Ultra-High Temperature Materials I

Igor L. Shabalin

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Carbon (Graphene/Graphite) and Refractory Metals

A Comprehensive Guide and Reference Book

Springer

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This book is dedicated to two noble Russian ladies:

—Countess Valentina G. Getmanoff (1889–1978), one of the best military interpreters in Russia during WWII, my beloved granny

and

—Miss Vera L. Shabalin (born in 2012), my beloved granddaughter

Preface

I am a Materials Designer. During my long-term professional career, from the early 1970s till date, my particular job is to invent, explore and develop novel types and compositions of special materials for technical applications at high and ultra-high temperatures. My customers and consumers are numerous enterprises in the aerospace industry, nuclear engineering, machinery and metallurgy. With my assistance they would like to overcome the troubles, which are directly connected with the deleterious effect of high and ultra-high temperatures on various machines, mechanisms, devices and installations. In this way I have been involved in several materials design projects focused, for example, upon leading edges of anti-ballistic missiles, critical cross-sections of nozzles in rocket and torpedo motors, nuclear fuels for spacecraft power stations, thermo-electrical insulation for Hall thrusters (ion engines), refractory diaphragms for continuing casting of metals and alloys and many other apparatuses affected by the intensive thermo-mechanical and/or thermo-chemical loading, which results in fracture or severe erosion (corrosion) of the main parts. From the beginning of my career I have collected all the information about physical and chemical properties of high and ultra-high temperature substances: elements, chemical compounds, alloys and composites, which are extremely necessary for the selection of known materials as well as for the design of new ones. I believe, now it is the time to share this collection with all the specialists who are just working in the area of the ultra-high temperature applications of carbons, metals, ceramics and composites, or intend to do similar projects in the future. During the last three years I have updated considerably all my previous records on the ultra-high temperature materials and accommodated new experimental and calculated data recently obtained for these types of materials, including some last achievements of nanotechnology in this area. Thus, I would like to offer my readers and users a reference book containing the comprehensive physico-chemical description of all the substances and materials with melting (sublimation or decomposition) points around or above 2500 °C. The first volume of the book contains data on the elemental materials (carbon and refractory metals); the next volumes will include the information on chemical compounds (carbides, nitrides, oxides, borides, silicides) and complex

materials (refractory alloys, carbon and ceramics containing composites). I hope that the book will be of interest to many researchers, engineers, postgraduate and undergraduate students working or studying in the different engineering and technological areas connected with high and ultra-high temperature environments.

Also, I would like to ask everybody, who has any remarks, observations, or possibly corrections and personal opinions, concerning the book and its contents, to send them directly to my e-mail. It will be very useful for the author to take into account all these responses before publishing the next volumes.

Like any author of a scientific book, I am indebted to previous researchers and writers on ultra-high temperature materials from USA, UK, Ukraine, Russia and many other countries. However, first of all I have to acknowledge the encouragement of my colleagues and friends from Manchester and UK, who helped me to adapt to the British Academy conditions since I immigrated to the UK in 2003. I am absolutely sure that this book had no chance to appear without their kind assistance to me in continuing my career here. Since 2005 I have been supported by Prof. Keith Ross, former Director of Institute for Materials Research (University of Salford, Manchester) in all my undertaking activities in the university. Also, I would like to express my sincere gratitude to other Mancunians, my friends and colleagues: Prof. Alan Oates, Dr. Daniel Roach, Dr. Olga Umnova, Ms. Vera Barron, all from the University of Salford; Prof. Frank Sale and Prof. Kostya Novoselov from the University of Manchester; Dr. Vlad Vishnyakov and Prof. John Colligon from the Manchester Metropolitan University, as well as Oxbridge and London representatives: Prof. Richard Brook and Prof. Richard Todd from the University of Oxford; Dr. Kevin Knowles from the University of Cambridge; Prof. Xiao Guo and Prof. Mohan Edirisinghe from the University College of London; Prof. Mike Reece from Queen Mary, University of London, and finally my special thankfulness to Prof. Julie Yeomans from the University of Surrey and all our colleagues from the SCERN project.

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Manchester, UK, July 2013 Igor L. Shabalin

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About the Author

In his professional career Igor L. Shabalin has over 40 years experience in Ultra-High Temperature Materials Design, Science and Engineering. He was born in Russia, graduated in Technology of Less-Common Metals and received his M.Sc. and Ph.D. from the Ural Polytechnic University (UPI), Yekaterinburg (former—Sverdlovsk), Russia. He has held academic positions at the UPI and was the founder of the Special Research Laboratory for Aerospace Industry (ONIL-123). As head of the laboratory and member of several scientific councils, he established collaboration between universities and industry by running a variety of R&D projects and was involved in the management of some world leading programmes in rocketry and spacecraft development in the USSR Ministry of Aerospace Industry (MOM). In 2003, Prof. Shabalin immigrated to the UK, and joined the University of Salford, Manchester, as a researcher in Materials in 2005. He has published about 250 scientific and technical papers and holds more than 40 patents. His research focuses mainly on high and ultra-high temperature hetero-modulus ceramic composites with graphene-like (carbon and boron nitride) constituents.

Abstract

This work represents a thorough treatment of ultra-high temperature materials with melting points over 2500 °C. In the first volume are included physical (structural, thermal, electro-magnetic, optical, mechanical, nuclear) and chemical (binary, ternary and multi-component systems, solid-state diffusion, wettability, interaction with chemicals, gases and aqueous solutions) properties of elemental materials: carbon (graphene/graphite) C and refractory metals (tungsten W, rhenium Re, osmium Os, tantalum Ta, molybdenum Mo, niobium Nb and iridium Ir). It will be of interest to researchers, engineers, postgraduate, graduate and undergraduate students alike. The reader is provided with the full qualitative and quantitative assessment for the materials, which could be applied in various engineering devices and environmental conditions at ultra-high temperatures, on the basis of the latest updates in the fields of physics, chemistry, materials science, engineering and nanotechnology.