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High T_c superconductive thin films on semiconductor substrates

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Abstract :

The deposition of superconductive thin films on semiconducting substrates is one of the most important goals of technological application in «hybrid» devices . We present in this paper the role of the buffer layer between silicon and the superconductive film . These insulating buffer layers induce MIS properties which can be used in microelectronics .

1- INTRODUCTION

Since the discovery of HTc superconducting oxides, considerable progress has been made in developing procedures for the deposition of thin films on different substrates. Oxide single crystals like SrTiO_3 , MgO , ZrO_2 , LaAlO_3 have allowed for the deposition of thin and ultra thin films with excellent physical and structural properties. But, even if the main work of researchers in the field of thin films is focussed on oriented films on oxide single crystals, the deposition of high-quality superconducting films on silicon represents the first aim for future hybrid semiconductor-superconductor devices. In the current "state of the art", direct deposition of mixed valence copper oxides on bare silicon has not been achieved as a buffer layer is needed to avoid strong diffusion of cationic species during the high temperature deposition cycle. This buffer layer, which must be a good diffusion barrier, must also present a crystallographic structure compatible with silicon's and YBCO's lattice parameters. Several ways have been tested to find a good diffusion barrier (1-2) and the latter point considerably reduces the choice of a possible buffer layer which has a very small mismatch with silicon.

Following these considerations, yttrium stabilized zirconia (named YSZ), used for the first time by Mogro-Campero *et al* (2) is one of the best candidates for deposition of YBCO on silicon. Several attempts have been made using the combination of Si_3N_4 and ZrO_2 as a buffer layer but our results show that although

silicon nitride constitutes a good diffusion barrier (1), the crystallographic parameters of zirconia are more suitable for the deposition of $\text{YBa}_2\text{Cu}_3\text{O}_7$

Pure zirconia can be obtained as single crystals in different structures as a function of temperature. Partial substitution of different oxides like MgO , CaO , Y_2O_3 , CeO_2 into zirconia gives a stabilized structure with the lattice parameter varying with the substitution ratio. By this way, it is then possible to stabilize zirconia in the cubic structure. When the substitution molar ratio is between 9 and 40%, the "a" parameter which varies between 5.14 and 5.23 Å is close to the "a" parameter of silicon ($a = 5.43 \text{ Å}$).

2 - EXPERIMENTS

Different deposition techniques can be used for preparation of YSZ thin films on silicon. The most usual are : sputtering, laser ablation and thermal evaporation.

Sputtering processes can be used for a YSZ target in R.F. mode in pure argon or in an Ar/O_2 mixture to avoid oxygen vacancies (3). In these cases, we have obtained cubic YSZ films in a polycrystalline form with a columnar growth which is characteristic of sputtered films. On these substrates, the subsequent deposition of YBCO gives a resistive transition with T_c ($R = 0$) between 70 and 80K (figure 1).

FIGURE 1 $R=f(T)$ plots of $\text{YBa}_2\text{Cu}_3\text{O}_7$ film on Si with ZrO_2 buffer layer

Laser ablation from a stoichiometric target has also been used to allow, in our configuration, a complete "in-situ" film deposition. We have obtained YBCO films with the same characteristics as sputtered ones. In the two methods, we have identified a transition zone between YBCO and YSZ layers corresponding to the compound BaZrO_3 with a thickness of about 30nm. This phenomenon has been previously observed by several authors (see for example 4 and 5) and suggests that BaZrO_3 might be a good candidate for a buffer layer between YBCO and silicon. But in this latter case, the mismatch between the lattice parameters of BaZrO_3 and silicon gives a polycrystalline film with a disordered structure.

3 - (I-V) and (C.V.) CHARACTERISTICS

The heterostructure Si-YSZ-YBCO is a M.O.S. structure with a particular gate which gives C-V plots (figure 2) with a low flat-band. The insulator deposited on silicon has a low resistivity compared with its bulk value.

We attribute this phenomenon to the presence of impurities distributed in the zirconia during the high temperature deposition of $\text{YBa}_2\text{Cu}_3\text{O}_7$ by preferential diffusion of cationic species Y, Ba, Cu and perhaps to the formation of a transition zone containing compounds like BaZrO_3 . On the other hand, this phenomenon, which increases the carrier density in the insulator, is an advantage when the structure is used as a photodetector.

FIGURE 2 : C-V plots of a Si- ZrO_2 - $\text{YBa}_2\text{Cu}_3\text{O}_7$ heterostructure

figure 3 : I-V plots of a Si- ZrO_2 - $\text{YBa}_2\text{Cu}_3\text{O}_7$ heterostructure a) obscurity current
b) total current under irradiation with visible light

4 - PHOTOCONDUCTION AND PHOTOVOLTAIC EFFECTS :

When the films are irradiated by a visible light, the resulting I-V curves (figure 3) can be interpreted by :

- a photoconduction effect corresponding to an increase of the total current
- and - a photovoltaic effect with a short-circuit current and an open-circuit voltage

The short circuit current is proportional to the intensity of light, which is most usually observed in the photovoltaic effect. The sensitivity measured within the solar spectrum reaches 1mA/Watt . From our experiments, the threshold which is situated in the infra-red region seems to be compatible with a photoexcitation in the silicon and transport by carriers in the zirconia.

5 - CONCLUSION :

This study shows that hybrids Si- ZrO_2 - $\text{YBa}_2\text{Cu}_3\text{O}_7$ structures operate as good M.O.S. capacitors and photocapacitors which could have applications in charge-coupled-devices

Future applications of superconductors in microelectronics , will include the "all superconductor" technology based principally on Josephson junctions and the "hybrid" semiconductor-superconductor devices. Recently, Burns *et al* (6) have shown that it might be possible to deposit superconductors and semiconductors on the same sapphire substrate . If existing semiconductor devices can be placed in junctions and MOS field effect transistors working at low temperature (77K or down); then SQUIDS and Josephson junctions can be leave on the same substrate without external connections .

Complementary studies must be achieved in fundamental physics : for example under illumination, the built-in electric field which appears at the $\text{YBa}_2\text{Cu}_3\text{O}_7\text{-ZrO}_2$ interface allows field effects on free carriers (Cooper pairs) in the superconductive film.

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