NANOPHASE MATERIALS: SYNTHESIS — PROPERTIES — APPLICATIONS
NATO Advanced Study Institute (ASI) 920873
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Submitted to:

Dr. Lawrence Kabacoff
Scientific Officer - Materials Division
ONR Code 1131M
Office of the Chief of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

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Submitted by:

George C. Hadjipanayis
Department of Physics and Astronomy
University of Delaware
Newark, DE 19716-2570
General Report

The concept of a NATO/ASI on nanophase materials originated in September of 1990 at the Conference on Nanostructured Materials in Atlantic City. It was clear in that conference that there was a need for a more tutorial-type meeting to review the present state of nanophase materials and discuss future research directions and technological applications. I also knew that such a school needed special attention because of its multidisciplinary nature. However, my previous experience directing the successful interdisciplinary NATO/ASI on "The Science and Technology of Nanostructure Magnetic Materials" (held in Crete during 1990) gave me confidence in my ability to organize such a multidisciplinary school with successful results.

The idea matured during the NATO Advanced Workshop on "The Physics and Chemistry of Finite Systems: from Clusters to Crystals" held in Richmond, Virginia, in 1992 and right after the workshop I asked Dr. Siegel, who is considered to be one of the few experts in nanophase materials, to be the Co-Director of the school.

We then formed an international committee and gathered information about the ASI lecturers. Our choices were based on pioneer work on nanophase research, as well as excellence in teaching. We advertised the NATO/ASI at several conferences, including the Cancun International Conference on
Nanostructured Materials (September 1992), the 3M Conference in Houston (November 1992), the MRS Meeting in Boston (December 1992), and the Intermag Conference in Stockholm (April 1993). We also sent letters to most of the groups working on nanophase materials in the USA and Europe (as well as in Eastern Europe and Russia). The response was overwhelming, with over 150 applications. This allowed us to choose a number of invited talks to complement and strengthen our program and, as we found out later, that was an excellent idea because of the multidisciplinary nature of the school. However, we soon realized that the percentage of graduate students who applied was rather low. At that time, we decided to send letters again and even call the various groups asking them to have their graduate students apply. This worked well and, ultimately, a large number of graduate students attended the conference (more than 30%). The fact that so many young people participated gave this ASI a very special tone of enthusiasm.

We prepared a booklet containing the agenda, summaries of lectures and abstracts of invited talks, a listing of posters, and complete participant address list and this was distributed to participants upon arrival. We were surprised at the extent to which the scientific community now relies on electronic mail and most of the conference correspondence was conducted via E-mail; indeed, we found this the only feasible way to communicate with scientists in Russia and Eastern Europe.

The program of the NATO/ASI was divided into the following sessions: Synthesis/Characterization, Mechanical Properties, Thermodynamic Properties, Electronic Properties, Optical Properties, Magnetic Properties, and Applications. Each session was comprised of lectures, invited talks, and posters, as well as a one-hour panel discussion. The major topic of the panel
discussion in each session was "Current Problems and Future Directions." The moderator of the panel talked to the students and to the speakers of the session and gathered questions from the students for further discussion. The discussion was opened to all the participants. We believe that this format allowed thorough coverage of each topic.

From the comments we received, we have reason to believe that this was an excellent ASI. Everybody praised this meeting as one of its kind. The scientific program was excellent. The participants represented a diverse mixture of physicists, chemists, and materials scientists who learned from each other. The social activities program was also rich consisting of a reception, dinner galas and banquet, and excursions to various places in Corfu. As a result of the excellent scientific and social programs, a strong interaction and friendship among the participants was established which will hopefully lead to future scientific collaborations.

Scientific Report

The Institute covered a broad spectrum of topics from the disciplines of physics, chemistry, biology and materials science that comprise the developing field of nanophase materials. The nature of nanophase materials and the fundamental criteria for their synthesis were elucidated.

The various types of nanostructured materials share three features: atomic domains (grains or phases) spatially confined to less than 100 nm, significant atom fractions associated with interfacial environments, and interactions between their constituent domains. Thus, nanostructured materials include zero-dimensionality atom clusters and cluster assemblies,
one- and two-dimensionally modulated multilayers and overlayers, respectively, and their three-dimensional analogues, nanophase materials.

Interest in the possibilities of nanostructuring materials has resulted in a variety of new methodologies for manufacturing novel materials with ultrafine structural or phase domains by means of which creation of new levels of property engineering become possible through the sophisticated control of scale, morphology, interaction, and architecture. A variety of these synthesis methods was described including synthesis from molecular precursors (gas condensation; chemical precipitation; aerosol reactions; biological templating), from processing of bulk precursors (mechanical attrition; crystallization from the amorphous state; phase separation), and from nature (biological systems).

The atomic-scale structures of nanophase materials play a dominant role in determining their properties. Among the primary topics discussed were grain boundaries and other interfaces between the constituent phases which make up the materials, the atomic defects, dislocations, and strains within the constituent grains, porosity among the grains and its control, and connectivity among grains and percolation through granular networks. The tremendous importance of the detailed chemical nature of the grain interfaces was clearly evident in several presentations and discussions. The ability to experimentally characterize this chemistry on the nanometer-length scales associated with nanophase materials is an important current challenge. Also, the degree of atomic order (local or short-range; mid-range; long-range) within the grains was discussed frequently and the ability to differentiate among these degrees experimentally was clearly a concern.
Grain size affects the properties of nanophase materials in many ways. These range from electronic and optical effects (so-called "quantum size effects") caused by spatial confinement of delocalized valence electrons to altered cooperative ("many body") atom phenomena, such as lattice vibrations and melting, to the suppression of such lattice-defect mechanisms as dislocation generation and migration in confined grain sizes. Various possibilities were discussed for creating nanophase materials with controlled grains sizes and, hence, unique or improved properties, which can impact our ability to engineer a wide variety of controlled optical, electrical, magnetic, mechanical, and chemical properties and create opportunities for their future technological applications to the good of society.
Main Lectures Given

X-Ray and Neutron Diffraction Studies of Nanostructured Materials
   Dr. Rainer Birringer, Universität des Saarlandes, Germany
Quantum Confine in Semiconductor Nanocrystals: Isolated Crystallites and Porous Silicon
   Dr. L. E. Brus, A T & T Bell Laboratories, USA
Mechanical Properties of Granular Solids and Multilayers
   Dr. Robert Cammarata, Johns Hopkins University, USA
Magnetic Granular Solids
   Dr. C. L. Chien, Johns Hopkins University, USA
Physical and Chemical Properties of High-Nucletarity Metal Cluster Compounds: Model Systems for Ultra-Small Particles
   Dr. Joseph de Jongh, Rijksuniversiteit Leiden, The Netherlands
Biological Applications
   Dr. D. P. E. Dickson, University of Liverpool, UK
Nanophase Materials by Mechanical Attrition
   Dr. H.-J. Fecht, Technical University of Berlin, Germany
Chemical Synthesis of Nanophase Materials
   Dr. K. Klabunde, Kansas State University, USA
Catalysis and Surface Chemistry
   Dr. K. Klabunde, Kansas State University, USA
Optical Properties of Granular Solids
   Dr. Jacques Lafait, L'Université Pierre et Marie Curie, France
Surface Magnetism of Nanometer Particles
   Dr. A. H. Morrish, University of Manitoba, Canada
Amorphous Magnetic Particles
   Dr. Steen Mørup, Technical University of Denmark, Denmark
Electronic Transport in Granular Metal Films (Theory)
   Dr. Ping Sheng, Exxon Research and Engineering Company, USA
Mechanical Properties of Nanophase Materials
   Dr. Richard Siegel, Argonne National Laboratory, USA
Gas Evaporation and Electron Microscopical Observations of Small Particles
   Dr. Anders Thølen, Technical University of Denmark, Denmark
Organizing Committee

Dr. G. C. Hadjipanayis (Director), University of Delaware, USA
Dr. R. W. Siegel (Co-director), Argonne National Laboratory, USA
Dr. A. Kostikas, Demokritos Research Centre, Greece
Dr. M. Muhammed, Royal Institute of Technology, Sweden

Publication

List of Participants

1. LECTURERS

A. H. Morrish
Department of Physics
University of Manitoba
Winnipeg, R3T 2N2
CANADA

S. Mørup
Laboratory of Applied Physics
Technical University of Denmark
DK-2800 Lyngby
DENMARK

Anders Thølen
Laboratory of Applied Physics LTF
Building 307
Technical University of Denmark
2800 Lyngby DK
DENMARK

Jacques Lafait
Laboratoire D'Optique des Solides
L'Université Pierre et Marie Curie
Boite 80 - 4, Place Jussieu
75252 Paris Cedex 05
FRANCE

Rainer Birringer
Universität des Saarlandes
Werkstoffwissenschaften und Fertigungstechnik
GEB. 43
W-6600 Saarbrücken
GERMANY

Hans J. Fecht
Technical University of Berlin
Institut of Materials Research
Hardenbergstrasse 36
W-1000 Berlin
GERMANY
L. J. de Jongh
Kamerlingh Onnes Laboratory
Der Rijksuniversiteit Leiden
Rostbus 9506
Leiden RA 2300
NETHERLANDS

D. P. E. Dickson
Oliver Lodge Laboratory
Department of Physics
University of Liverpool
P. O. Box 147
Liverpool L69 3BX, England
UNITED KINGDOM

L. E. Brus
AT & T Bell Laboratories
Materials Science & Engineering
Research Division 1A258
600 Mountain Avenue
Murray Hill, NJ 07974
USA

Robert C. Cammarata
Department of MS & E
102 Maryland Hall
Johns Hopkins University
Baltimore MD 21218
USA

C. L. Chien
Department of Physics
Charles & 34th Street
Johns Hopkins University
Baltimore, MD 21218
USA

K. J. Klabunde
Chemistry Department
Kansas State University
Manhattan, KS 66506
USA
2. ASI STUDENTS

A. Arrott
Simon Frazier University
Department of Physics
Burnaby, BC V5A 1S6
CANADA

Michel L. Trudeau
Hydro-Québec Research Institute
1800 Montée Ste-Julie
Varennes, Québec
CANADA

Franz Bodker
Department of Physics
Building 307
Technical University of Denmark
DK-2800 Lyngby
DENMARK

Seren Linderoth
Materials Department
Riso National Laboratory
P. O. Box 49
DK-4000 Roskilde
DENMARK
Michael S. Pedersen  
Laboratory of Applied Physics  
Building 307  
Technical University of Denmark  
DK-2800 Lyngby  
DENMARK

Muhail A. Sethi  
Laboratory of Applied Physics  
Building 307  
Technical University of Denmark  
DK-2800 Lyngby  
DENMARK

B. Barbara  
Laboratoire de Magnetisme Louis Neel  
BP1266, 38052 Grenoble  
CEDEX 9  
FRANCE

Michel Cauchetier  
Commissariat à l’Energie Atomique  
Centre d’Etudes de Saclay  
Services des Photons, Atomes et Molecules  
CEN Saclay - 91191 Gif. sur. Yvette CEDEX  
FRANCE

J. L. Dorman  
Laboratoire de Magnetism CNRS  
1 Pl. A. Briand  
92125 Meudon CEDEX  
FRANCE

Nathalie Herlin  
Commissariat à l’Energie Atomique  
Centre d’Etudes de Saclay  
Service des Photons, Atomes, et Molecules  
Centre d’Etudes de Saclay – Bat 522  
F-91 191 Gif/Yvette CEDEX  
FRANCE

Jean-Pierre Jolivet  
Chimie de la Matiere Condensee URACNRS 1466  
Université P. et M. Curie  
4 Place Jussieu T54 E5  
75 252 Paris  
FRANCE
Claude Monty  
Centre National de La Recherche Scientifique  
Laboratoire de Physique des Matériaux  
1, Place Aristide Briand, Bellevue  
92195 Meudon CEDEX  
FRANCE

Elisabeth Tronc  
Chimie de la Materire Condensee  
University Pierre et Marie Curie  
4, place Jussieu (T54-E5  
75252 PARIS CEDEX 05  
FRANCE

Wolfgang Dickenscheid  
Institut fur Werkstoffphysik  
FB 15  
W6600 Saarbrucken  
GERMANY

Volker Haas  
Universitat des Saarlandes  
FB 15  
Gebaeude 43  
D-6600 Saarbrucken  
GERMANY

H. W. Hahn  
Technische Universitat Darmstadt  
FB21 - Material Wissenschast  
Fachgebiet Duene  
Schichten Hilperstr. 31  
D-6100 Darmstadt  
GERMANY

Herbert Hofmeister  
Max-Planck-Institut fur Mikrostrukturphysik  
Weinberg 2  
D-0-4050 Halle/Saale  
GERMANY

Peter Hockel  
FB 15, Gebaeude 43  
Universitat des Saarlandes  
W-6600 Saarbrucken  
GERMANY
A. Kehrel
Technische Universität Berlin
Institut für Metallforschung
Metallphysik
Hardenbergstr. 36
1000 Berlin 12
GERMANY

Heike Konrad
FB 15, Geb. 43
Universität des Saarlandes
D-6600 Saarbrücken
GERMANY

Carl E. Krill
FB 15 Werkstoffwissenschaften
Universität des Saarlandes
Gebäude 43
W-6600 Saarbrücken
GERMANY

H. Micklitz
11 Physikalisches Institut
Universität zu Köln 41
Sielpicher Str. 77
5000 Köln 41
GERMANY

H.-E. Schaefer
Institut für Theoretische und Angewandte Physik
Universität Stuttgart
Pfaffenwaldring 57/VI
7000 Stuttgart 80
GERMANY

Ursel Wagner
Physik Department #15
Technische Universität München
D8046-Garching
GERMANY

Ashraf Yussouff
Fakultät für Physik
LS Dieterich
Universität Konstanz
7750 Konstanz
GERMANY
D. Nicolaides
Institute of Materials Science
"Demokritos" National Research Center for Physical Sciences
153 10 ag. Paraskevi Attiki
P.O.B. 60228
GREECE

Ioannis Panagiotopoulos
Department of Physics
The University of Ioannina
P. O. Box 1186 GR-451 10
Ioannina
GREECE

Vassilios Papaefthymiou
Department of Physics
The University of Ioannina
P. O. Box 1186 GR-451 10
Ioannina
GREECE

G. C. Papavasiliou
Department of Physics
The University of Ioannina
P. O. Box 1186 GR-451 10
Ioannina
GREECE

D. Petrides
Department of Physics
The University of Ioannina
P. O. Box 1186 GR-451 10
Ioannina
GREECE

K. Soukoulis
Department of Physics
University of Crete
Iraklion
GREECE

Padelis Trikalitis
Department of Physics
The University of Ioannina
P. O. Box 1186 GR-451 10
Ioannina
GREECE
P. Trohidou
Institute of Materials Science
"Demokritos" National Research Center for Physical Sciences
153 10 ag. Paraskevi Attiki
P.O.B. 60228
GREECE

C. Volteras
Department of Physics
The University of Ioannina
P. O. Box 1186 GR-451 10
Ioannina
GREECE

Giovanni Asti
University of Parma
Dpto. Di Fisica, V. Le Dell Scienze
43100 Parma
ITALY

Diego Bassett
Dipartimento di Scienze e Tecnologie Chimiche
Università degli Studi di Udine
Vio Cotonificio 108
I-33100 Udine
ITALY

D. Fiorani
ICMAT - Area della Ricerca di Roma
V. Salaria 29.5
C. p. 10 - 00016 Monterodondo Stazione (Roma)
ITALY

Federica Malizia
Universita di Ferrara - Dipartimento di Fisica
Via Paradiso 12
1-44100 Ferrara
ITALY

José Maria Fonte Ferreira
Departamento de Engenharia Cerâmica e do Vidro
Universidade de Aveiro
3800 Aveiro
PORTUGAL
Pedro Gorria Korres  
Instituto de Magnetismo Aplicado  
Apdo. Correos 155  
28230 Las Rosas  
Madrid  
SPAIN

A. Hernando  
Instituto de Magnetismo Aplicado  
RENFE-UCM  
P. O. Box 155, Las Rozas  
Madrid 28230  
SPAIN

Juan S. Muñoz  
Departament de Física  
Universitat Autònoma de Barcelona  
Edifici C  
08193 Bellaterra (Barcelona)  
SPAIN

J. Navarro  
Instituto de Magnetismo Aplicado  
RENFE-UCM  
P. O. Box 155, Las Rozas  
Madrid 28230  
SPAIN

X. X. Zhang  
Departament de Física Fonamental  
Universitat de Barcelona  
Av. Diagonal, 647  
E-08028 Barcelona  
SPAIN

H. A. Davies  
University of Sheffield  
School of Materials  
P. O. Box 600, Sir Robert Hadfield Bldg.  
Mappin Street  
Sheffield S1 4DU  
UNITED KINGDOM
Andreas Lyberatos
Physics Department
Keele University
Keele, Staffordshire ST5 5BG
UNITED KINGDOM

Pantelis Alexopoulos
IBM Almaden Research Center
650 Harry Road, K64–807
San Jose, CA 95120
USA

Paul Alivisatos
Department of Chemistry
University of California
Berkeley, CA 94720
USA

Richard Ambroze
Department of Physics
Charles & 34th Street
Johns Hopkins University
Baltimore, MD 21218
USA

Ami Berkowitz
Department of Physics and Center for Magnetic
Recording Research, 0401
University of California, San Diego
LaJolla, CA 92–92
USA

Altaf H. Carim
Dept. of Materials Sciences & Engineering
Pennsylvania State University
118 Steidle Building
University Park, PA 16802
USA

Jian-Ping Chen
Physics Department
Kansas State University
Manhattan, KS 66506
USA

Aris Christou
Dept. of Mechanical Engineering
University of Maryland
College Park, MD 20742–3035
USA
Siu-Tat Chui  
Bartol Research Institute  
University of Delaware  
217 Sharp Laboratory  
Newark, DE 19716  
USA

Brian Elliott  
Department of Materials Science  
Northwestern University  
Materials and Life Sciences Facility (MLSF)  
2225 N. Campus Drive  
Evanston, IL 60208-3108  
USA

Alan S. Edelstein  
Naval Research Laboratory  
Materials Science & Technology 6371  
4555 Overlook Avenue, S. W.  
Washington, DC 20375-5000  
USA

Aniruddh Fadnis  
117 Swain West  
Indiana University  
Bloomington, IN 47405  
USA

Charles M. Falco  
Optical Sciences Center  
University of Arizona  
Tucson, AZ 85721  
USA

E. P. Giannelis  
Cornell University  
Department of MS&E  
Bard Hall  
Ithaca, NY 14853  
USA

Gretchen E. Fougere  
Argonne National Laboratory  
Materials Science Division, Building 212, C-206  
9700 South Cass Avenue  
Argonne, IL 60439  
USA
Puru Jena
Physics Department
Virginia Commonwealth University
Box 2000
Richmond, VA 23284
USA

Samuel Jiang
Department of Physics
Charles & 34th Street
Johns Hopkins University
Baltimore, MD 21218
USA

Richard Kodama
Magnetic Recording Center
University of California at La Jolla
La Jolla, CA 92039
USA

Olga Koper
Chemistry Department
Kansas State University
Manhattan, KS 66506
USA

Xu-Hua Lin
Department of Physics and Astronomy
University of Delaware
Newark, DE 19716
USA

Jeffrey Long
Department of Chemistry
Harvard University
12 Oxford Street
Cambridge, MA 02138
USA

Kathy Mohs
Chemistry Department
Kansas State University
Manhattan, KS 66506
USA

Dimitrios A. Papaconstantopoulos
Naval Research Laboratory
Code 4600
4555 Overlook Avenue, SW
Washington, DC 20375-5000
USA
Andreas Tschoepe  
Massachusetts Institute of Technology  
Department of Chemical Engineering  
25 Ames Street, Room # 66-557  
Cambridge, MA 02139  
USA

Karl M. Unruh  
Department of Physics and Astronomy  
University of Delaware  
Newark, DE 19716  
USA

Omar M. Yaghi  
Department of Chemistry and Biochemistry  
Arizona State University  
Tempe, AZ 85281-1604  
USA

Jackie Y. Ying  
Department of Chemical Engineering  
Room 66-544  
Massachusetts Institute of Technology  
Cambridge MA 02139-4307  
USA

Iovka D. Dragieva  
Faculty of Physics  
Sofia University  
5 Anton Ivanov Boulevard  
BH-1126 Sofia  
BULGARIA

J. Geshev  
Faculty of Physics  
Sofia University  
5 Anton Ivanov Boulevard  
BH-1126 Sofia  
BULGARIA

Yana Kostova Athanasova  
Faculty of Physics  
Sofia University  
5 Anton Ivanov Boulevard  
BH-1126 Sofia  
BULGARIA

Imre Bakonyi  
Research Inst. for Solid State Physics  
Hungarian Academy of Sciences  
H-1525 Budapest, P. O. B. 49  
HUNGARY

22
G. I. Márk  
Central Research Institute for Physics  
P. O. Box 49  
H-1525 Budapest  
HUNGARY

Anna Slawska-Waniewska  
Institute of Physics  
Polish Academy of Sciences  
Al. Lotnikow 32/46  
02-668 Warszawa  
POLAND

Elena D. Obraztsova  
Department of Physics  
Moscow State University  
119899 Moscow  
RUSSIA

Rouslan Z. Valiev  
Institute of Metals Superplasticity Problems  
Russian Academy of Sciences  
Khalturina 39  
Ufa 450001  
RUSSIA

Mamoun Muhammed  
Inorganic Chemistry  
Royal Institute of Technology  
S-10044 Stockholm  
SWEDEN
The Institute covered a broad spectrum of topics from the disciplines of physics, chemistry, biology and materials science that comprise the developing field of nanophase materials. The nature of nanophase materials and the fundamental criteria for their synthesis were elucidated.

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