Essay

Vapor-Phase Synthesis and Processing of Nanoparticle Materials (NANO)

By Heinz J. Fissan* and Joop Schoonman

The scientific and technological issues of nanostructured particles and materials are currently attracting considerable attention. The reason for this is that nanostructured particles and materials, and the physical or chemical combination of substances at the nanometer or subnanometer scale, can lead to innovative materials with improved or even unexpected properties. Applications which could have a great impact can be anticipated in fields like catalysis, technical ceramics, membrane technology, optoelectronics, and solid-state ionics with emphasis on systems for clean energy conversion and storage. However, progress in these fields will largely depend on the pace of advance of the fundamental research on nanostructured particles and materials in solid-state chemistry, solid-state physics, and materials science.

In principle, the synthesis routes pursued today for the generation of nanostructured and nanocomposite particles and materials are based either on special solution processing techniques which have been derived from established solution chemistry, or on newly developed gas-phase deposition methods.

In solution processing, the possible combinations of constituents for the synthesis of mainly oxidic materials is restricted. Deposition from a vapor phase mixture of the components through gas-phase techniques is more versatile, and widely applicable, as gas-phase techniques can be applied to nearly any material.

The new gas-phase synthesis route makes it possible to generate new nanoparticles and nanostructured new materials from, in principle, a nearly unlimited variety of starting materials. The starting-point of the gas-phase synthesis of nanostructured materials is the generation of gas-born nano-sized particles. Such a particle system represents an aerosol. Over the past decade, aerosols occurring in other disciplines have been studied in detail, especially the formation of these gas-born nanoparticles, their characterization, as well as their handling. Aerosol researchers, in particular in the United States, are now starting to

apply this aerosol expertise to the field of nanostructured materials development. Also, materials scientists in the US have begun to use aerosol formation processes for the creation of materials with improved or new properties, i.e., for the "synthesis of material properties".

In order to promote research activities in nanostructured particles and materials, bridges between the aerosol community and the materials science community are a prerequisite. This was the main conclusion of the ESF-Exploratory Workshop on Aerosol Methods and Advanced Techniques for Nano-Particle Science and Nano-Powder Technology, held in Duisburg, October 1993, on the recommendation of the ESRC ad hoc Group on Technical Sciences. Further discussions among interested groups resulted in the formation of the NANO initiative, sponsored by the ESF, the activities of which are described below.

The Program was approved by the ESF Executive Council in November 1994 for a period of five years from January 1995. The chairmen of the program are Professor Fissan, University of Duisburg, Germany, and Professor Schoonman, Delft University, The Netherlands. There are more than twenty groups in different countries in Europe involved. The program is organized by a steering group and funds are available for the travel expenses for meetings of different groups involved in the program. The exchange of students and researchers is also supported. The funds stem from contributions from institutions supporting research in several European countries.

In connection with its annual meeting, the Steering Committee organizes a one-day Scientific Program Meeting at which each Task Force will report on its "Theme". The Program Meetings will be linked to the European Aerosol Conference and the International Conference on Nanostructured Materials. A 'mid-term review' is planned after the first three years. In the light of that review, the research themes and format of the Program may be adjusted.

The members of the steering group are:

Prof. B. Briscoe	London, UK
Prof. J. O. Carlsson	Uppsala, Sweden
Prof. H. Gleiter	Karlsruhe, Germany
Prof. M. Grätzel	Lausanne, Switzerland
Prof. J.-C. Joubert	Saint Martin d'Hères, France
Dr. E. I. Kauppinen	Espoo, Finland
Dr. H. U. Karow	Strasbourg, France
Prof. R. Winand	Brussels, Belgium

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The next meeting of the steering and working groups is on the occasion of the European Aerosol Conference (EAC '96) in Delft, 9–12 September, 1996.

The scientific thrust of the research is the synthesis of ceramic aerosols and films using gas phase techniques, with the aim of generating single-phase, or nanodispersed structural ceramic materials and electroceramics with new or improved properties. The research themes (see below) concentrate on fundamental research problems needed to be solved for optimal synthesis in the gas phase of nanoparticles and nanostructured materials with tailored microstructures.

Those interested in further details or in participation should contact the authors of this article.

Theme 1: Nanoparticle Synthesis in the Gas Phase

In order to achieve the desired properties of the nanostructured materials it is necessary to generate appropriate properties in the primary particles formed in the gas phase. Important properties are particle size and shape, as well as chemical composition, phase and crystallinity. In aerosol science, several techniques for particle synthesis have been developed and investigated in the past.

The most promising processes will be investigated in more detail by developing theoretical models and performing experiments. Since several processes as well as several sets of materials requirements are involved, it is important to perform this investigation on a broad basis such as that provided through the ESF Program.

Theme 2: Characterization in the Gas Phase

As mentioned above, the properties of nanostructured materials are strongly dependent on the properties of the primary particles in the gas phase. Therefore, and also to understand the formation processes, the particles have to be characterized in the gas phase. For process control purposes, on line and in situ techniques are of great importance; these will be developed.

Theme 3: Development of Particle Collection Processes

To form a nanostructured material from the particles formed in the gas phase, the nanoparticles need to be collected from the

gas phase. Several separation processes are being developed and investigated. Both theoretical modeling and experiments work will determine the parameters governing the collection processes, and this will promote the control as well as the optimization of the processes.

Theme 4: Interfacing Materials & Aerosol Science

The program will be successful if the various disciplines are properly interfaced. Therefore, special emphasis is put on developing communicative tools and definitions. This interfacing can only be achieved if scientists from the different disciplines are brought together, share their experience and expertise, and adjust their terminology.

Theme 5: Nanostructured Materials and Applications

The discovery of new materials and methods for the synthesis and processing is crucial to the advancement of clean energy conversion and storage systems. While this holds true also for other technologies, the main emphasis in this ESF program is on nanostructured materials for application in rechargeable batteries, HT ceramic fuel cells and solar cells.

The synthesis methods and tailored (micro)structures to be developed within this ESF Program are by no means limited to the class of electroceramic and semiconducting materials. The participants should, as a spin-off, be able to translate the insights gained in order to benefit other applications.

Theme 6: Chemical and Physical Properties

The compositions of the nanoparticles and the nanostructured materials will be determined using a variety of non-destructive microanalytical techniques: energy dispersive X-ray fluorescence, secondary ion mass spectroscopy, Rutherford backscattering, and X-ray photoelectron spectroscopy. The microstructure of the nanostructured materials will be investigated by transmission and scanning electron microscopy (TEM, SEM) and atomic force microscopy (AFM). X-ray diffraction and extended X-ray absorption fine-structure measurements will determine the atomic structure of, possibly amorphous, nanoparticles and nanostructured materials. Determination of the properties will strengthen the interfacing between the disciplines.

Heinz Fissan is Director of Process and Aerosol Measurement Technology Division, Electrical Engineering Department, University of Duisburg, Germany. He studied engineering at the RWTH Aachen and habilitated in 1974. His research interests, apart from nanostructured materials, include aerosol technology, particles in flames and other combustion processes, and contaminant-free processing technology. He has published over 180 papers and books and has been awarded the International Aerosol Fellow Award, and the Max Planck Forschungspreis.