纳米科学与技术

国家出版基金项目
NATIONAL PUBLICATION FOUNDATION

超导纳米电子学基础

Fundamentals of Superconducting Nanoelectronics

Anatolie Sidorenko

科学出版社

纳米科学与技术

超导纳米电子学基础

Fundamentals of Superconducting Nanoelectronics

Anatolie Sidorenko

科学出版社
北京

图：01-2014-4080

图书在版编目（CIP）数据

超导纳米电子学基础＝Fundamentals of superconducting nanoelectronics：英文/（摩尔）西多（Sidorenko）主编.—影印本.—北京：科学出版社，2014.7
（纳米科学与技术）
ISBN 978-7-03-041425-0
Ⅰ.①超… Ⅱ.①西…Ⅲ.①纳米材料-电子器件-英文 Ⅳ.①TN103
中国版本图书馆 CIP 数据核字（2014）第 165839 号

丛书策划：杨 震 / 责任编辑：王化冰
责任印制：钱玉芬 / 封面设计：陈 敬

科学出版社出版
北京东黄城根北街 16 号
邮政编码：100717
http://www.sciencep.com
中国科学院印刷厂印制
科学出版社发行 各地新华书店经销
*
2014 年 7 月第 一 版 开本：720×1000 1/16
2014 年 7 月第一次印刷 印张：21 1/2
字数：436 000
定价：158.00 元
（如有印装质量问题，我社负责调换）

《纳米科学与技术》丛书序

在新兴前沿领域的快速发展过程中，及时整理、归纳、出版前沿科学的系统性专著，一直是发达国家在国家层面上推动科学与技术发展的重要手段，是一个国家保持科学技术的领先权和引领作用的重要策略之一。

科学技术的发展和应用，离不开知识的传播：我们从事科学研究，得到了“数据”（论文），这只是“信息”。将相关的大量信息进行整理、分析，使之形成体系并付诸实践，才变成“知识”。信息和知识如果不能交流，就没有用处，所以需要“传播”（出版），这样才能被更多的人“应用”，被更有效地应用，被更准确地应用，知识才能产生更大的社会效益，国家才能在越来越高的水平上发展。所以，数据→信息→知识→传播→应用→效益→发展，这是科学技术推动社会发展的基本流程。其中，知识的传播，无疑具有桥梁的作用。

整个 20 世纪，我国在及时地编辑、归纳、出版各个领域的科学技术前沿的系列专著方面，已经大大地落后于科技发达国家，其中的原因有许多，我认为更主要的是缘于科学文化的习惯不同：中国科学家不习惯去花时间整理和梳理自己所从事的研究领域的知识，将其变成具有系统性的知识结构。所以，很多学科领域的第一本原创性“教科书”，大都来自欧美国家。当然，真正优秀的著作不仅需要花费时间和精力，更重要的是要有自己的学术思想以及对这个学科领域充分把握和高度概括的学术能力。

纳米科技已经成为 21 世纪前沿科学技术的代表领域之一，其对经济和社会发展所产生的潜在影响，已经成为全球关注的焦点。国际纯粹与应用化学联合会（IUPAC）会刊在 2006 年 12 月评论：“现在的发达国家如果不发展纳米科技，今后必将沦为第三世界发展中国家。”因此，世界各国，尤其是科技强国，都将发展纳米科技作为国家战略。

兴起于 20 世纪后期的纳米科技，给我国提供了与科技发达国家同步发展的良好机遇。目前，各国政府都在加大力度出版纳米科技领域的教材、专著以及科普读物。在我国，纳米科技领域尚没有一套能够系统、科学地展现纳米科学技术各个方面前沿进展的系统性专著。因此，国家纳米科学中心与科学出版社共同发起并组织出版《纳米科学与技术》，力求体现本领域出版读物的科学性、准确性和系统性，全面科学地阐述纳米科学技术前沿、基础和应用。本套丛书的出版以高质量、科学性、准确性、系统性、实用性为目标，将涵盖纳米科学技术的所有领域，全面介绍国内外纳米科学技术发展的前沿知识；并长期组织专家撰写、编辑出版下去，为我国

纳米科技各个相关基础学科和技术领域的科技工作者和研究生、本科生等，提供一套重要的参考资料。

这是我们努力实践“科学发展观”思想的一次创新，也是一件利国利民、对国家科学技术发展具有重要意义的大事。感谢科学出版社给我们提供的这个平台，这不仅有助于我国在科研一线工作的高水平科学家逐渐增强归纳、整理和传播知识的主动性（这也是科学研究回馈和服务社会的重要内涵之一），而且有助于培养我国各个领域的人士对前沿科学技术发展的敏感性和兴趣爱好，从而为提高全民科学素养作出贡献。

我谨代表《纳米科学与技术》编委会，感谢为此付出辛勤劳动的作者、编委会委员和出版社的同仁们。

同时希望您，尊贵的读者，如获此书，开卷有益！

中国科学院院长

国家纳米科技指导协调委员会首席科学家

2011 年 3 月于北京

Preface

The idea to write this book appeared after a series of workshops devoted to superconductivity of low-dimensional objects, which we organized last decade. In 2004 director of Walther-Meißner-Institut Professor Rudolf Gross and I organized an NATO Advanced Research Workshop "Nanoscale Devices, Fundamentals and Applications" and published the book with the same title, collecting the best of reports, presented on that workshop. As we realized a bit later, the book was in demand by colleagues, who deal with applications of superconductivity. For example, the group of researchers is engaged in development and fabrication of a very sensitive superconducting sensor for infrared radiation, superconducting thin-film bolometer, would like to achieve the highest possible sensitivity. They develop different technological processes for improvement of the quality of the superconducting film, trying to obtain thin films with the narrowest width of superconducting transition. In case, when a member of such group has knowledge in superconducting fluctuations (which are rather noticeable for low-dimensional objects) that there exists a limitation of the smallest possible width of the superconducting transition, ΔT_c, given by the Ginsburg criteria, $\Delta T_c = GiT_c$, then such group of researchers can save a lot of time and instead of many experimental attempts to improve the quality of the films, just select the most suitable material with the smallest value of the parameter Gi. This is a simple example how the knowledge of the intrinsic phenomena in superconductivity at nanoscale can help the experimentalists to save their resources and time to achieve the desirable result.

Recently, some very interesting effects were first predicted theoretically and then detected experimentally in layered and low-dimensional superconductors – triplet superconductivity, crossed Andreev reflection, and pi-shift. How one can use them for novel devices? What kind of nanostructures should be prepared for detection and application of those effects? In order to highlight some of the rosen questions, well-known experts were invited to write chapters for this book.

We believe that the book can attract attention of researchers, engineers, Ph.D. students and others, who would like to gain knowledge about some intrinsic effects of Superconductivity at nanoscale.

Kishinev, June 2011 *Anatolie Sidorenko*

Contributors

K.Yu. Arutyunov Nano Science Center, Department of Physics, University of Jyväskylä, PB35, 0014 Jyväskylä, Finland
and
Nuclear Physics Institute, Moscow State University, 119992 Moscow, Russia, konstantin.arutyunov@phys.jyu.fi

Y. Asano Department of Applied Physics, Hokkaido University, Sapporo 060-8628, Japan

D. Beckmann Institut für Nanotechnologie, Karlsruher Institut für Technologie, P.O. Box 3640, 76021 Karlsruhe, Germany, detlef.beckmann@kit.edu

Manfred Birk DLR German Aerospace Centre, Remote Sensing Technology Institute, 82234 Wessling, Germany

Dick Boersma SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

Johannes Dercksen SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

Pavel Dmitriev Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Science, Mokhovaya st. 11/7, 125009 Moscow, Russia

Andrey B. Ermakov Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Science, Mokhovaya st. 11/7, 125009 Moscow, Russia
and
SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

Lyudmila V. Filippenko SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

E. Goldobin Physikalisches Institut–Experimental physic II and Center for Collective Quantum Phenomena, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany, gold@uni-tuebingen.de

Hans Golstein SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

A.A. Golubov Faculty of Science and Technology, University of Twente, 7500 AE Enschede, The Netherlands
and
MESA+ Institute of Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands, A.A.Golubov@tnw.utwente.nl

Ruud W.M. Hoogeveen SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

Leo de Jong SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

K.V. Kalashnikov Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Science, Mokhovaya st. 11/7, 125009 Moscow, Russia

Mikhail S. Kalenkov I.E. Tamm Department of Theoretical Physics, P.N. Lebedev Physics Institute, 119991 Moscow, Russia

T.Yu. Karminskaya Nuclear Physics Institute, Moscow State University, 119992 Moscow, Russia

Andrey V. Khudchenko Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Science, Mokhovaya st. 11/7, 125009 Moscow, Russia
and
SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands, Khudchenko@hitech.cplire.ru

Nickolay V. Kinev Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Science, Mokhovaya st. 11/7, 125009 Moscow, Russia
and
SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

Oleg S. Kiselev Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Science, Mokhovaya st. 11/7, 125009 Moscow, Russia
and
SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

R. Kleiner Physikalisches Institut–Experimental physic II and Center for Collective Quantum Phenomena, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany, kleiner@uni-tuebingen.de

D. Koelle Physikalisches Institut–Experimental physic II and Center for Collective Quantum Phenomena, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany, koelle@uni-tuebingen.de

Valery P. Koshelets Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Science, Mokhovaya st. 11/7, 125009 Moscow, Russia
and
SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands, valery@hitech.cplire.ru

Pavel V. Kudryashov Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Science, Mokhovaya st. 11/7, 125009 Moscow, Russia

Bart van Kuik SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

M.Yu. Kupriyanov Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, GSP-1, Leninskie Gory, 119991 Moscow, Russia
and
Nuclear Physics Institute, Moscow State University, 119992 Moscow, Russia, mkupr@pn.sinp.msu.ru

C. Lacroix Institut N'eel, CNRS-UJF, BP166, 38042 Grenoble Cedex 9, France, claudine.lacroix@grenoble.cnrs.fr

Arno de Lange SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

Gert de Lange SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

Irina L. Lapitsky SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

Yu. G. Naidyuk B. Verkin Institute for Low Temperature Physics and Engineering, National Academy of Sciences of Ukraine, 47 Lenin ave., 61103 Kharkiv, Ukraine, naidyuk@ilt.kharkov.ua

Sergey I. Pripolzin Institute for Physics of Microstructure, Russian Academy of Science, Ulyanova 46, GSP-105, Nizhny Novgorod, Russia

N.G. Pugach Faculty of Physics, M.V. Lomonosov Moscow State University, GSP-2, Leninskie Gory, 119991 Moscow, Russia, pugach@magn.ru

Joris van Rantwijk SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

V.V. Ryazanov Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow District, 142432 Russia, valery.ryazanov@gmail.com

Avri M. Selig SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

A.S. Sidorenko Institute of Electronic Engineering and Nanotechnologies ASM, MD2028 Kishinev, Moldova
and
Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), D-76021 Karlsruhe, Germany, anatoli.sidorenko@kit.edu

Alexander S. Sobolev Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Science, Mokhovaya st. 11/7, 125009 Moscow, Russia

Y. Tanaka Department of Applied Physics, Nagoya University, Nagoya 464-8603, Japan

Y. Tanuma Institute of Physics, Kanagawa University, 3-7-1, Rokkakubashi, Kanagawa-ku, Yokohama 221-8686, Japan

Mikhail Yu. Torgashin Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Science, Mokhovaya st. 11/7, 125009 Moscow, Russia

Vladimir L. Vaks Institute for Physics of Microstructure, Russian Academy of Science, Ulyanova 46, GSP-105, Nizhny Novgorod, Russia

A.A. Varlamov Institute of Superconductivity and Innovative Materials of National Research Council (SPIN-CNR), Viale del Politecnico 1, I-00133 Rome, Italy, andrei.varlamov@spin.cnr.it

Ed de Vries SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands

Georg Wagner DLR German Aerospace Centre, Remote Sensing Technology Institute, 82234 Wessling, Germany

Pavel A. Yagoubov SRON Netherlands Institute for Space Research, 9700 AV Groningen, The Netherlands
and
European Organization for Astronomical Research in the Southern Hemisphere (ESO), Karl-Schwarzschild-Strasse 2, 85748 Garching bei München, Germany

I.K. Yanson B. Verkin Institute for Low Temperature Physics and Engineering, National Academy of Sciences of Ukraine, 47 Lenin ave., 61103 Kharkiv, Ukraine, naidyuk@ilt.kharkov.ua

Andrei D. Zaikin Institut für Nanotechnologie, Karlsruher Institut für Tehnologie (KIT), 76021 Karlsruhe, Germany
and
I.E. Tamm Department of Theoretical Physics, P.N. Lebedev Physics Institute, 119991 Moscow, Russia, andrei.zaikin@kit.edu

Contents