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Report of International NanoSPD Steering Committee and statistics on recent NanoSPD activities

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Abstract. The Université de Lorraine in Metz, France, is the selected site for the 6th International Conference on Nanomaterials by Severe Plastic Deformation (NanoSPD6) following a series of five earlier conferences. This introductory paper reports on several major developments in NanoSPD activities as well as on very recent NanoSPD citation data which confirm the continued growth and expansion of this important research area. Close attention is given to the topics of workshops, conferences and seminars organized during these last three years as well as on books and reviews published prior to the NanoSPD6 conference. A special concern of the committee is in introducing and discussing the appropriate terminology to be applied in this new field of materials science and engineering.

1. Introduction

The conferences of the NanoSPD series have come a long way in establishing and exploring bulk nanostructured materials (BNM) processed by severe plastic deformation (SPD). These conferences have been held all over the world, starting in 1999 (Moscow, Russia) and then continuing in 2002 (Vienna, Austria), 2005 (Fukuoka, Japan), 2008 (Goslar, Germany), 2011 (Nanjing, China) and now in 2014 (Metz, France). This latest meeting provides a new impetus to scientific and applied research and provides an opportunity to look back at the important events related to NanoSPD and to the activities of the International NanoSPD Steering Committee (www.nanospd.org).

This introductory report is designed to present a summary of the main results that have occurred in NanoSPD over the last three years since our meeting in Nanjing in 2011 and to discuss the important achievements and to provide a performance summary. In addition, statistics on publication citation data are presented to illustrate the major impact of NanoSPD within the broad field of Materials Science.



2. Main events and publications as a platform for the exchange of ideas and research in the NanoSPD field

Major NanoSPD related conferences and symposia over the period 2011-2014

The last three years since the 5th International Conference on Nanomaterials by Severe Plastic Deformation (NanoSPD5) in Nanjing, China, have seen extensive research in the NanoSPD area with a number of international conferences and meetings. These have provided a platform for thorough exchanges within the research community, industry representatives and emerging experts for bringing the ideas from a laboratory scale to the mass production of products as well as offering the participants an opportunity for cultural activities and receptions to establish new connections and ties. Of the primary events aimed at enhancing research in these areas, the authors would like to emphasize the following:

THERMEC 2011, including a symposium on Severe Plastic Deformation held on August 1-5, 2011 in Quebec, Canada. The 7th International Conference on Processing and Manufacturing of Advanced Materials brought together researchers and engineers/technologists working on various aspects of the processing, fabrication, structure/property evaluation and applications of both ferrous and non-ferrous materials; including biomaterials and smart/intelligent materials with 27 keynote speeches and 505 papers published in the conference proceedings.

The Third International Symposium on “Bulk Nanostructured Materials: from Science to Innovation” was held in the Congress Hall in Ufa, Russia, on August 22-26, 2011. This meeting included the Second Russian-French-German Workshop on “Atomic Transport in BNM and Related Unique Properties.” The meeting was chaired by Prof. Ruslan Z. Valiev and co-chaired by Prof. Terence G. Langdon and it attracted about 300 participants from more than 25 countries. The program focused on recent advances in BNM processing, achievements of superior mechanical, functional and service properties as well as paths for commercialization of articles and semi-products from BNM (there was a special series of round-table discussions on global market needs). As in previous BNM symposia, a major emphasis was given to participation by young scientists with awards presented for the best oral and poster presentations. The second BNM Achievement Award was presented to Prof. Horst Hahn of Karlsruhe, Germany, for his outstanding contributions in the development of bulk nanostructured materials.

The European Materials Research Society (E-MRS) Fall Meeting was held in Warsaw, Poland, on September 19-23, 2011 with a special symposium entitled “Mechanical Properties of Nanomaterials – Experiments and Modelling” that was a great success with many scientific contributions from both within and outside of Europe. The symposium organizers were Michael Zehetbauer (University of Vienna), Malgorzata Lewandowska (Warsaw University of Technology) and Gerhard Wilde (University of Muenster).

The 3rd Bi-Annual International Conference on Ultrafine Grained and Nanostructured Materials (UFGNSM-11) was held on November 2 - 3, 2011, at the University of Tehran in Tehran, Iran, under the auspices of the Center of Excellence for High Performance Materials in the School of Metallurgy and Materials Engineering at the University of Tehran. The conference was chaired by Prof. Mohammad H. Parsa and attracted a large number of participants from Iran and from several foreign countries and included a wide range of oral and poster presentations. The main emphasis of this meeting was on fundamental research on ultrafine-grained materials, especially in the development of new and innovative processing techniques.

The Fall Meeting of the European Materials Research Society (E-MRS) was held in Warsaw, Poland, on September 17-21, 2012, organized by Malgorzata Lewandowska (Warsaw University of Technology), Laszlo P. Biro (Hungarian Academy of Sciences, Hungary), Valentin Craciun (University of Florida, USA), Hanns-Ulrich Habermeier (MPI FKF, GERMANY) and supported by the Polish Ministry for Science and Higher Education. This E-MRS Fall meeting included 12 thematic symposia, a plenary session and satellite events and was marked by the Acta Materialia Gold Medal Symposium entitled "Recent Developments in the Processing and Properties of Ultrafine-Grained Materials" to honor Prof. Terence Langdon of the University of Southampton and the University of Southern California as the recipient of the 2012 Acta Materialia Gold Medal (Fig. 1). This symposium was very well attended and included four days of presentations plus a large poster session.



Figure 1. Prof. Thaddeus Massalski of Carnegie Mellon University (on left), the Executive Secretary of the Board of Governors of Acta Materialia, presenting the gold medal to Prof. Terence G. Langdon (right).

The TMS Annual Meeting on March 11-15, 2012, in the framework of which *the Seventh International Symposium on Ultrafine Grained Materials (UFG-VII)* was held in Orlando, Florida, USA. The symposium was organized by Suveen Mathaudhu (U.S. Army Research Office), Xiaoxu Huang (Risø DTU, Denmark), Hyoung Seop Kim (POSTECH, Korea), Terence Langdon (University of Southern California), Terry Lowe (Manhattan Scientifics, Inc.), Ruslan Valiev (Ufa State Aviation Technical University, Russia), Xiaolei Wu (Chinese Academy of Sciences) and Michael Zehetbauer (University of Vienna, Austria). This symposium attracted 160 abstracts from 25 countries, making it the largest symposium at the 2012 TMS Annual Meeting and Exhibition. The UFG symposium provides a forum on the topics of fabrication of UFG and nanocrystalline materials including conventional and emerging technologies and advancements, fundamental issues in severe plastic deformation (SPD) processing and SPD-processed materials, UFG and nanocrystalline microstructure evolution, mechanical and physical properties, deformation mechanisms, superplasticity, joining and bonding, computational and analytical modeling, structural and functional applications and thermal stability.

XI International Conference on Nanostructured Materials on August 26-31, 2012, Rhodes, Greece, including 6 Plenary Talks, over 189 invited talks and 246 contributed talks distributed in eight parallel sessions and over 300 Poster contributions divided into three sessions. These contributions, devoted to 30 specific technical topics, were presented by participants from approximately 70 countries. Several sessions of the conference included presentations from the NanoSPD field. The event marked the XI Nanomaterials conference for the past 20 years under the auspices of the International Committee on

Nanostructured Materials (ICNN), founded in 1990. Such conferences offer scientists world-wide a forum to present state-of-the-art research and advanced discoveries in the field of Nanomaterials. Moreover, NANO2012 celebrated the "Twentieth Year Commemoration" of such conferences.

Strength of Fine Grained Materials – 60 years of Hall-Petch was held on July 16-18, 2013, in Tokyo, Japan, chaired by Prof. Shin Takeuchi. This international symposium was held under the auspices of the Japan Society for the Promotion of Science to review the present state of the art of the Hall-Petch relationship from experimental and theoretical viewpoints and to understand the role of grain boundaries in the mechanical properties of polycrystalline materials with a special emphasis on UFG metals. The program included a number of lectures on the Hall-Petch relationship, the inverse Hall-Petch relation, superplasticity, strength of ultrafine-grained steels and alloys, grain boundary segregation and its effects on strength.

The 4th Bi-Annual International Conference on Ultrafine Grained and Nanostructured Materials (UFGNSM-2013) was held on November 5 - 6, 2013, at the University of Tehran in Tehran, Iran, with the program focused on but not limited to bulk nanostructured materials, characterization of UFG-NSM, modeling and simulation of UFG-NSM, nanobiomaterials, nanocoatings and thin films, nanocomposites, nanoelectronic and magnetic materials, nanotechnology education, novel approaches, UFG-NSM commercialization and industrial applications. The conference was well attended by a very large number of Iranian participants and delegates from a number of foreign countries.

THERMEC 2013, the International Conference on the Processing and Properties of Advanced Materials, was held on December 2–6, 2013, in Las Vegas, Nevada, USA. This large meeting included a special symposium entitled *Ultrafine-Grained Materials: the Prof. T.G. Langdon Symposium*, organized by Roberto Figueiredo (Federal University of Minas Gerais, Brazil), Nobuhiro Tsuji (Kyoto University, Japan), Hyoung-Seop Kim (Pohang University of Science and Technology, Korea), Teresa Pérez-Prado (IMDEA- Materials Institute, Madrid, Spain) and Ruslan Valiev (Ufa State Aviation Technical University, Russia). The symposium was well attended and included three days of intense discussions on all aspects of UFG materials.

The 2014 TMS Annual Meeting was held on February 16-20, 2014, in San Diego, California, USA, and included *the 8th International Symposium on Ultrafine Grained Materials (UFG VIII)*. This large annual meeting was dedicated to fostering the exchange of learning and ideas across the entire range of materials science and engineering, from minerals processing and primary metals production, to basic research and the advanced applications of materials. The 8th UFG symposium was organized by Suveen Mathaudhu (U.S. Army Research Office, USA), Yuri Estrin (Monash University, Australia), Zenji Horita (Kyushu University, Japan), Enrique Lavernia (University of Davis, California, USA), Xiaozhou Liao (University of Sydney, Australia), Lei Lu (Institute of Metal Research, China), Quiming Wei (University of North Carolina, USA), Gerhard Wilde (University of Muenster, Germany) and Yuntian Zhu (North Carolina State University, USA). The symposium covered a broad scope from fundamental science to applications of bulk UFG materials and included a number of specialized topical sessions in key developing areas of nano materials science such as gradient and layered nanostructures, stability of nanostructured materials, bio-inspired nanomaterials, powder processing of BNM and others. The TMS 2014 meeting was marked by the election of Prof. Ruslan Z. Valiev to TMS 2014 Fellow for his pioneering work in the processing, fundamental study and innovations of ultrafine-grained and nanostructured materials produced by severe plastic deformation.

The BioTiNet Winter School on 25 February- 01 March, 2014, was held in Vienna, Austria, and focused on materials development at the nanoscale and specifically addressing highly significant and up-to-date research questions in the areas of nanomaterials science and engineering, physics and

chemistry of nanostructures, laser-assisted rapid manufacturing, skeletal tissue engineering, electrochemistry, surface science and microbiology.

Major NanoSPD related reviews, special issues and books on NanoSPD research over 2011-2014

A number of new reviews and special issues on the results of recent NanoSPD materials-related studies and developments were published following the NanoSPD5 conference in Nanjing, China in 2011. The authors would like to draw attention to the first special treatise and book on this subject entitled “Bulk Nanostructured Materials: Fundamentals and Applications” published jointly by Wiley and TMS. There were also some significant key publications during the period under review and these are now summarized:

Y. Estrin and A. Vinogradov: *Extreme grain refinement by severe plastic deformation: A wealth of challenging science* [1]. This article presents an introduction to bulk ultrafine-grained materials produced by SPD, at the same time highlighting some polemic issues that may be of interest to those specialising in bulk nanomaterials produced by SPD. A brief overview of the available SPD technologies is given, together with a summary of unusual mechanical, physical and other properties achievable by SPD processing. The authors identify and discuss certain challenges that the research is facing, both of a generic and specific character.

T.G. Langdon: *Twenty-five years of ultrafine-grained materials: Achieving exceptional properties through grain refinement* [2]. This paper is based on the 2012 Acta Materialia Gold Medal lecture presented at the Fall Meeting of the European Materials Research Society in Warsaw, Poland, in September 2012. Twenty five years prior to this publication, in 1988, there appeared a first description of the application of SPD to bulk solids in order to achieve exceptional grain refinement to the submicrometer level leading to novel properties [3]. This report and later publications initiated considerable interest in materials science laboratories around the world and many experiments were subsequently performed to evaluate the principles and practice of SPD processing. This paper provides an overview of the more recent developments in this field, with special emphasis on the opportunities for achieving homogeneity in the as-processed materials and on the general characteristics of the mechanical properties achieved after SPD processing. For simplicity, special emphasis is placed on the two techniques of equal-channel angular pressing and high-pressure torsion as these are currently the most popular procedures for applying SPD processing.

A new journal, *Materials Research Letters*, was initiated and edited by Prof. Yuntian T. Zhu as a high impact fast communication letters journal for the materials research community [4]. The articles selected for publication are based on novelty, significance and potential impact of the reported results and subjects of interest include, but are not limited to, structural materials, energy materials, functional materials and low dimensional materials.

R.Z. Valiev, A.P. Zhilyaev and T.G. Langdon: *Bulk Nanostructured Materials: Fundamentals and Applications*, published by John Wiley & Sons, Inc, Hoboken, New Jersey, USA, and TMS (2014) [5]. This book contains 440 pages and blends the features of a textbook in its introductory sections together with detailed descriptions of new developments in the field of NanoSPD research and a consideration of the main terms and definitions used in the field of NanoSPD. The book is devoted specifically to BNM produced by severe plastic deformation (SPD) (Fig. 2). In recent years, a breakthrough has developed in studies of nanostructured metals and alloys as advanced structural and functional materials associated both with the development of new processing routes for the fabrication of BNM using SPD and with investigations of the fundamental mechanisms that lead to the new properties of these materials. This book describes the new concepts and principles in using SPD processing to fabricate bulk nanostructured metals with advanced properties. Special emphasis is

placed on the relationships between the microstructural features and the properties, as well as the innovation potential of SPD-produced nanomaterials. The book is divided into five parts with part one and the Introduction including definitions and the concepts of bulk nanomaterials, part two dealing with high-pressure torsion processing, part three with equal-channel angular pressing, part four with fundamentals and the properties of materials after SPD and part five with the innovation potential and the prospects for SPD applications.

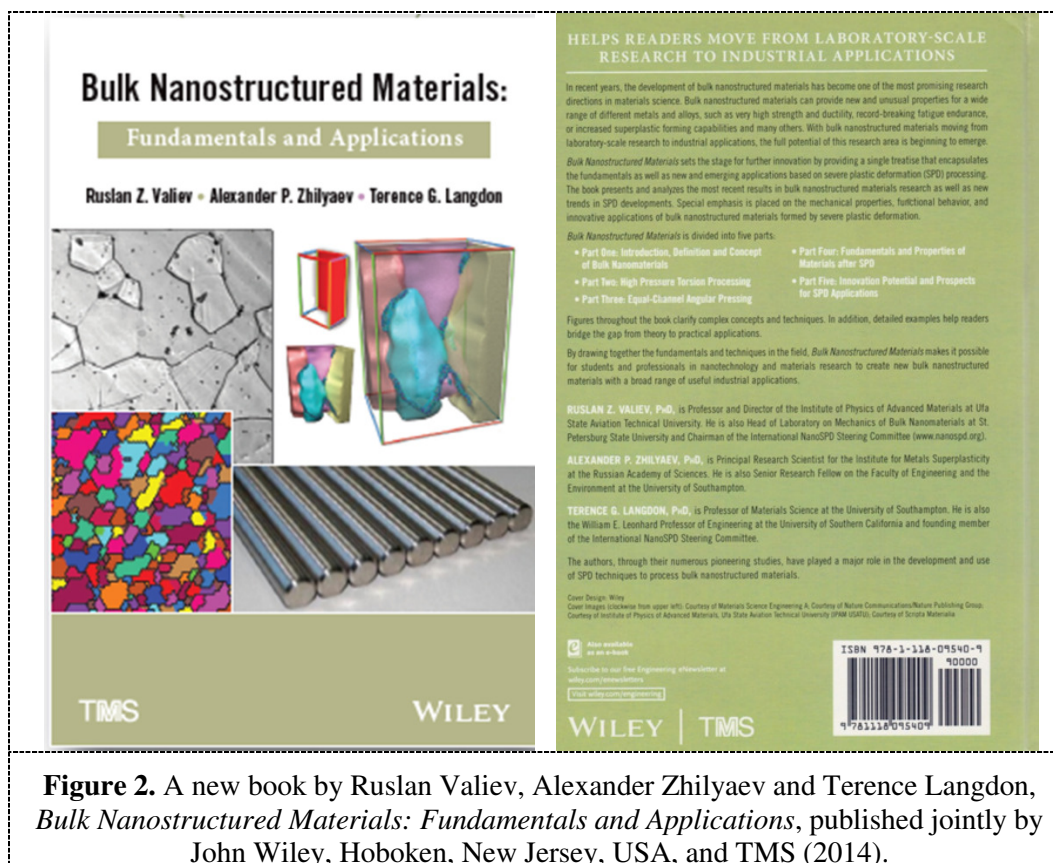


Figure 2. A new book by Ruslan Valiev, Alexander Zhilyaev and Terence Langdon, *Bulk Nanostructured Materials: Fundamentals and Applications*, published jointly by John Wiley, Hoboken, New Jersey, USA, and TMS (2014).

Sung H. Whang (editor): *Nanostructured Metals and Alloys: Processing, Microstructure, Mechanical Properties and Applications*, published by Woodhead Publishing Ltd., Cambridge, UK (2011). This book reviews the latest technologies used in the production of nanostructured metals and alloys, as well as recent advances in research into their structure and mechanical properties, including tensile strength, fatigue strength and ductility [6]. The publication is distinguished for its prominent editor and international team of contributors and is of interest to those engaged both in research and metal industry. Part one of the book describes the different methods used to process bulk nanostructured metals and alloys, including, among others, chapters on severe plastic deformation, mechanical alloying and electrodeposition. Part two focuses on the microstructure and properties of nanostructured metals, with chapters studying deformation structures such as twins, microstructure of ferrous alloys by equal-channel angular pressing, and the characteristic structures of nanostructured metals prepared by severe plastic deformation. In part three, the mechanical properties of nanostructured metals and alloys are discussed and part four deals with the present and arising applications of nanostructured metals and alloys.

In 2012 there was a Themed Issue on Nanomaterials published in *JOM* with a focus on functional materials, progress with bulk nanostructured materials and the defect roles in nanomaterials. The issue included an overview by R.Z. Valiev, I. Sabirov, A.P. Zhilyaev and T.G. Langdon on bulk nanostructured metals for innovative applications [7].

In 2012 there was a fourth special issue of *Journal of Materials Science* on ultrafine-grained materials with selected papers from the Seventh International Symposium on Ultrafine-Grained Materials (UFG VII) which was held in Orlando, Florida, USA, from March 11-15, 2012 [8].

In 2014 there was a special issue of *Materials Transactions* edited by Profs. Shin Takeuchi, Masaharu Kato and Takahito Ohmura with contributed and overview papers by invited and oral speakers attending the Hall-Petch international symposium held on July 16-18, 2013, in Tokyo, Japan [9]. These papers were aimed at providing a deeper understanding of the effect of grain refinement on the mechanical properties of crystals and on procedures for developing new ultrafine-grained materials.

3. Citation statistics for publications in NanoSPD

The first description of the application of SPD processing in order to achieve a UFG microstructure and exceptional properties appeared in the Russian literature in 1988 [3]. Twenty-one years ago, in 1993, there was the first publication outside of Russia describing the processing and properties of an aluminium-based alloy by SPD [10]. These and subsequent publications initiated a worldwide interest in using various SPD techniques for fabricating and testing a wide range of pure metals and metallic alloys and even extending the field to powder consolidation and non-metallic materials. Some of the potential applications for SPD processing and UFG materials were summarized in a recent report [2].

It is clear from this description that NanoSPD is a relatively new field within the broad framework of Materials Science. It does not have the long history of more conventional topics such as crystalline plasticity, flow mechanisms, phase transformations, precipitation hardening and mechanical testing in fatigue or creep. Nevertheless, despite this very short history, research in NanoSPD has had a remarkable impact within the field of Materials Science. This impact, based on citation data, was described in two earlier reports [11,12] and it is very appropriate now, with the advent of NanoSPD6, to re-examine these data and provide a comprehensive updated listing of citation information.

This information is given for five major journals in Tables 1 to 5. Each Table is devoted to a single journal and provides information on the rankings of publications related to NanoSPD based on an examination of the top ten all-time most cited articles for each journal. Thus, Table 1 is for *Progress in Materials Science* which is a major review journal publishing lengthy review articles on selected topics. For this journal, a total of 410 papers have been published to date and the Impact factor (IF) of the journal is 23.19 where this is high because of publishing only review articles. Four papers within the top ten are related to NanoSPD materials and these papers are listed together with the numbers of citations for each publication. Similar information is given in Table 2 for *Acta Materialis*, Table 3 for *Scripta Materialia*, Table 4 for *Materials Science and Engineering A* and Table 5 for *JOM* where the latter is a U.S. publication publishing primarily invited papers and with the journal distributed to all members of TMS. All data were collected from the ISI Web of Science website in early April 2014. Thus, these citation numbers will gradually increase with time but they provide a snapshot of the situation in April 2014 and the overall rankings will remain almost unchanged.

Inspection of the Tables shows that NanoSPD has had a remarkable impact on Materials Science. It accounts for four or five most-cited papers in the major journals including either the first or second publication in every journal. These results demonstrate the considerable current interest in using SPD as a processing tool for refining the microstructure and achieving new and unusual properties.

Table 1. All-time ranking for *Progress in Materials Science* (410 papers; IF = 23.19)

Ranking	Author(s)	Year	No. of citations	Reference
1	Valiev <i>et al.</i>	2000	3244	[13]
3	Gleiter	1989	2707	[14]
4	Valiev and Langdon	2006	1385	[15]
6	Meyers <i>et al.</i>	2006	1188	[16]

Table 2. All-time ranking for *Acta Materialia* (19,548 papers; IF = 3.94)

Ranking	Author(s)	Year	No. of citations	Reference
2	Gleiter	2000	1370	[17]
3	Kumar <i>et al.</i>	2003	955	[18]
4	Saito <i>et al.</i>	1999	895	[19]
6	Iwahashi <i>et al.</i>	1998	851	[20]
8	Iwahashi <i>et al.</i>	1997	647	[21]

Table 3. All-time ranking for *Scripta Materialia* (17,917 papers; IF = 2.82)

Ranking	Author(s)	Year	No. of citations	Reference
1	Iwahashi <i>et al.</i>	1996	1197	[22]
2	Saito <i>et al.</i>	1998	597	[23]
3	Mukai <i>et al.</i>	2001	480	[24]
5	Tsuji <i>et al.</i>	2002	446	[25]
10	Tsuji <i>et al.</i>	1999	329	[26]

Table 4. All-time ranking for *Materials Science and Engineering A* (43,756 papers; IF = 2.11)

Ranking	Author(s)	Year	No. of citations	Reference
2	Segal	1995	1521	[27]
3	Valiev <i>et al.</i>	1993	898	[28]
5	Furukawa <i>et al.</i>	1998	727	[29]
6	Valiev <i>et al.</i>	1991	715	[30]

Table 5. All-time ranking for *JOM* (1890 papers; IF = 1.05)

Ranking	Authors(s)	Year	No. of citations	Reference
1	Valiev <i>et al.</i>	2006	524	[31]
2	Ma	2006	163	[32]
4	Zhu and Langdon	2004	97	[33]

4. Innovation activity

To date, it is well established that bulk SPD processing is an attractive procedure for many advanced applications as it can significantly enhance the properties of a wide range of metals and alloys. Metallic materials subjected to SPD can possess not only an ultrafine-grained structure but also specific nanostructural features, such as non-equilibrium grain boundaries, nanotwins, grain boundary segregations and nano particles. As a result, a generation of new and unusual properties has been demonstrated for a wide range of different metals and alloys, including enhanced functional (electric, magnetic, corrosion, etc.), mechanical properties and many other.

A transition from laboratory-scale research to industrial applications is now starting to emerge and many companies worldwide are involved in the R&D activities in this area. Therefore, in several recent articles a special emphasis is placed on the new trends in BNM processing and forming, the principles of nanostructuring by SPD processing for superior properties, as well as the fabrication of advanced pilot articles from nanostructured metals with new functionality [1, 2, 7, 34]. Among existing examples, one can find such articles made from nanotitanium and Ti alloys for biomedical applications, nanostructured Cu and Al alloys for prospective electroconductors, nanostructured Mg alloys for hydrogen storage, microdevices from BNMs and nanomagnets for high-speed electric machines.

Currently, medicine holds one of the leading positions in application of nanostructured titanium materials due to their high strength and biocompatibility. Production of nanostructured metals has been established under the following trademarks: Samurai Metals TM (Metallicum Inc. - rods), "NanoMeT ltd" (NanoMeT - rods), NanoimplantTM (Timplant - dental implants) and BiotaniumTM (BASIC Dental Inc. - dental implants). The company 'Timplant' (Ostrava, Czech Republic) used nanostructured Ti to design and fabricate a new generation of dental implants under the trademark Nanoimplant® [www.timplant.cz]. To date, these implants have been certified according to the European standard EN ISO 13485:2003.

We envisage significant new developments in the area of industrial applications over the next three years leading up to NanoSPD7.

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