SOCIETÀ ITALIANA DI FISICA

PROCEEDINGS
OF THE
INTERNATIONAL SCHOOL OF PHYSICS
«ENRICO FERMI»

COURSE CXLIV

Nanometer Scale Science and Technology

SOCIETÀ ITALIANA DI FISICA BOLOGNA-ITALY

ITALIAN PHYSICAL SOCIETY

PROCEEDINGS

OF THE

INTERNATIONAL SCHOOL OF PHYSICS

"ENRICO FERMI"

COURSE CXLIV

edited by M. ALLEGRINI, N. GARCÍA and O. MARTI

Directors of the Course

VARENNA ON LAKE COMO

VILLA MONASTERO

27 June - 7 July 2000

Nanometer Scale Science and Technology

IOS Press

Ohmsha

AMSTERDAM, OXFORD, TOKYO, WASHINGTON DC

ISBN 1 58603 165 1 (IOS Press)
ISBN 4 274 90458X C3042 (Ohmsha)
Library of Congress Catalog Card Number: 2001090873

Production Manager
A. Oleandri

Copy Editor
M. Missiroli

Publisher
IOS PRESS
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The Netherlands
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e-mail: order@iopress.nl

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Proprietà Letteraria Riservata
Printed in Italy

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SCUOLA INTERNAZIONALE DI FISICA

"ENRICO FERMI"

CXLIV Corso

a cura di M. Allegrini, N. García and O. Marti

Direttori del Corso

VARENNA SUL LAGO DI COMO

VILLA MONASTERO

27 Giugno - 7 Luglio 2000

Scienza e tecnologia a scala nanometrica

2001

SOCIETÀ ITALIANA DI FISICA
BOLOGNA-ITALY

Supported by the European Commission, Research DG, Human Potential Programme, High-Level Scientific Conferences HPCF-CT-1999-00094

Supported by UNESCO VENICE OFFICE (UVO-ROSTE)

Supported by the European Commission, DGXII Research and Development, Training and Mobility of Researchers Programme: Network "Near Field Optics for Nanotechnology" (NanoSNOM), ERBFMRX-CT-98-0242

Supported by European Office of Naval Research (ONRIFO)

Supported by Swiss National Science Foundation

Supported by Gruppo Nazionale di Struttura della Materia (GNSM-CNR)

Preface

The many wonders of nanophysics were first anticipated by Richard Feynman in a speech he gave in late 1959, subsequently published under the title "There's Plenty of Room at the Bottom". Feynman was able to grasp the new physics at the atomic or nanometer scale, which has arrived at the verge of fruition today in many areas from information technology and medicine to manufacturing and the environment. Nanophysics is not synonimous with nanotechnology, but it depends heavily on the nanotechnologies required to produce, to investigate and to manipulate single atoms and molecules and other nanostructures. Nanophysics, however, goes one step further than nanotechnology because it also requires a profound understanding of the magical world on the length scales where the smallest of human-made devices and the large molecules of living systems meet.

The CXLIV Course of the Enrico Fermi School, held in Varenna at the beautifully renovated Villa Monastero from June 27 to July 7, 2000, focuses on "Nanometer Scale Science and Technology". This is one of the most rapidly expanding research fields and it is considered one of the most important issues in forming future societies. Nanoscience and nanotechnology are at the interface between physics, chemistry, engineering and, most importantly, biology. The most fundamental processes of living matter occur on the nanometer scale. Micro-electrical mechanical systems are approaching the dimensions of biological cells, opening up the possibility of connecting machines to individual cells. This Course, the first in this field at the Enrico Fermi School, successfully attempted to convey to students the flavour of "the magic of the small". In physics it is the domain of the interface between condensed matter and atoms and molecules. Given the highly interdisciplinary character of this advanced research, we have been forced to select a few topics among a large variety. The Course was based on local probes (STM, AFM, SNOM) and related supreme technological achievements. These topics were extensively covered in a set of lectures and seminars, mainly devoted to instrumentation aspects. From a more fundamental point of view it also covers advanced subjects such as clusters, nanocontacts, photonic band gap materials, atom manipulation by light, atom optics with Bose-Einstein

condensates and quantum computing. The information industry has been driving the field of nanotechnology, whose top issues are tolerance, interfaces, intensities and peripherals. Tolerance means that true nanoscale devices should be designed to assure operation even if their dimensions on an energy scale are spread considerably. Intensities describe the fact that even though extensive quantities such as length, number of particles and currents become small, intensities remain large or become even larger. Power densities, not light intensity and electric fields may become the limiting values. Peripherals finally address the fact that nanoscale objects are hard to interface to the macroworld. One example, discussed at this School, are nanotubes. Currently, the problem of how to make electrical contacts is one of the most prominent open questions. One consequence of these four issues is that nano-objects and nanodevices should have an optimal size.

One impressive fact of this Course was that all leading researchers were leaving their original discipline and have started to work at the interfaces of physics, chemistry, biology and engineering. The lectures addressed both fundamental subjects as well as instrumental issues. A fascinating overview of the basics of quantum computing was given in four lectures. Optical properties of nanoscale objects were covered extensively, and in one seminar it was concisely shown how periodic arrays of these particles lead to photonic band gap materials. Key examples of the fabrication of nanostructures were given. Electrical properties are some of the most sought after capabilities in the microworld: ballistic magnetoresistance, nanoscale electronics and nanotubes were some of the examples presented. Two sets of lectures were devoted to showing how to bridge physics and chemistry to biology, leading to the final lectures on the nanoscience of living matter.

All through the lectures it was very clear that nanotechnology would be the future of further technological development, but that it is also a multidisciplinary technology that more than ever requires basic scientific developments for its advancement. It could be said that nanotechnology and nanoscience, the new scientific developments on the nanoscale, are simply inseparable. Also future developments as well as those of the present, necessitate a close collaboration of physicists, chemists, biologists and mathematicians.

In the discussions it was also pointed out that developments in nanotechnology in the near future will be based on the CMOS techniques that so successfully have been fuelling the micro- and submicron technology. Nanodevices will have to be compatible with the existing CMOS technology, otherwise it will be virtually impossible to introduce them into today's markets. This seems to be the opinion of the more application-oriented participants. However, there were others who think that we should learn to "imitate" Nature and its self-replicating mechanism in order to create not only memory but also operating and functional memories. The attitude of nanotechnology so far has been to reduce the size of chips and devices, which have permitted an increase in memory and compactness, but this is not enough if we really want to open up new avenues for the future. The ideas that will constitute a break-through are still to come.

In addition to the lectures and seminars, a Round Table was organized by N. García, following the opening talks of H. Rohrer who brought to the minds of all participants that science and technology cannot be discussed ignoring ethical and social consequences.

Lively discussions among the participants deepened the awareness of the problem.

The success of this Course on Nanometer Scale Science and Technology was made possible firstly by all the participants, speakers, young students and senior observers, and secondly by the cooperation of many persons and institutions. We wish to thank all lecturers to whom the largest part of the credit must be given and the numerous students, from seventeen different countries all over the world, who interacted constantly and very intensively. A special thought of gratitude is due to Prof. G. F. BASSANI, the President of the Italian Physical Society, who has supported our initiative with enthusiasm and knowledge from the early stages of application to the very end of the Course. Special thanks are due to Dr. M. LABARDI for his dedicated work as secretary of the Course. We wish to thank Dr. I. VODYANOY of the Office of Naval Research who followed the entire Course and contributed with lively scientific discussions as well as with a special seminar on "Funding from the US: ONRIFO International Program". Thanks also to Dr. R. COMPAÑÓ and Dr. N. DELIYANAKIS of the European Commission who paid a short but intense visit to our school and brought the news about the great efforts that the European Commission is making in the field of nanotechnology. B. ALZANI and C. VASINI from the staff of the Italian Physical Society were marvellous in solving the logistic problems, on which the directors had no influence. R. BRIGATTI, F. SABADINI and S. REICHARD efficiently and cheerfully helped in a smooth running of the Course. Our thanks to all of them.

We acknowledge the generous support by the Italian Physical Society (SIF), the European Commission through its Euroconferences and Euroschools programme and the TMR Network NanoSNOM, the European Office of Naval Research (ONRIFO), the UNESCO, the Swiss National Science Foundation and the Gruppo Nazionale di Struttura della Materia of the Italian National Research Council (GNSM-CNR).

M. ALLEGRINI, N. GARCÍA and O. MARTI

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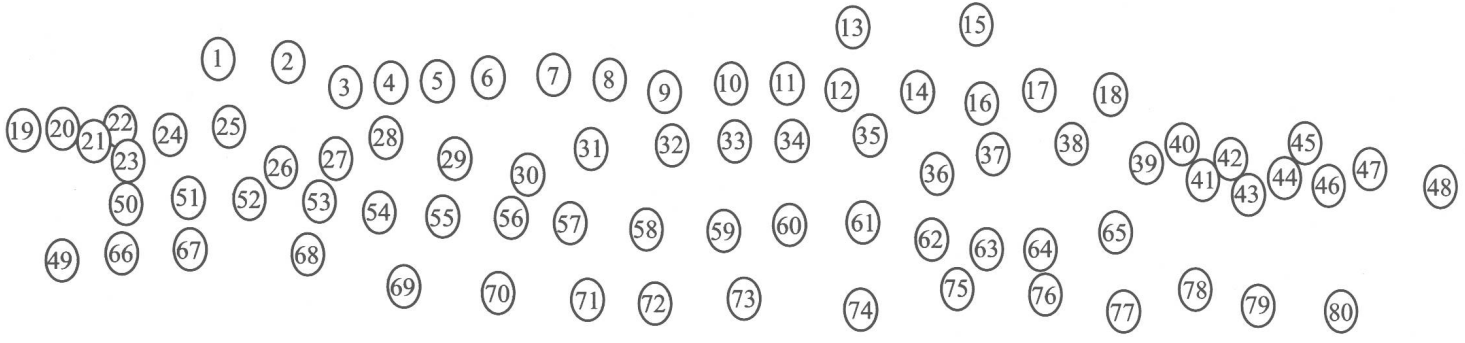

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