Final Report

NANOPHASE MATERIALS: SYNTHESIS — PROPERTIES — APPLICATIONS

NATO Advanced Study Institute (ASI) 920873
20th June - 2nd July, 1993, Corfu, Greece

Submitted to:

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NANOPHASE MATERIALS: SYNTHESIS — PROPERTIES — APPLICATIONS
NATO Advanced Study Institute (ASI) 920873
20th June - 2nd July, 1993, Corfu, Greece

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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 varous 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-Nuclearity 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 Thölen, Technical University of Denmark, Denmark

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Dr. A. Kostikas, Demokritos Research Centre, Greece

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Publication

Nanophase Materials: Synthesis — Properties — Applications, G. C. Hadjipanayis and R. W. Siegel, eds., Kluwer Academic Press, Dordrecht, The Netherlands (1994).

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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.

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