Study of Substrates Materials for Depositing High Quality Epitaxial Superconducting Thin Film

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Abstract : This paper is mainly describe to substrates materials for depositing high quality epitaxial superconducting YBCO thin film. A brief review of various substrates available for depositing film is presented.

IndexTerms **– Substrates material, YBCO Thin Film, Perovskite Crystal Structure.**

I. INTRODUCTION

The search for substrates that can support the growth of high quality epitaxial films has centred on materials having the perovskite crystal structure, usually an oxide. The substrates and the deposited film should have similar crystal structure, very close lattice matching and similar thermal expansion coefficient in the range of process and use temperature. In addition the substrate should have good thermal and chemical stability, showing no interdiffusion at the interface, absence of phase transition and twins, other physical properties, such as dielectric constant, loss tangent etc compatible with the planned application of films and commercial availability, in sufficiently size, at reasonable cost.

II. SURFACE QUALITY OF SUBSTRATES

The smoothness of the surface of the substrate is crucial for deposting high quality epitaxial thin films. For example: prolonged exposure of polished MgO substrates to the laboratory atmosphere causes a slight surface degradation due to attack by water vapour. i.e. MgO reacts with water to form $Mg(OH)_2$. Thin films deposited on such degraded substrates generally have rough surfaces. This roughness may result from out of plane c-axis, pronounced surface outgrowth and isolated clusters of a-b axis crystallites. Similarly, if the substrate is not well polished, step edge Josephson weak links could be formed in films deposited on rough surface. This results in considerable reduction in J_c of the film[1]. The roughness of the substrate surface was considerably reduced after annealing in flowing oxygen.

III. SUPERCONDUCTING YBCO COMPATIBLE SUBSTRATES

Among the various YBCO compatible substrates, (100) $SrTiO_3$ has a near perfect lattice match with YBCO and, it has shown the best results so far [2]. It has perovskite structure with a lattice constant of 3.90Å. However, its high dielectric constant (ε=300) and loss tangent [3] make it unsuitable for application at frequencies higher than few GHz. MgO is available as large sized wagers, at a reasonable cost and has dielectric properties suitable for microwave applications. It has modest dielectric constant (ε=9.65)[4]. Highly oriented and epitaxial films have been grown on MgO (100) substrates. It has a 9% lattice mismatch with YBCO. MgO substrate is suitable for fabrication of high T_c microwave resonators, delay lines and filters [5]. The perovskite $LaAlO_3$ has a compatible thermal expansion property with YBCO[6], low dielectric constant (ε=23), low microwave losses. Highly oriented epitaxial films were grown on (100) $LaAlO_3$. Film deposited in the (100) face of stabilized ZrO_2 (YSZ) were generally polycrystalline with poor quality. It has a modest dielectric constant (ε=9.34). The dielectric properties of sapphire are anisotropic, making it difficult to model the performance of microwave devices. This substrate is found to be suitable for high performance bolometer due to its high mechanical strength. Its lattice parameter and thermal expansion coefficient match reasonably well, with YBCO and its dielectric constant at room temperature is smaller than that of $SrTiO_3$ by one order of magnitude (ε=25). Its crystal structure is orthorhombic. Properties of some substrate materials used for depositing high-T_c superconducting YBCO thin films are summarized in table 1.

TABLE-1

The properties of some substrate material used for high-T_c superconductors.

Substrate material	Crystal system	Lattice constant (nm)	Thermal expansion coeff. $10^{-6}C^{-1}$	Loss tangent ($X10^{-4}$) 77K	Dielectric constant	Melting temp. (^0C)	% age mismatch with YBCO a=0.386nm
$SrTiO_3$	Cubic	a=0.3905	9.4	>200	300	2080	-1.15
MgO	Cubic	a= 0.4212	14	91 (1MHZ)	9.6-10	2825	-8.36
YSZ	Cubic	a= 0.516 (0.365)	11.4	54 (1MHZ)	25	2550	+5.75
$LaGaO_3$	Ortho rhombic perovskite	a= 0.5482 b= 0.5526 (a,b=0.3892)	9	18 (1MHZ)	25	1715	-0.82
$LaAlO_3$	Hexagonal	a= 0.536 c= 1.311 (0.379)	10-13	5.8 (10GHZ)	20.5-27	2100	1.85
Al_2O_3	Trigonal	a= 0.514 (0.363)	9.4	10^{-4}	9.4-11.6	2049	6.34

IV. RESULT AND DISCUSSION

Superconducting YBCO thin films were deposited on different substrates: $SrTiO_3$, $LaAlO_3$, MgO and YSZ under optimized condition for $SrTiO_3$. It was found that all the four deposited films show a metallic behaviour in the normal state and a sharp superconducting transition. The thin film deposited on (100) $SrTiO_3$ substrate had least resistivity at room temperature. This is expected as there is a close matching of the film and substrate crystallographic lattices, which minimizes the internal stresses in the thin film. The resistivity ratio R_{300K}/R_{100K} was found to be maximum (~3) for films deposited on (100) $SrTiO_3$ substrate. Thus, the important parameters for substrate selection are cost, lattice matching, reaction between film and substrate and the matching of thermal expansion coefficients of the thin film and substrate.

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