCTION

The recent discovery of ternary metal oxide ceramic superconducting materials ($T_c \approx 98K$) has led to a sudden burst of research activity all over the world (1-9). The demonstrtion of $10^5 A/cm^2$ critical current density at 77K (7) the boost the of transition temperature to 155K by adding fluorine atoms to the superconductor structure (10) and some evidence of room temperature superconductors further promoted the promise and interest of these materials. Processing of these materials into useful forms such as wires, rods, tubes, films, ribbons, ... etc. will make it possible for applications to high-field magnets, power transmission lines, magnetic coil, microelectronics ... etc. Among these special forms of superconductor, thick film is probably one of the most promising approaches to the high frequency, broad band electronic and magnetic shielding applications.

The term "thick film" (11) has gained acceptance as the preferred generic description for microelectronics in which specially formulated pastes are applied and fired onto a ceramic substrate in a definite pattern and sequence to produce a set of individual components, such as resistors and capacitors, or a complete functional circuit. The pastes are usually applied using a silk-screen method. The high temperature firing matures the thick film elements and bonds them integrally to the ceramic substrate. Typically, the thickness of a thick film element will be 0.5 to 1 mil or more. This distinguishes it from thin film technology, where conductor thickness are generally much thinner. When active devices such as high frequency diodes and transistors are attached to a thick film network, the resulting product is known as a thick film hybrid circuit.

The advantages of thick film technology include higher performance, greater flexibility, outstanding reliability and cost-effectiveness. Resistors and capacitors in any of a wide variety of combinations, values, and characteristics can be constructed with the basic thick film materials and substrates. Thick film can even be employed in high power, high voltage and high frequency applications. Complete functional circuits from simple amplifiers to complex arrays containing many chip-type monolithic integrated circuits are possible in thick film form. Thick film circuits operating in the gigahertz range are routinely achievable.

Thick film hybrid microelectronic technology will be explored based on the ternary metal oxide ceramics $YBa_2Cu_3O_{6+x}$. The application of this new class of very exciting superconducting materials to microelectronics relies on the search for solutions to the problems in relatively low superconductor critical current density for non-single-crystalline materials and high metal-superconductor or semiconductor-superconductor contact resistance. Scientists in IBM have indirectly demonstrated the critical current density above 10^5 A/cm^2 in single crystalline $YBa_2 Cu_3O_{6+x}$ thin films which were electron beam evaporated and recrystallized on single crystalline strontium titanate substrates. In order to use this high current density capability, new and difficult techniques need to be invented so that single crystalline superconductor films can be deposited on other more interesting and lattice mismatched substrates, e.g., Si and GaAs.

One of immediate applications of polycrystalline superconducting materials is to form relatively dense thick films so that the critical current density is not a limiting factor. The main objective of this work is therefore devoted to the development of processing technology for hybrid system fabrication.

EXPERIMENTAL

Conventional screen printing techniques as well as direct painting on ceramic or other suitable substrates are investigated. This involves the choice of printing vehicles, the preparation of printing pastes, film thickness optimization, heat treatment of the printed films, and the formation of metal-superconductor and semiconductor-superconductor contacts.

Superconducting ternary metal oxide ceramics similar to that discovered by Professor M. K. Wu at University of Alabama in Huntsville, is prepared and tested. The $YBa_2Cu_3O_{6+x}$ ceramic is then ground into powder of about one micrometer in size and mixed with commercially available or custom-designed printing vehicles and/or thinners for pattern formation by means of a screen printer or direct painting. The $YBa_2Cu_3O_{6+x}$ thick film is sintered at 950°C in an oxygen flowing tube for 12 hours and then removed from the furnace slowly.

RESULTS AND DISCUSSION

Shown in Figure 1 are an $YBa_2Cu_3O_{6+x}$ superconductor pellet, a directly painted superconductor thick film and screen printed superconductor patterns. These films are thicker than 1 mil. Four contacts are formed using silver paint at four corners of the samples in order to measure the resistance as a function of temperature. Shown in Figure 2 is a R v.s. T curve for the thick films. These superconductor thick films have superconductivity transition temperatures greater than 90°K and the zero resistance state occurs at temperatures greater than 77K. XRD spectrum shows that the printed thick films have the same crystal structure as the superconductor pellets. This is shown in Figure 3. Some minor peaks due to the existence of multiple-phase structures can be seen in Figure 3.

The successful demonstration of high temperature superconductor thick films by means of a conventional printing technique can provide immediate applications of this material in desired patterns to hybrid microelectronics and microsensors. Further study is being done to investigate and optimize the printing and sintering processes in order to achieve a reliable superconductor-substrate interface and a higher superconductor critical current density.

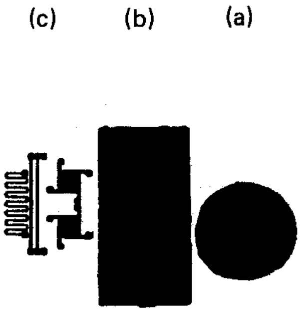

Figure 1. Superconductor Samples. (a) Superconductor pellets, (b) Superconductor painted on an alumina substrate, (c) Superconductor screen printed on an alumina substrate.

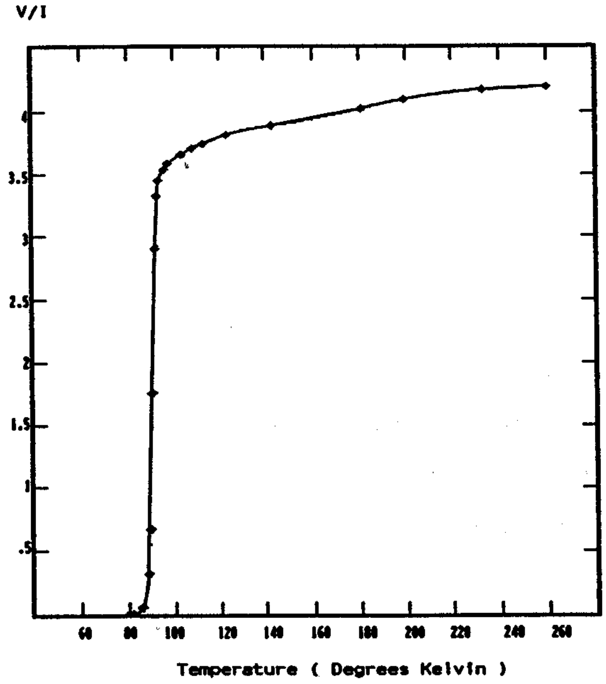

Figure 2. Four-point resistance measurement of a HTSC thick film.

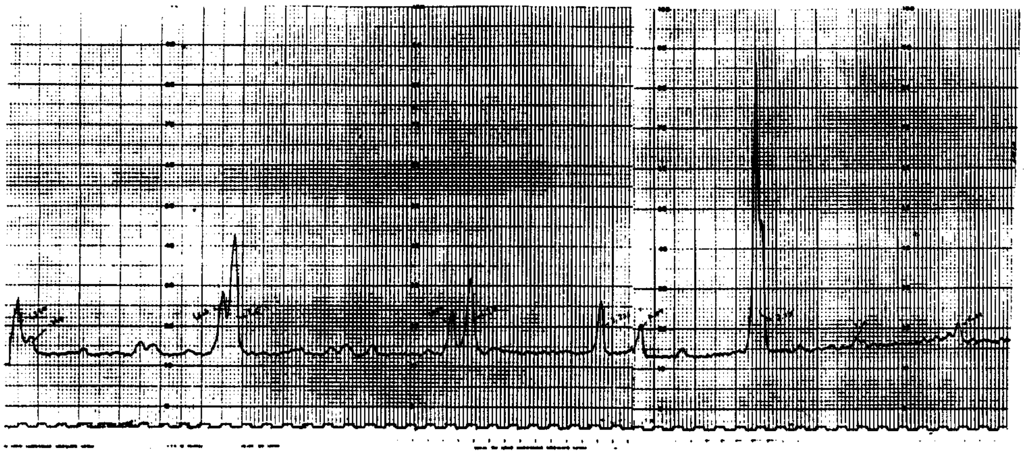

Figure 3. XRD spectrum of a HTSC thick film.

CONCLUSIONS

High temperature superconductor thick films based on the ternary metal oxide $YBa_2Cu_3O_{6+x}$ have been successfully fabricated. These films have Tc greater than 90°K and the zero resistance state starts at temperatures greater than 77°K. High temperature superconductor thick films of arbitrary shapes can be formed using this technique.

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