Materials Science and Engineering R 76 (2014) 1–53

Contents lists available at ScienceDirect

Materials Science and Engineering R

journal homepage: www.elsevier.com/locate/mser

Materials properties measurements and particle beam interactions studies using electrostatic levitation

Paul-François Paradis [a,b,*], Takehiko Ishikawa [a], Geun-Woo Lee [c,d], Dirk Holland-Moritz [e], Jürgen Brillo [e], Won-Kyu Rhim [f], Junpei T. Okada [a,g]

[a] *Japan Aerospace Exploration Agency, Tsukuba Space Center, 2-1-1 Sengen, Tsukuba, Ibaraki 305-8505, Japan*
[b] *INO, Remote Sensing Group, 2740 Einstein, Québec, Québec G1P 4S4, Canada*
[c] *Korea Research Institute of Standards and Science, 267 Gajeong-ro, Yuseong-gu, Daejeon 305-340, Republic of Korea*
[d] *Department of Science of Measurement, University of Science and Technology, Daejon, 305-333, Republic of Korea*
[e] *Institut für Materialphysik im Weltraum, Deutsches Zentrum für Luft- und Raumfahrt (DLR), 51170 Köln, Germany*
[f] *California Institute of Technology, Materials Science Department, Mail Stop 138-78, Pasadena, CA 91125, United States*
[g] *Japan Science and Technology Agency, Precursory Research for Embryonic Science and Technology (PRESTO), Kawaguchi, Saitama 332-0012, Japan*

ARTICLE INFO

Article history:
Available online 25 December 2013

Keywords:
Electrostatic levitation
Materials processing
Supercooling
Nucleation
Thermophysical properties measurement
Atomic dynamics

ABSTRACT

Electrostatic levitators have been around for more than 30 years and have become mature tools for the material science community. Originally developed as positioners for materials and fluid science experiments in space, they saw a myriad of offsprings throughout the world for ground-based research, not only in space agencies but also in governmental laboratories, in universities and in the industry. Electrostatic levitators eliminate any physical contact with a container allowing to process and study corrosive or high temperature materials in their solid or liquid phases. Moreover, heterogeneous contamination from the container being avoided, it is possible to reach and maintain supercooled and metastable phases. This, in turns, permits a host of fundamental and applied studies. The nucleation and solidification phenomena can be scrutinized, the atomic structure and dynamic of liquid and metastable phases can be probed and the physics of molten drops could be investigated. On a more applied standpoint, the measure of thermophysical properties and the synthesis of materials with new properties are also possible with current facilities.

This paper first describes the principle of electrostatic levitation and retraces the development of various facilities throughout the world, focusing on the advances made by each research group. The capabilities of electrostatic levitation for materials processing and synthesis under different environments are then presented. The paper successively covers in length its contribution for the measurements of thermophysical properties and for fundamental studies using high energy particle beams. Finally, the outlook of electrostatic levitators and its attractiveness for space experiments in materials sciences are discussed.

Abbreviations: AC, alternative current; A/D, analog to digital; ADL, aerodynamic levitation; BESL, beam electrostatic levitator; BMG, bulk metallic glass; Caltech, California Institute of Technology; CCD, charge coupled device; CN, coordination number; CNT, classical nucleation theory; CPMD, Car-Parrinello molecular dynamics; D/A, digital to analog; DC, direct current; DISRO, distorted icosahedral short-range ordering; DLR, Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center); DSC, differential scanning calorimetry; DTA, differential thermal analysis; ESCAPES, electrostatic containerless processing system; ELF, electrostatic levitation furnace; ESA, European Space Agency; ESL, electrostatic levitator; FTIR, Fourier transform infrared; GFA, glass forming ability; HDL, high density metallic liquid; Hi-Lite, High Temperature Levitation Instruments for Thermophysical Evaluation; HRIS, high resolution inelastic scattering; HRPD, high resolution power diffractometer; HTESL, high temperature electrostatic levitator; IHI, Ishikawajima Heavy Industries; ISRO, icosahedral short-range ordering; ISS, International Space Station; ITS, International Temperature Scale; JAERI, Japan Atomic Energy Research Institute; JAXA, Japan Aerospace Exploration Agency; JPL, Jet Propulsion Laboratory; KRISS, Korea Research Institute of Standards and Science; LDL, low density semimetallic liquid; LLPT, liquid liquid phase transition; MCPD, multi channel photo detector; MLWF, maximally localized Wannier functions; MRO, medium range order; NASA, National Aeronautics and Space Administration; NASDA, National Space Development Agency; NIMS, National Institute for Materials Science; MSFC, Marshall Space Flight Center; PID, proportional integral derivative; PSD, position sensing detector; RF, radio-frequency; RMC, reverse Monte-Carlo calculations; SEM, scanning electron microscope; SRO, short range order; TTT, temperature time transformation; UV, ultraviolet; WU-BESL, Washington University Beam Electrostatic Levitator; YAG, yttrium aluminum garnet.

* Corresponding author at: INO, Remote Sensing Group, 2740 Einstein, Québec, Québec G1P 4S4, Canada.
E-mail address: paul-francois.paradis@ino.ca (P.-F. Paradis).

0927-796X/$ – see front matter
http://dx.doi.org/10.1016/j.mser.2013.12.001

Contents

1. Introduction

The processing of materials without any containers, crucibles, or walls has several advantages [1–3]. For one, it allows the processing of corrosive materials or materials whose melting temperatures are higher than that of the crucible. Handling of high temperature materials in their solid or liquid phases is thus achievable. It also eliminates or reduces the temperature gradients within the material being processed or studied that are caused by the thermal conduction of the crucible or walls. Because there is no physical contact with a container, physico-chemical contamination from the crucible or walls is avoided. This implies that thermodynamic property determination of the original material can be obtained. Moreover, heterogeneous contamination from the container being avoided, this makes possible to reach and maintain supercooled and metastable phases, leading to vitrification of