

*WTEC Panel on*

## **NANOSTRUCTURE SCIENCE AND TECHNOLOGY**

### **R&D Status and Trends in Nanoparticles, Nanostructured Materials, and Nanodevices**

#### **FINAL REPORT**

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## WTEC PANEL ON NANOPARTICLES, NANOSTRUCTURED MATERIALS, AND NANODEVICES

Sponsored by the National Science Foundation, the Air Force Office of Scientific Research, the Office of Naval Research, the Department of Commerce, the Department of Energy, the National Institutes of Health, and the National Aeronautics and Space Administration of the United States Government.

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## INTERNATIONAL TECHNOLOGY RESEARCH INSTITUTE World Technology (WTEC) Division

WTEC at Loyola College (previously known as the Japanese Technology Evaluation Center, JTEC) provides assessments of foreign research and development in selected technologies under a cooperative agreement with the National Science Foundation (NSF). Loyola's International Technology Research Institute (ITRI), R.D. Shelton, Director, is the umbrella organization for WTEC. Paul Herer, Senior Advisor for Planning and Technology Evaluation at NSF's Engineering Directorate, is NSF Program Director for WTEC. Several other U.S. government agencies provide support for the program through NSF.

WTEC's mission is to inform U.S. scientists, engineers, and policymakers of global trends in science and technology in a manner that is timely, credible, relevant, efficient, and useful. WTEC's role is central to the government's effort to measure its performance in science and technology. WTEC assessments cover basic research, advanced development, and applications. Panels of typically six technical experts conduct WTEC assessments. Panelists are leading authorities in their field, technically active, and knowledgeable about U.S. and foreign research programs. As part of the assessment process, panels visit and carry out extensive discussions with foreign scientists and engineers in their labs.

The ITRI staff at Loyola College help select topics, recruit expert panelists, arrange study visits to foreign laboratories, organize workshop presentations, and finally, edit and disseminate the final reports.

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## **ABSTRACT**

This report reviews the status of research and development in nanoparticles, nanostructured materials, and nanodevices worldwide, with particular focus on comparisons between the United States and other leading industrialized countries. Topics covered include particle synthesis and assembly, dispersions and coatings of nanoparticles, high surface area materials, functional nanoscale devices, bulk behavior of nanostructured materials, and biological methods and applications. The final chapter is a review of related government funding programs around the world. The report also includes site reports for visits conducted by the panel to leading research laboratories in Japan and Europe. The panel held workshops in the United States, Germany, Sweden, and Russia to gather additional information for this report on activities in those countries. The proceedings of the U.S. and Russia workshops are being published separately by WTEC. The panel's conclusions include the following: (1) In the synthesis and assembly area (Chapter 2), the U.S. appears to be ahead with Europe following and then Japan; (2) In the area of biological approaches and applications (Chapter 7), the U.S. and Europe appear to be rather on a par with Japan following; (3) In nanoscale dispersions and coatings (Chapter 3), the U.S. and Europe are again similar with Japan following; (4) For high surface area materials (Chapter 4), the U.S. is clearly ahead of Europe and then Japan; (5) In the nanodevices area (Chapter 5), Japan seems to be leading quite strongly with Europe and the U.S. following; In the area of consolidated materials (Chapter 6), Japan is a clear leader with the U.S. and Europe following. These and other conclusions are reviewed in detail in the panel's executive summary.

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Sincerely,

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## Foreword

Timely information on scientific and engineering developments occurring in laboratories around the world provides critical input to maintaining the economic and technological strength of the United States. Moreover, sharing this information quickly with other countries can greatly enhance the productivity of scientists and engineers. These are some of the reasons why the National Science Foundation (NSF) has been involved in funding science and technology assessments comparing the United States and foreign countries since the early 1980s. A substantial number of these studies have been conducted by the World Technology Evaluation Center (WTEC) managed by Loyola College through a cooperative agreement with NSF. The National Science and Technology Council (NSTC), Committee on Technology's Interagency Working Group on NanoScience, Engineering and Technology (CT/IWGN) worked with WTEC to develop the scope of this Nanostucture Science and Technology report in an effort to develop a baseline of understanding for how to strategically make Federal nanoscale R&D investments in the coming years.

The purpose of the NSTC/WTEC activity is to assess R&D efforts in other countries in specific areas of technology, to compare these efforts and their results to U.S. research in the same areas, and to identify opportunities for international collaboration in precompetitive research.

Many U.S. organizations support substantial data gathering and analysis efforts focusing on nations such as Japan. But often the results of these studies are not widely available. At the same time, government and privately sponsored studies that are in the public domain tend to be "input" studies. They enumerate inputs to the research and development process, such as monetary expenditures, personnel data, and facilities, but do not provide an

assessment of the quality or quantity of the outputs obtained. Studies of the outputs of the research and development process are more difficult to perform because they require a subjective analysis performed by individuals who are experts in the relevant scientific and technical fields. The NSF staff includes professionals with expertise in a wide range of disciplines. These individuals provide the expertise needed to assemble panels of experts who can perform competent, unbiased reviews of research and development activities. Specific technologies such as telecommunications, biotechnology, and nanotechnology are selected for study by government agencies that have an interest in obtaining the results of an assessment and are able to contribute to its funding. A typical WTEC assessment is sponsored by several agencies.

In the first few years of this activity, most of the studies focused on Japan, reflecting interest in that nation's growing economic prowess. Then, the program was called JTEC (Japanese Technology Evaluation Center). Beginning in 1990, we began to broaden the geographic focus of the studies. As interest in the European Community (now the European Union) grew, we added Europe as an area of study. With the breakup of the former Soviet Union, we began organizing visits to previously restricted research sites opening up there. Most recently, studies have begun to focus also on emerging science and technology capabilities in Asian countries such as the People's Republic of China.

In the past several years, we also have begun to substantially expand our efforts to disseminate information. Attendance at WTEC workshops (in which panels present preliminary findings) has increased, especially industry participation. Representatives of U.S. industry now routinely number 50% or more of the total attendance, with a broad cross-section of government and academic representatives making up the remainder. Publications by WTEC panel members based on our studies have increased, as have the number of presentations by panelists at professional society meetings.

The WTEC program will continue to evolve in response to changing conditions. New global information networks and electronic information management systems provide opportunities to improve both the content and timeliness of WTEC reports. We are now disseminating the results of WTEC studies via the Internet. Over 25 of the most recent WTEC final reports are now available on the World Wide Web (<http://itri.loyola.edu>) or via anonymous FTP ([ftp.wtec.loyola.edu/pub/](ftp:wtec.loyola.edu/pub/)).

As we seek to refine the WTEC activity, improving the methodology and enhancing the impact, program organizers and participants will continue to operate from the same basic premise that has been behind the program from its inception, i.e., improved awareness of international developments can significantly enhance the scope and effectiveness of international

collaboration and thus benefit the United States and all its international partners in collaborative research and development efforts.

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# Contents

Foreword	i
Table of Contents	v
Executive Summary	xiii
1. Introduction and Overview <i>RICHARD W. SIEGEL</i>	1
2. Synthesis and Assembly <i>EVELYN L. HU AND DAVID T. SHAW</i>	15
3. Dispersions and Coatings <i>JOHN MENDEL</i>	35
4. High Surface Area Materials <i>DONALD M. COX</i>	49
5. Functional Nanoscale Devices <i>HERB GORONKIN, PAUL VON ALLMEN, RAYMOND K. TSUI, AND THEODORE X. ZHU</i>	67
6. Bulk Behavior of Nanostructured Materials <i>CARL KOCH</i>	93

7. Biologically Related Aspects of Nanoparticles, Nanostructured Materials, and Nanodevices <i>LYNN JELINSKI</i>	113
8. Research Programs on Nanotechnology in the World <i>M.C. ROCO</i>	131
Appendix A. Biographies of Panelists and Other Team Members	151
Appendix B. Site Reports—Europe	159
Appendix C. European Roundtable Discussions	221
Appendix D. Site Reports—Japan	243
Appendix E. Site Reports—Taiwan	313
Appendix F. Glossary	327

## List of Figures

1.1	Organization of nanostructure science and technology and the WTEC study.	5
2.1	Schematic of variety of nanostructure synthesis and assembly approaches.	16
2.2	Interactive cycle of characterization, understanding and enhanced control in the synthesis and assembly of nanostructures.	18
2.3	TEM images of (a) the lamellar morphology, (b) the cubic phase with Ia3d symmetry viewed along its [111] zone axis, and (c) the hexagonal phase viewed along its [001] zone axis of the silica/surfactant nanostructured composites by co-assembly (McGehee et al. 1994) (bars = 30 nm).	26
2.4	TEM image of unlinked cluster array of 3.7 nm Au clusters encapsulated by dodecanethiol (Andres et al. 1998).	27
2.5	Array of InAs quantum dot structures grown on GaAs substrates (Mirin et al. 1996).	27
2.6	Variation of optical transparency with diameter of chemically synthesized CdSe nanocrystals (Alivisatos 1996).	27
2.7	A sequence of 670 nm by 670 nm AFM images taken during the manipulation of a 50 nm Au particle into the gap between two Au/Ti electrodes (Junno et al. 1998).	30
3.1	Transparency as a function of particle size (courtesy, Nanophase).	42

4.1	Schematic drawing of the experimental setup used in Göteborg for studies of chemical reactivity and/or sticking probability of various molecules with the clusters. The production of clusters is via laser vaporization of metal substrates and detection via photo-ionization time-of-flight mass spectrometry. (A. Rosen, University of Göteborg, Sweden.)	53
4.2	Effect of moisture on conversion profiles for CO oxidation over $\text{Co}_3\text{O}_4$ and $\text{Au}/\text{Co}_3\text{O}_4$ .	54
4.3	Hydrodesulfurization reaction. Selective catalysis is controlled by either the edge or rim of $\text{MoS}_2$ . (Chianelli 1998).	56
4.4	Hydrogen absorption-desorption characteristics for mixture of Mg and $\text{Mg}_2\text{Ni}$ prepared by mechanical alloying.	57
4.5	Typical zeolite structures together depicting the positions of the O atoms (vertices in upper figure) and two different zeolitic structures one (a) with a three dimensional structure and (b) a zeolite with a two dimensional channel structure.	58
4.6	Examples of carbon nanotube structures, including multiwalled and metal-atom-filled nanotubes.	61
5.1	Functional device scales.	68
5.2	Metal colloids, self-assembled monolayer (SAM) coatings, polysilicon, quantum dots embedded in $\text{SiO}_2$ (Hitachi, IBM, RIKEN, NTT, ETL, University of Lund).	71
5.3	Sidewall extensions of MOSFET gate (Toshiba).	71
5.4	Oxidation of metal or semiconductor with scanning tunneling microscope (STM) tip (ETL).	71
5.5	STM probe oxidation of metal on vicinal substrate steps (ETL).	71
5.6	Double barrier tunnel diode structure (Max-Planck-Institut, Stuttgart; NTT).	72
5.7	Gated double barrier tunnel diode structure (Max-Planck-Institut, Stuttgart; NTT; Purdue University).	72
5.8	Depletion layer control of 2DEG area (Hitachi, University of Glasgow, University of Tokyo).	72
5.9	Tetrahedral shaped recess, TSR (Fujitsu).	73
5.10	Double barrier metallic SET patterned by e-beam (NEC).	73
5.11	A single molecule connecting metallic contacts (Yale University, University of South Carolina, Delft University, Karlsruhe University).	74

5.12	Granular GMR—Co, Fe (Nagoya University, Tohoku University, CNRS-Thomson, UCSB, UCSD).	78
5.13	Current in plane (Matsushita, Fujitsu, Mitsubishi, Toshiba, Hitachi, Thomson, Philips, Siemens, IBM, Univ. Regensburg, IMEC, Nagoya University, Tohoku University, NIST).	78
5.14	Magnetic tunnel junction (IBM, MIT, HP, Tohoku University).	78
5.15	Ferromagnetic/metal/ferromagnetic: 3 - 60 periods free-standing (NRL, CNRS-Thomson, Philips, Michigan State, Lawrence Livermore Labs); plated into pores (L'École Polytechnique Fédérale de Lausanne, Johns Hopkins University, Université Catholique Louven).	79
5.16	Schematic of a semiconductor laser.	83
5.17	Density of electronic states as a function of structure size.	83
6.1	Ratio of the Young's (E) and shear (G) moduli of nanocrystalline materials to those of conventional grain size materials as a function of grain size. The dashed and solid curves correspond to a grain boundary thickness of 0.5 and 1 nm, respectively (Shen et al. 1995).	96
6.2	Elongation to failure in tension vs. grain size for some nanocrystalline metals and alloys.	98
6.3	Effective permeability, $\mu_e$ , vs. saturation magnetic flux density, $B_s$ , for soft ferromagnetic materials (after A. Inoue 1997).	105
7.1	Organization of the WTEC study; sections with large biological content are indicated.	114
7.2	Top: a 36-mer protein polymer with the repeat sequence (alanine-glycine) <sub>3</sub> – glutamic acid – glycine. Bottom: idealized folding of this protein polymer, where the glutamic acid sidechains (+) are on the surface of the folds.	115
7.3	Idealized truncated octahedron assembled from DNA. This view is down the four-fold axis of the squares. Each edge of the octahedron contains two double-helical turns of DNA.	117
7.4	An elastomeric stamp (top left) is made from an original master (bottom left). The stamp is dipped into the biological material (top right) and the pattern is transferred to the substrate (bottom right).	119
7.5	Mushroom-shaped clusters formed from self-assembly of rod-coil molecules; these clusters can undergo further packing to form sheets.	119

- 7.6 Novel combinations of DNA, metal ligands, DNA templating, and proteins are being investigated for molecular wires, inductors, and switches (photo courtesy of Shionoya and coworkers, Inst. for Molecular Science). 123

## List of Tables

ES.1	Technological Impact: Present and Potential	xvi
ES.2	Comparison of Activities in Nanostructure Science and Technology in Europe, Japan, and the United States	xvii
3.1	Nanoparticle Preparation for Dispersions/Coatings	40
3.2	Particle Properties	42
3.3	Dispersions and Coatings—Nanotechnology Comparisons Between the United States, Europe, and Japan	46
4.1	Zeolite Channel “Window” Dimension for Number of Oxygens in Ring	59
5.1	SET Architectures	75
5.2	Quantum Dot Flash Memory	75
5.3	Giant Magnetoresistance Activities	77
5.4	Summary of Quantum Dot Laser Results	85
5.5	Nanotube Fabrication Methods	87
5.6	Electrical and Field Emission Properties of Nanotubes	88
7.1	Comparisons between Japan, Europe, and the United States in Biologically Related Aspects of Nanotechnology	127
8.1	Support for Nanotechnology Research from U.S. Federal Agencies in 1997	133
8.2	Government Expenditures on Nanotechnology Research in 1997, Based on the WTEC Site Interviews	147

