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Multilayering approach to enhance current carrying capability of YBa₂Cu₃O₇ films

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Multilayering approach to enhance current carrying
capability of $\text{YBa}_2\text{Cu}_3\text{O}_7$ films

A thesis submitted in fulfilment of the requirements for the award of

the degree of

Doctor of Philosophy of

UNIVERSITY OF WOLLONGONG

by

Serhiy Pysarenko

Faculty of Engineering

Institute for Superconducting and Electronic Materials

January 2010

Declaration

I, Serhiy Pysarenko, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Faculty of Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Serhiy Pysarenko

Wollongong

January 2010

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Abstract

High temperature superconducting (HTS) thin films deposited onto metallic substrates are known as coated conductors (CC) and are currently the most promising HTS candidates for wide-scale industrial applications. These films are fabricated from $\text{ReBa}_2\text{Cu}_3\text{O}_7$ (where Re is a rare earth element) ceramics and have very specific requirements with regard to their manufacturing and maintenance, due to their complex stoichiometry and large anisotropy. One of the most important problems studied by many researchers around the world is the improvement of critical current capability in such superconducting films. Structures consisting, for example, of both $\text{YBa}_2\text{Cu}_3\text{O}_7$ (YBCO) layers and layers of different superconductive or non-superconductive materials having a similar crystal structure are likely to have enhanced microstructural properties, and they are able to carry larger critical currents as compared to their monolayer counterparts. Such sandwich-like films are called multilayer structures.

Usually, in order to increase the amount of electrical current being transported through a coated conductor, one needs to make necessary adjustments to the superconducting layer. An "obvious" way to enhance transport electrical current is to increase the thickness of the superconducting film. However, this approach has one very significant flaw: the fact that critical current density degrades with increasing thickness of the film. This phenomenon is widely observed in coated conductors, which are already used for transmission of electricity in electric motors and high-field magnets around the globe.

The present work involves fundamental studies of the fabrication of multilayered

structures on single crystal and metallic substrates with the emphasis on improvement of the critical current density and understanding the mechanisms responsible for the behaviour of the critical current in such superconducting multilayer thin films. Enhancement of the critical current density has been achieved, reaching 3.4 MAcm^{-2} at 77 K in $\text{YBa}_2\text{Cu}_3\text{O}_7/\text{NdBa}_2\text{Cu}_3\text{O}_7$ based multilayers about $1 \mu\text{m}$ thick. This critical current density is higher than that for the best quality and optimal thickness $\text{YBa}_2\text{Cu}_3\text{O}_7$ monolayer films.

Investigation of the crystal structure and electromagnetic properties of mono- and sandwich-like structures has been performed to clarify the origin of the critical current enhancement in the multilayer structures. It was found that, from the structural point of view, the multilayer films have much better microstructure and surface quality (i.e. the smoothness of the surface) than is the case for monolayer films. This is due to the increased filling factor in the multilayered structures, because the holes which are usually observed in the film, have been successfully eliminated. With one of the critical problems being solved, which is degradation of critical current due to thickness of the superconducting film, multilayer structures offer great potential to be utilized not only for electrical power transmission, but also, for example, in fabrication of superconducting electronic components, such as magnetic detectors, superconducting quantum interference devices, etc.

Enhancement of the critical current capability of multilayer structures was investigated using a newly developed theoretical model. Mathematical modelling of critical current behaviour in thin superconducting films is one of the most complicated tasks of modern solid state physics. Theoretical investigation of multilayering is crucial for understanding the superconductivity and for further improvement of the superconducting properties of such structures. The qualitative analysis of electric current properties in superconductors can uncover the nature of the coexistence and interaction of two states: the solid state and the field state of the matter. The existing theory of vortex lattice behaviour in superconducting thin films in the field state of matter is an intriguing part of the research, as parameters controlling such a lattice

are controllable. By changing these parameters, a variety of structural defects and crystal characteristics on macroscopic and microscopic scales can be investigated.

One of the major objectives of this PhD project was to develop a theoretical model that would allow modelling of critical current behaviour in superconducting films. The constraints and applicability of the model are discussed in accordance with experimental data and fitting procedures. Calculation results, obtained within reasonable approximations, can well describe various properties of the crystal structures of monolayer and multilayer thin films. An automated computer program was successfully designed on the basis of the statistical theory for the quantification of the crystal structure parameters in superconducting thin films. Observed data showed that multilayering is crucial to enhance the quality of the upper layers of the films and to increase the amount of dislocations that act as effective pinning centres, resulting in improved critical current carrying capability.

During this work, a few additional related research problems have been addressed. An emphasis was put onto development of the pulsed laser deposition method (to prepare thin film samples of the highest quality) and investigation of the effect of Ag doping, which has a positive influence on the critical current carrying capability of YBCO superconducting films.

Fabrication of high quality YBCO thin films implies usage of very reactive oxygen atmosphere and high temperature. These peculiarities make the process very sensitive to a number of various deposition parameters. Optimal deposition conditions were verified and, as a consequence, a new heater was designed and fabricated. As a result of this work, the amount of time required to be spent on optimization of deposition conditions has been considerably reduced. This, in fact, significantly increased the productivity of the pulsed laser deposition system. A comprehensive study of one deposition parameter, the target to substrate distance was performed. The obtained results showed that the target to substrate distance plays a crucial role in pulsed laser deposition of monolayer and multilayer structures.

Special efforts were also dedicated to the investigation of Ag doping of the YBCO

superconducting thin films. It was found that doping strongly improves critical current at low applied magnetic fields. Research was directed towards uncovering the nature of advanced critical current carrying capabilities in Ag doped films. Microstructural analysis revealed that Ag doping leads to the enhancement of transparency for electrical current flow in the films. This is achieved in the process of deposition of the $\text{YBa}_2\text{Cu}_3\text{O}_7$ films, in which silver particles transfer extra energy to the $\text{YBa}_2\text{Cu}_3\text{O}_7$ ablated adatoms, thus ordering the microstructure during growth of the film. Moreover, the amount of silver which remains in the intergrain boundaries increases the transparency of films to the supercurrent flow and presumably plays a role as a barrier against oxygen depletion.

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