



# Rare Metal Technology 2015

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# Rare Metal Technology 2015

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*Edited by:*

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## PREFACE

*Rare Metal Technology 2015* is the second proceedings of the symposium on Rare Metal Extraction & Processing initiated in 2014 and sponsored by the Hydrometallurgy and Electrometallurgy Committee of the TMS Extraction and Processing Division. The symposium has been organized to encompass the extraction of rare metals as well as rare extraction processing techniques used in metal production.

The intent of the symposium is to cover discussions on the extraction of rare metals, that is, less common metals or minor metals not covered by other TMS symposia. The elements considered include antimony, bismuth, barium, beryllium, boron, calcium, chromium, gallium, germanium, hafnium, indium, manganese, molybdenum, platinum group metals, rare earth metals, rhenium, scandium, selenium, sodium, strontium, tantalum, tellurium, tungsten, etc. These are rare metals of low-tonnage sales compared to high-tonnage metals such as iron, copper, nickel, lead, tin, zinc, or light metals such as aluminum, magnesium, or titanium and electronic metalloid silicon. Rare processing included biometallurgy, hydrometallurgy, electrometallurgy, as well as extraction of values from EAF dusts, and less common waste streams not discussed in recycling symposia. Rare high temperature processes to be included microwave heating, solar-thermal reaction synthesis, and cold crucible synthesis of the rare metals and the design of extraction equipment used in these processes as well as laboratory and pilot plant studies.

This proceedings volume covers about 15 rare metal elements and 15 rare earth elements in 29 papers. The symposium is organized into four sessions encompassing (1) rare metal process, (2) precious metals, (3) rare earth metals, and (4) V–Mo–W (vanadium–molybdenum–tungsten). There is also a poster session. In addition, most of the poster papers have the manuscripts included in the proceedings.

We acknowledge the efforts by the organizing and editing team consisting of Neale R. Neelameggham, Shafiq Alam, Harald Oosterhof, Animesh Jha, David Dreisinger, and Shijie Wang. We thank Bing Li who helped in the review process. In addition to above six, we thank Takashi Nakamura, Tohoku University, Japan and Joon Soo Kim, Chonnam National University, Gwangju, Korea who will form the session co-chairs. Our thanks to Trudi Dunlap and Patricia Warren of TMS in assembling the proceedings, and Matt Baker for facilitating the proceedings. We appreciate all the authors who contributed to this proceedings as well as column reformatting which was requested during the review.

**Neale Neelameggham**



## EDITORS



### **Lead Editor: Neale R. Neelameggham**

Neale R. Neelameggham is 'The Guru' [Professor] at IND LLC, involved in Technology marketing and international consulting in the field of light metals and associated chemicals (boron, magnesium, titanium, lithium, and alkali metals), rare earth elements, battery and energy technologies, etc. He has been a senior consultant for global engineering companies on various metal and chemical processes. In 2012 he was a visiting expert at Beihang University of Aeronautics and Astronautics, Beijing, China and was a plenary speaker at the recent Light Metals 2014

Conference in Pilanesberg, South Africa. Neale has been an advisor for several other metal production and energy process and engineering firms.

Dr. Neelameggham has over 38 years of expertise in magnesium production technology from the Great Salt Lake Brine in Utah, involved in process development of its startup company NL Magnesium through to the present US Magnesium LLC from where he retired in 2011. He was instrumental in most of the process and equipment development of all areas of the plant from the raw material source – the Great Salt Lake Brine to metal. In addition, Dr. Neelameggham's expertise includes an in-depth and detailed knowledge of all competing technologies worldwide of magnesium production, both electrolytic and thermal processes, as well as alloy development. He also has extensive knowledge of titanium chemicals and metal production. He and his partners are promoting a thiometallurgical process—a new concept of using sulfur as the reductant and or fuel—for magnesium and titanium production with the least greenhouse gas emissions. His expertise in process development extends to the development of a convective model for the global anthropogenic warming from thermal emissions which is based on all energy conversions irrespective of whether it is combustion conversion or from renewables.

Dr. Neelameggham holds 13 patents and patent applications on sustainable light metal production. He has several technical papers to his credit. As a member of TMS, AIChE, and a former member of American Ceramics Society he is well versed in energy engineering, bio-fuels, rare-earth minerals and metal processing and related processes. He has served in the Magnesium Committee of the TMS Light Metals Division (LMD) since its inception in 2000, chaired it in 2005, and in 2007 he was made a permanent co-organizer for the Magnesium Technology Symposium. He has been a member of the Reactive Metals Committee, Recycling Committee, and Titanium Committee, and a Programming Committee Representative for LMD. In 2008, LMD and the Extraction and Processing Division created the Energy Committee following



the CO<sub>2</sub> Reduction Metallurgy Symposium that Dr. Neelameggham initiated, and he was the first chair of that committee. He has been a co-organizer of the Energy Technology symposium each year since 2008.

Dr. Neelameggham is currently the chair of the Hydrometallurgy and Electrometallurgy Committee, and he organized the Rare Metal Technology 2014 and 2015 symposia. He is the co-editor of the *Essential Readings in Magnesium Technology* compendium of TMS papers published in 2014. He is a co-editor of 2015 symposium on *Drying, Roasting and Calcining*.

Dr. Neelameggham received the LMD Distinguished Service Award in 2010. He holds a doctorate in extractive metallurgy from the University of Utah.



### **Shafiq Alam**

Shafiq Alam is an associate professor at the University of Saskatchewan, Canada. In 1998, he received his Ph.D. degree in chemical engineering from Saga University, Japan. From 1999 to 2001 he was appointed as a post-doctoral research fellow at the University of British Columbia and the University of Toronto, Canada.

Dr. Alam has extensive experience in industrial operations, management, engineering, design, consulting, teaching, research, and professional services. Before joining academia in 2006, he worked with many different companies, such as Shell, Process Research ORTECH Inc., Fluor Canada Ltd., and the National Institute of Advanced Industrial Science and Technology (AIST), Japan. Dr. Alam is highly experienced in the area of mineral processing and extractive metallurgy. He possesses two patents and has over 120 publications in the area of extractive metallurgy. He is the co-editor of two books and an associate editor of the *International Journal of Mining, Materials and Metallurgical Engineering (IJMMME)*.

Dr. Alam is a registered professional engineer and has worked on projects with many different mining industries including Xstrata, Phelps Dodge, INCO, Barrick Gold Corporation, Rambler Metals, and Anaconda Mining. He is an Executive Committee Member of the Hydrometallurgy Section of the Metallurgy and Materials Society (MetSoc) of CIM and currently he holds the office of secretary with MetSoc (2013-2015). Dr. Alam is also the Vice-Chair of the Hydrometallurgy and Electrometallurgy Committee of the Extraction and Processing Division (EPD) of TMS (2013-2015). He is actively involved in organizing different international conferences, such as, the Conference of Metallurgists (COM) in Canada; Ni-Co Symposium at TMS 2013 in

Texas, USA; the Copper 2013 Conference in Chile; and the Rare Metal Extraction & Processing Symposium at TMS 2014 and TMS 2015 in San Diego and Orlando, USA.



### **Harald Oosterhof**

Harald Oosterhof graduated as a chemical engineer from Twente University in The Netherlands in 1994. In the same year, he assumed a position as researcher at TU Delft where he worked in the laboratory for process equipment. His research on anti-solvent crystallization of well-soluble salts was rewarded with two patents and a dozen publications. After receiving his Ph.D. from Delft University in 1999, he assumed the position of project manager at Umicore, a global materials and technology group that is based in Belgium. During his first assignment as Project Leader

– Hydrometallurgy, he focused on the refining of cobalt, nickel, and germanium. Since 2011, Dr. Oosterhof has worked as scientist in the Recycling and Extraction Technology group at Umicore's Central R&D department. His main competence areas are special metals hydrometallurgy, recycling and refining of rare earth metals, base metal hydrometallurgy, and recycling of spent rechargeable batteries. In his current job, Dr. Oosterhof is frequently involved in business development of scarce metals recycling and he is heading a team of hydrometallurgical specialists.



### **Animesh Jha**

Animesh Jha has been a professor of materials science at the University of Leeds in the United Kingdom since August 2000. He obtained his Bachelor of Engineering (BE) degree in metallurgy in June 1979 from the University of Roorkee (India); his Master of Engineering (ME) degree in metallurgical engineering in July 1981 from the Indian Institute of Science, Bangalore in India; and Ph.D. and DIC from Imperial College (London) in October 1984 in the area of chemical and process metallurgy. After earning his Ph.D., he did a short postdoctoral research engagement at Purdue

University (US) in 1985-86, before returning to Sheffield, UK in December 1986 where he started research on phase transformations in novel salt-based and metallic glass systems. In May 1989, he took his academic position at Brunel University, Uxbridge, UK where he developed his academic career in the areas of IR glasses and mineral processing. He has since 1989 continued research in these two areas and produced over 24 Ph.D. theses from 1992 to 2014.

He has published over 400 research papers in peer-reviewed journals and reviewed conference proceedings. He has been a member of TMS since 1992, a fellow of the Institute of Physics in London, and member of the Optical Society of America and IEEE. He serves as an external reviewer for overseas research agencies including US, Canada, and EU countries. He is also actively involved in translational research, which allows the lab work to reach industry.



### **David Dreisinger**

David Dreisinger holds the position of Professor and Industrial Research Chair in Hydrometallurgy at the University of British Columbia (UBC). Dr. Dreisinger received B.Sc. and Ph.D. degrees in metallurgical engineering from Queen's University in Kingston before beginning his career at UBC in 1984.

At UBC, Dr. Dreisinger supervises a wide ranging program of research and development in pressure leaching of ores and concentrates, solution purification, and use of electrochemical methods for metal recovery. Dr. Dreisinger has published extensively and has received (with co-workers) 17 U.S. patents for work in areas such as pressure leaching, ion exchange removal of impurities from process solutions and use of thiosulfate as an alternative to cyanide in gold leaching.

Dr. Dreisinger has received a number of awards including the Sherritt Hydrometallurgy Award (1993), the Metal Chemistry Award from CMSC (2001), the Extraction and Processing Division Science Award from the TMS (2005), and the INCO Medal (2008). Dr. Dreisinger has been named a Fellow of the Canadian Academy of Engineering and the Canadian Institute of Mining, Metallurgy and Petroleum. Dr. Dreisinger has been actively organizing conferences and teaching short courses around the world through the Industrial Research Chair in Hydrometallurgy. The Chair is sponsored by 18 international companies with an interest in Hydrometallurgy.



### **Shijie Wang**

Shijie Wang received his B.Sc. in Mineral Processing from China and his Masters and Ph.D. in Metallurgical Engineering from the University of Nevada at Reno. Dr. Wang has experience working at the Beijing General Research Institute for Non-Ferrous Metals, ASARCO Inc., and Phelps Dodge Corporation. He is currently Superintendent of Precious Metals/Rare Metals Operations at Rio Tinto Kennecott Utah Copper. Dr. Wang has been active in extractive metallurgy and has experience

in metallurgical process development, existing operation optimization, and troubleshooting. His work interests include metal recovery, operational efficiency, and profitability as well as process safety management. Dr. Wang holds three U.S. patents and has published 20 journal papers including non-ferrous metals', precious metals', rare metals', and rare earth metals' resourcefulness and recovery. He is a copper, gold, silver, selenium and tellurium refining subject matter expert. Dr. Wang has been a TMS member since 1991 and is former chair of the Hydrometallurgy and Electrometallurgy Committee of TMS from 2011 to 2013.



## **SESSION CHAIRS**

### **Rare Metal Processes**

Shafiq Alam  
Takashi Nakamura

### **Precious Metals**

David Dreisinger  
Shijie Wang

### **Rare Earth Metals**

Neale R. Neelameggham  
Joon Soo Kim

### **Vanadium-Molybdenum-Tungsten**

Harald Oosterhof  
Bing Li



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