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Nanomaterials in Extreme Environments

Fundamentals and Applications

Springer

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Foreword

Most of today's technologies depend on the availability of materials with specific properties, such as high strength, light weight, specific electronic properties, superconductivity, and many others. The development of all of these materials may be divided into two periods of time. The first period is characterized by the discovery of a new effect or the proposal of a conceptually new idea. This initial period involves a small number of scientists who focus primarily on exploring the discovery or the new concepts. Their work is in most cases characterized by close interactions among the scientists involved.

During the second period of development, the number and the breadth of the studies performed and the diversity of methods applied increases significantly. This change results in a rapidly growing body of knowledge about the new field. This knowledge provides the basis for the development of a fundamental understanding of the results obtained so far. On the other hand, this fundamental understanding is the prerequisite for the following two developments: (1) the design of further studies deepening and broadening our understanding and (2) the recognition of conceivable technological applications.

In the history of nanomaterials, the two periods of development mentioned above are clearly born out. In 1979, the new concept of nanomaterials was proposed. The basic idea was to create crystalline materials consisting of a large (50 % or more) volume fraction of intercrystalline interfaces. As the arrangements of atoms in intercrystalline interfaces differ from the ones in the corresponding crystals and glasses, it was suggested that nanostructured materials would open the way to materials with new atomic structures and hence new properties. When this concept was confirmed by the pioneering studies during the early 1980s, the number of publications increased rapidly. In fact, today more than 300 papers related to all kinds of nanoscale effects published daily and in 2014 more than 120,000 publications in this young field of Science/Technology were retrieved by the Science Citation Index Expanded.

As a consequence, further progress in the area of nanomaterials depends critically on the availability of overviews in which the wide spectrum of the rapidly growing number of new results is presented within a limited number of pages, and in a critical way. In fact, the crucial tasks of these overviews have to be (1) to focus on the new insights gained by the newly published papers and (2) to create the "shoulders" on which the next generation of researchers can safely stand, when they try to look beyond the presently existing limits. Clearly, overviews of this type have to cover a wide spectrum of aspects, extending from different atomic, electronic, and chemical structures of nanomaterials all the way to thermodynamic aspects (such as questions of their stability, their kinetic properties, etc.), the various types of interactions with their environments (e.g., optical, chemical, electric, and other ones) and, moreover, it has to include the wide variety of specific nanostructured solids, such as fullerenes, nanotubes, polymeric nanostructures, nanoglasses, etc. So far, no overview seems available covering all of these aspects. The overview presented by Prof. Rostislav Andrievski and Dr. Arsen Khatchoyan is a first and important step in this direction. Their ability to review a significant portion of the field of nanomaterials is clearly evidenced by the contributions they have made in the past. In fact, Prof. R. Andrievski is well known as an editor and an author of international reputation in the area of nanomaterials and Dr. A. Khatchoyan made himself a name as a translator. In view of the rapid growth of this field, a review of this kind seems of particular importance for the next generation of scientists who try to work in that area. For all of them, there is still "plenty of room at the bottom." However, it will be the task of the further generations to find their way through the "room at the bottom" and to discover some of the fascinating effects that are still waiting there for all of us. Certainly, important navigational tools for these expeditions into "the room at the bottom" will be overviews of the kind presented by Prof. Andrievski and Dr. Khatchoyan.

Karlsruhe, Germany Prof. Dr. Dr. h.c. mult Herbert Gleiter

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About the Authors

Prof. Rostislav A. Andrievski Dr. Sci. (Materials Science) is a Principal Scientist at the Institute of Problems of Chemical Physics, Russian Academy of Science. He was born in 1933. He graduated from Kiev Polytechnic Institute, Department of Metal Science and Powder Metallurgy, and received his Ph.D. here in 1959 (Thesis “Sintering of Metal Powders”). From 1959 to 1962, Dr. Andrievski worked as a Senior Scientist at the Institute of Metal-Ceramics and Special Alloys, Ukrainian Academy of Sciences (Kiev). From 1963 up to 1976, Dr. Andrievski worked as a Head of Department of Materials Science at the Podolsk Technological Institute. He received his Doctorate at the Moscow All-Union Institute of Inorganic Materials in 1969 (topic of dissertation “Diffusion and Creep in Carbides and Nitrides”). From 1977 to 1984, he worked as Professor at the Moscow Lomonosov Institute of Fine Chemical Technology, Department of Refractory Compounds. In 1984, he was elected Corresponding Member of the Kirghiz Academy of Sciences and worked as Deputy Director of the Institute of Physics in Frunze (now Bishkek). Since 1990 and currently, Dr. Andrievski works at the Institute of Problems of Chemical Physics located in Chernogolovka, near Moscow. His main scientific interests are physics, chemistry, and technology of materials-based high-melting point compounds (such as carbides, nitrides, borides, oxides, etc.) as well as hydrides, especially in nanocrystalline state.

He has authored over 470 publications including 11 monographs (in Russian), 70 reviews, and 90 papers in reviewed foreign Journals and Proceedings. According to SCOPUS data, his Hirsch Index is 20 and Citation Index CI is 1450. He is a Supervisor of 33 Ph.D. theses and a Consultant of six Doctors of Sciences. Dr. Andrievski is a member of four International Editorial Boards and four of those are Russian, as well as a Guest Editor of three special Issues on nanomaterials in International Journals. He is a Member of the Materials Research Society (USA) and a Full Member of the International Institute for the Science of Sintering

(Serbia). Professor Andrievski was invited as a guest lecturer in a number of foreign Universities, such as Limoges University (France), Coimbra University (Portugal), Ben-Gurion University (Israel), Harbin Institute of Technology (China), and Indian Institute of Technology Kanpur (India). He is a well-known specialist in the field of size effects in nanomaterials and their stability at extremes. He presented his scientific results at all 12 International NANO Conferences—from Cancun-first (1992) to Moscow-twelve (2014).

Arsen V. Khatchoyan Ph.D. (Physics) is a Senior Scientist at the Institute of Structural Macrokinetics and Material Sciences, Russian Academy of Sciences. He was born in 1942 and graduated from the Erevan State University (Department of Nuclear Physics) in 1965. In 1966–1969, he was a postgraduate student in the Moscow Laboratory of the well-known Prof. L.S. Polak. In 1971, he received his Ph.D. at the Moscow Physical Technical Institute (Ph.D. thesis: "Rate Constants of Non-Equilibrium Plasmochemical Reactions"). In 1970–1976, he worked as a Scientist/Senior Scientist at the Institute of Physics and Mathematical Center of the Armenian Academy of Science; in 1974–1979, he worked as a lecturer of Physical Faculty at the Armenian Pedagogy Institute (courses on thermodynamics and statistical physics). From 1980, he is a Senior Scientist at the Chernogolovka Division of the Moscow Chemical Physics Institute (after reorganization and now the Institute of Structural Macrokinetics and Material Science, Russian Academy of Sciences). The scopes of his scientific interest are plasmochemistry, Boltzmann equation, and nonequilibrium statistical physics (about 40 scientific publications).

He is well known also as a translator/editor of the technical literature in general, and, from 1980, worked at MIR and other Russian Publishing Houses. He is the author of the first Japanese–Russian Chemical Dictionary (Moscow, Russkii Yazyk Publ. 1986, 35,000 terms) and the scientific editor of the first Japanese–Russian Radio-Electronics Dictionary (Moscow, Russkii Yazyk Publ., 1981). He is the translator and editor (partly together with Prof. R.A. Andrievski) of more than 30 translated books concerning modern physics, chemistry, and nanotechnology (some books are listed below):

1. V. Stiller. Arrhenius Equation and Non-Equilibrium Kinetics. Moscow, MIR Publ., 2000, p. 179
2. Nanotechnology Research Directions: IWGN Workshop Report. Vision for Nanotechnology R&D in the Next Decade (Eds.: M.C. Roco, R.S. Williams, and P. Alivisatos). Moscow, MIR Publ., 2002, p. 292
3. J. Altmann. Military Nanotechnology. Moscow, Technosphera Publ., 2006, p. 424

4. N. Kobayashi. Introduction in Nanotechnology. Moscow, BINOM Publ., 2007, p. 134 (translation from Japanese)
5. Lynn E. Foster. Nanotechnology. Moscow, Technosphera Publ., 2008, p. 340
6. E. Roduner. Nanoscopic Materials. Size-Dependent Phenomena. Moscow, Technosphera Publ., 2010, p. 352
7. Nanostructured Coatings (Eds.: A. Cavaleiro and J.T.M. De Hosson). Moscow, Technosphera Publ., 2011, p. 752

Acronyms

APT	Atom probe tomography
ARB	Accumulative roll bonding
BCC	Body-centered cubic
BET	Brunauer, Emmett, and Taylor
CG	Coarse-grained
CI	Citation index
CR	Cold rolling
CVD	Chemical vapor deposition
CVI	Chemical vapor infiltration
DFT	Density function theory
dpa	Displacements per atom
DTA	Differential thermal analysis
EBSD	Electron back-scattering diffraction
ECAP	Equal-channel angular pressing
EDS	Energy dispersion spectroscopy
FCC	Face-centered cubic
FMRR	Fast multiple rotation rolling
GBs	Grain boundaries
GG	Grain growth
GIAXRD	Glancing-incident angle X-ray diffraction
GS	Grain size
HE/R	Hot extrusion and rolling
HIP	Hot isostatic pressing
HMPC	High-melting point compounds
HPT	High-pressure torsion
HRSEM	High-resolution scanning electron microscopy
HRTEM	High-resolution transmission electron microscopy
IAV	Interstitial atoms and vacancies
ITER	International Thermonuclear Experimental Reactor
MA	Mechanical alloying
MD	Molecular dynamics
NLS	Nanolaminated structure

NMs	Nanomaterials
ODS	Oxide dispersion strengthened
PKA	Primary knocked-out atoms
SAED	Selected area electron diffraction
SEM	Scanning electron microscopy
SFT	Stacking-fault tetrahedra
SMAT	Surface mechanical attrition treatment
SMGT	Surface mechanical grinding treatment
SPD	Severe plastic deformation
SRT	Surface rolling treatment
TBs	Twinned boundaries
TEM	Transmission electron microscopy
TGA	Thermo gravimetric analysis
TJs	Triple junctions
UFG	Ultrafine-grained
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction