THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Approaching the depairing critical current in superconducting $YBa_2Cu_3O_{7-x}$ nanowires

SHAHID NAWAZ

Department of Microtechnology and Nanoscience - MC2
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2013

Approaching the depairing critical current in superconducting $YBa_2Cu_3O_{7-x}$ nanowires
SHAHID NAWAZ
ISBN 978-91-7385-861-8

Doktorsavhandlingar vid Chalmers tekniska högskola
Ny serie nr 3542
ISSN 0346-718X

Quantum Device Physics Laboratory
Department of Microtechnology and Nanoscience - MC2
Chalmers University of Technology
SE–412 96 Göteborg
Sweden
Telephone: +46 (0)31-772 1000

ISSN 1652-0769
Technical Report MC2-249

Chalmers Reproservice
Göteborg, Sweden 2013

Approaching the depairing critical current in superconducting $YBa_2Cu_3O_{7-x}$ nanowires

SHAHID NAWAZ
Department of Microtechnology and Nanoscience
Chalmers University of Technology
Göteborg, Sweden 2013

Abstract

The microscopic origin of High critical Temperature Superconductivity is still an open issue in condensed matter physics. In these complex oxides electrons self-organize in ways qualitatively different from those of conventional metals and insulators. The study of these materials at the nanoscale can help to shed light on various ordering and phase transitions giving new hints into the origin of high critical temperature superconductivity.

In this thesis a systematic study of the transport properties of nanowires made of High critical Temperature Superconductor (HTS) $YBa_2Cu_3O_{7-\delta}$ (YBCO) is presented. A soft nano-patterning technology for the fabrication of these nanowires has been implemented to preserve a homogeneous character of YBCO nano-structures. Two interesting observations are reported regarding the critical current density J_c carried by the nanowires:

1) Its value increases by reducing the nanowire width w.

2) For the smallest wires with $w \simeq 40$ nm the value of J_c approaches for the first time the theoretical depairing limit indicating nanostructure with properties very close to as grown films.

The behavior of the critical current density as a function of width has been explained in terms of current crowding at the inner corners at the connection between the nanowires and the wide electrodes .

YBCO nanowire based nanoSQUIDs have been also fabricated. The nano-SQUIDs can work in the whole temperature range from 300mK to 80K. Critical current modulation as a function of an externally applied magnetic field at different temperatures has been studied and the screening parameter β_L has been extracted. The experimental and simulated values of β_L are in good agreement indicating a Josephson-like behavior in the whole temperature range.

Keywords: Superconductivity, Nanowires, HTS, NanoSQUIDs, YBCO

LIST OF APPENDED PAPERS

This thesis is based on the work contained in the following papers

I. **Microwave Response of Superconducting $YBa_2Cu_3O_{7-\delta}$ Nanowire Bridges Sustaining the Critical Depairing Current: Evidence of Josephson-like Behavior**
S. Nawaz, R. Arpaia, F. Lombardi and T. Bauch
Phys. Rev. Lett. **10**, 4824 (2013).

II. **Approaching the theoretical depairing current in $YBa_2Cu_3O_{7-\delta}$ nanowires**
S. Nawaz, R. Arpaia, T. Bauch and F. Lombardi, *Nanotechnology* (submitted-2013)

III. **Improved Nanopatterning for YBCO Nanowires Approaching the Depairing Current**
R. Arpaia, S. Nawaz, F. Lombardi and T. Bauch,
IEEE Trans. Appl. Supercond. **23**, 3 (2013)

IV. **Transport Properties of YBCO Nanowires**
Shahid Nawaz, T. Bauch and F. Lombardi
IEEE Trans. Appl. Supercond. **21**, 3 (2011)

Papers NOT Included in this thesis

I. **Low capacitance HTS junctions for single electron transistors**
D. Gustafsson, T. Bauch, S. Nawaz, M. Mumtaz Virk, G. Signorello, and F. Lombardi
Physica C **470**, S188 (2010).

II. **High critical temperature superconductor Josephson junctions for quantum circuit applications**
T. Bauch, D. Gustafsson, K. Cedergren, S. Nawaz, M. Mumtaz Virk, H. Pettersson, E. Olsson, and F. Lombardi
Physica Scripta **T173**, 014006 (2009).

III. **Transport Properties of YBCO Nanowires**, Shahid Nawaz, Thilo Bauch and Floriana Lombardi
Technical report number **186** - Proceedings The Linneaus Summer School in Quantum Engineering, Hindas (2010),
Department of Microtechnology and Nanoscience - MC2, Chalmers

Contents