Springer Theses

Recognizing Outstanding Ph.D. Research

Aims and Scope

The series "Springer Theses" brings together a selection of the very best Ph.D. theses from around the world and across the physical sciences. Nominated and endorsed by two recognized specialists, each published volume has been selected for its scientific excellence and the high impact of its contents for the pertinent field of research. For greater accessibility to non-specialists, the published versions include an extended introduction, as well as a foreword by the student's supervisor explaining the special relevance of the work for the field. As a whole, the series will provide a valuable resource both for newcomers to the research fields described, and for other scientists seeking detailed background information on special questions. Finally, it provides an accredited documentation of the valuable contributions made by today's younger generation of scientists.

Theses are accepted into the series by invited nomination only and must fulfill all of the following criteria

- They must be written in good English.
- The topic should fall within the confines of Chemistry, Physics, Earth Sciences, Engineering and related interdisciplinary fields such as Materials, Nanoscience, Chemical Engineering, Complex Systems and Biophysics.
- The work reported in the thesis must represent a significant scientific advance.
- If the thesis includes previously published material, permission to reproduce this must be gained from the respective copyright holder.
- They must have been examined and passed during the 12 months prior to nomination.
- Each thesis should include a foreword by the supervisor outlining the significance of its content.
- The theses should have a clearly defined structure including an introduction accessible to scientists not expert in that particular field.

More information about this series at http://www.springer.com/series/8790

Ece Uykur

Pseudogap and Precursor Superconductivity Study of Zn doped YBCO

Doctoral Thesis accepted by
Osaka University, Osaka, Japan

Springer

Author
Dr. Ece Uykur
Department of Physics, Graduate School of Science
Osaka University
Osaka
Japan

Supervisor
Setsuko Tajima
Department of Physics, Graduate School of Science
Osaka University
Osaka
Japan

ISSN 2190-5053 ISSN 2190-5061 (electronic)
Springer Theses
ISBN 978-4-431-55509-4 ISBN 978-4-431-55510-0 (eBook)
DOI 10.1007/978-4-431-55510-0

Library of Congress Control Number: 2015932455

Springer Tokyo Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer Japan KK is part of Springer Science+Business Media (www.springer.com)

Parts of this thesis have been published in the following journal articles:

1. **E. Uykur**, K. Tanaka, T. Masui, S. Miyasaka, and S. Tajima, "Persistence of superconducting condensate far above T_c in high temperature cuprate superconductors: Optical study of Zn- and carrier-doping dependences", Phys. Rev. Lett., 112 (2014) 127003
2. **E. Uykur**, K. Tanaka, T. Masui, S. Miyasaka, and S. Tajima, "Precursor superconductivity and superconducting fluctuation regime revealed by the *c*-axis optical spectra of $YBa_2(Cu_{1-x}Zn_x)_3O_y$, Physics Procedia, 45 (2013) 45
3. **E. Uykur**, K. Tanaka, T. Masui, S. Miyasaka, and S. Tajima, "Coexistence of the Pseudogap and the Superconducting Gap Revealed by the *c*-Axis Optical Study of $YBa_2(Cu_{1-x}Zn_x)_3O_{7-\delta}$", JPSJ, 82 (2013) 033701
4. **E. Uykur**, K. Tanaka, T. Masui, S. Miyasaka, and S. Tajima, "Pseudogap Study Using *c*-axis Optical Spectra of Underdoped $YBa_2Cu_3O_{7-\delta}$", JPSJ, 81 (2012) SB035

Supervisor's Foreword

High-temperature superconductivity is one of the most interesting and puzzling issues in physics. Despite a tremendous number of studies, its mechanism has not been elucidated so far. One of the serious problems is the "abnormal" normal state called the "pseudogap state". The present thesis challenges this issue through the measurement of *c*-axis polarized optical spectra for Zn-doped $YBa_2Cu_3O_y$ (YBCO).

The author has precisely measured the *c*-axis optical reflectivity spectra of YBCO over a wide energy range from 2.5 meV to 20 eV and has investigated their temperature, carrier doping, and Zn-content dependences. As a result, she found that (i) carriers involved in the pseudogap formation do not contribute to superconductivity, (ii) the pseudogap continues to open even below T_c, (iii) the pseudogap is observed even in the nonsuperconducting YBCO with Zn-substitution, and (iv) the pseudogap temperature is below the superconducting transition temperature in the overdoped regime. Concerning the origin of the pseudogap, there has been a long debate between two different interpretations: one is that the pseudogap phenomenon is a precursor of superconductivity and the other is that it is an order competing with superconductivity. All the findings listed above clearly disprove the former interpretation and support the latter.

Although a precursor of superconductivity turns out not to be the origin of the pseudogap, it does not mean that there is no such phenomenon. In fact, there have been several reports that a precursor phenomenon of superconductivity was observed at a temperature lower than the pseudogap temperature. However, the characteristic temperature and its doping dependence are different, depending on the measurement probe, which leaves us far from the understanding of this phenomenon. In the present thesis work, from the analysis of the spectral weight of the optical conductivity, a superconducting condensate was detected far above T_c. The presence of superconducting condensate was also confirmed in the imaginary part of the optical conductivity. The characteristic temperature, T_p, was found to decrease with Zn-substitution, following the T_c change with Zn-content, which indicates that the observed phenomenon is indeed a precursor of superconductivity.

Surprisingly, as the carrier doping is reduced, T_p increases whereas T_c decreases. This strongly suggests that the superconductivity pairing mechanism is connected with the strong electron correlation giving a Mott insulator. Furthermore, the author succeeded in detecting a conventional superconducting fluctuation whose onset temperature coincides with what was reported previously as a precursor of superconductivity. The present systematic study has successfully settled the controversial problem related to a precursor of superconductivity.

Summing up, the present study makes a big contribution to the elucidation of the electronic state and the superconductivity mechanism of the cuprate superconductors, which is a result of the author's fine work including careful preparation of samples, precise measurement of the optical spectra, and detailed analyses of the data.

Osaka, Japan, June 2014 Setsuko Tajima

Acknowledgments

First of all, I would like to thank my supervisor, Prof. Setsuko Tajima, for her guidance and support during this work. Her advices and discussions were valuable for me. I am also grateful to her for answering all my questions and for careful reading of this thesis.

I would like to express my sincere gratitude to Prof. Shigeki Miyasaka for teaching me how to use the FTIR spectrometer and for his help in resolving problems related to the experimental setup and measurements.

I am very grateful to Dr. Takahiko Masui for growing the single crystals used in this work. The high-quality crystals were very much appreciated.

I would also like to thank Dr. Kiyohisa Tanaka for his discussions, suggestions, and guidance during the measurements and data analysis.

I also want to thank Ms. Yoshiko Ishimoto, the Secretary of the Tajima group, for her help with the endless paperwork. My thanks extend to all members of the Tajima group for their help and patience related or unrelated to the laboratory work.

I especially thank Mustafa Çağatay Tulun for his help in refining the programs used for data analysis; and Pham Tan Thi, Kwing To Lai, Nguyen Minh Hien, and Nguyen Trung Hieu for the fun times we had.

Finally, I would like to thank my parents for their encouragement and continuous support.

Ece Uykur

Contents

Abbreviations

ARPES	Angle-resolved photoemission spectroscopy
BSC theory	Bardeen-Schrieffer-Cooper theory
FGT	Ferrel-Glover-Tinkham
FTIR spectroscopy	Fourier transform infrared spectroscopy
HTSC	High-temperature superconductors
KE	Kinetic energy
KK relation	Kramers–Krönig relation
NMR	Nuclear magnetic resonance
p	Doping level
STM	Scanning tunnelling microscopy
SW	Spectral weight
T^*	Pseudogap temperature
T_c	Superconducting transition temperature
$T_c^{'}$	Conventional superconducting fluctuation temperature
THz-TDS	Terahertz time domain spectroscopy
TJP	Transverse Josephson plasma
T_p	Precursor superconducting temperature
x	Zn-content
YBCO	$YBa_2Cu_3O_y$