

WFC (IMS) Friday 08:00 – 17:00 BCEC Room 156C

Recent Advances in Microwave Power Applications and Techniques (RAMPAnT)

Full-day workshop reviewed by MTT-15, MTT-1, IMS09

Organizer(s):

Malgorzata Celuch, Warsaw University of Technology, Poland; IMS TPC.

Vadim V. Yakovlev, Worcester Polytechnic Institute, USA.

The RAMPAnT workshop presents an overview of current and emerging microwave energy applications in science and industry. It also exposes the MTT community to the recent advancements in electromagnetic modeling techniques relevant to high-power microwave processes, computer-aided optimization of microwave heating systems, experimental studies in material processing, imaging and measurements for high-power microwave scenarios, and developments of new industrial microwave technologies. Contemporary applications of microwave power span an increasing number of research and industrial sectors. Beyond widely known microwave heating and thawing of food products, they include sintering of particulate materials, powder metallurgy and metal casting, microwave plasma generation and acceleration of chemical reactions, manufacturing of nanomaterials, processing of biocompatible alloys, and surface coating of polymers. All of the quoted topics are represented in the workshop program. While on the fundamental level, microwave power applications deal with the same electromagnetic laws as conventional telecommunications, the multidisciplinary field of high power engineering has been historically staying somewhat aside the developments in the “traditional” electromagnetics. As a consequence, this field remains beyond the main scope of interests of the IEEE MTT Society. The RAMPAnT Workshop aims to bring the communities of “classical” and “high power” microwave theory and techniques closer to each other with the hope to initiate information exchange and to identify the areas of common concerns that could be jointly addressed by the experts of both parties.

Speakers:

1. Paolo Veronesi, University of Modena and Reggio Emilia, Modena, Italy

“Control of the Microstructure of Powder Metallurgy Products by Microwave Heating”

Powder metallurgy can benefit from the rapid and selective heating offered by microwaves, to obtain materials presenting unique microstructures and outstanding mechanical properties. Microwave rapid heating was applied to maintain the nanostructure in sintered metal parts, improving their hardness. Rapid microwave debinding and sintering in single mode applicator of stainless steel powder compacts can be achieved as well. The capability of microwaves to convey energy, and not heat, can be used to control the microstructure of compounds and coatings prepared by Self-propagating High temperature Synthesis (SHS) of powder mixtures. Numerical simulation and experimental results regarding SHS of wear resistant intermetallic coatings on Ti shows how heating selectivity allows to heat only the reacting components, while preserving the substrate integrity and microstructure. High power microwave heating has thus proved to be a new and efficient way to design new materials and coatings.

2. Aly E. Fathy, University of Tennessee, Knoxville, TN, USA

“Electromagnetic and Thermal Analysis of High Power Industrial Microwave Ovens for Metal Casting Applications”

Using microwave energy in metal casting could cut heating costs by about 30%. However, the design and development of appropriately large microwave furnaces is a challenging multi-physics task that requires addressing concurrently various electromagnetic, thermal, material, and chemical issues. The computational domain of such a problem is exceptionally large, and various materials properties are still unknown at such elevated temperatures. We have developed a multiphysics model using COMSOL that is based on finite elements analysis and can include dynamic modeling of electromagnetic, heat and chemical interaction. We shall discuss the analysis of modular and industrial ovens. While the results are technically informative, computing such large problems with the present tool requires huge computational resources. The subject of accelerating modeling and simulation methods for microwave power technologies will be raised for further consideration by the Workshop attendees.

3. Sébastien Vaucher, Swiss Federal Laboratories for Materials Testing and Research, Thun, Switzerland

“Time-Resolved Imaging of Material Changes Under Microwave Irradiation”

Though the use of microwave energy in processing and manufacturing of advanced nanomaterials is not new, the present knowledge on the interaction of matter with microwave fields remains essentially limited to observations performed at room temperature, before and after treatment. The present paper shows that the combined use of high brilliance synchrotron radiation sources and of fast X-ray detectors enables the real-time observation of the microwave-materials interaction and of its kinetic features. Information yielded by in situ time-resolved experiments can greatly improve our fundamental knowledge on the mechanisms on mass transport and structural phase transitions in the presence of e.m. fields, as well as our means to fine tune microwave processing for a broad variety of nanomaterials. Opportunities for developing new materials will emerge, with potential implications for powder metallurgy, microwave chemistry, catalysis, pharmacy, food processing, biology or medicine.

4. Wojciech K. Gwarek, Warsaw University of Technology, Warsaw, Poland

“Modeling and Measurements of Susceptors for Microwave Heating Applications”

Microwave susceptors are semitransparent metal sheets used to enhance local dissipation of power in a microwave heating process. Accurate electromagnetic characterization of susceptors is essential for the analysis and design of microwave power engineering systems. The work addresses outstanding issues in this area and presents their new and technologically feasible solutions. It is theoretically proved that, from the viewpoint of microwave power reflection, transmission, and dissipation properties, a microwave susceptor is fully characterized by its surface resistivity. Methods of surface resistivity

measurements are discussed, with focus on a new resonator method. A dedicated split post resonator and single-post resonator are introduced. Further, a surrogate scaled susceptor model is proposed for accurate and effective electromagnetic simulations. Final considerations on an emerging technology of patterned susceptors demonstrate their unexpected and counterintuitive properties.

5. José M. Catalá-Civera, Technical University of Valencia, Valencia, Spain
“Advanced Microwave Measurements for High-Power Applications”

Microwave heating is in most cases a dynamic process in which the processed workload changes with time. For instance, in drying applications, permittivity of the processed material varies dynamically as water is removed, and, as a consequence, some critical parameters of the microwave applicator change dynamically as well. Therefore, measurement data of such characteristics as impedance, and dielectric properties varying in the course of microwave heating process may provide unique control capabilities that can be crucial for successful applications. High-power impedance measurement devices have traditionally been designed as 6-port reflectometers. In this talk, we describe new efficient designs and implementations of such devices based on modern Bluetooth circuits. Bluetooth ICs allow effective amplitude and phase measurement in a wide frequency and dynamic range. At the same time, the equipment cost with these devices is very low compared to classical laboratory equipment.

6. Monika Willert-Porada, University of Bayreuth, Bayreuth, Germany
“Parameter Analysis of Atmospheric Microwave Plasma Generation in Fluidized Beds”

Fluidised bed technology is widely used in chemical engineering because of its capability of fast, efficient and homogeneous heat transfer in very large volumes of poor heat conducting particulate materials. A significant extension of this processing technology is possible when atmospheric microwave plasma is introduced into fluidised beds containing reactive particulate materials or reactive gases. This talk describes two examples of new processes which utilise microwave plasma for coating of particulate substrates and for synthesis of a very reactive chemical (TFE). Based on experiments, a model for the mechanism of plasma ignition and sustain is developed. It is experimentally verified, that depending upon the type of particulate solids the emission of thermal electrons or the evaporation of metal from the particulate solids are the ignition controlling steps, whereas the fluidised gas composition in the solid free bubbles governs the sustain of plasma at atmospheric pressure.

7. Matthias Graf, Fraunhofer Institute for Chemical Technology, Pfinztal, Germany
“FEM Simulation of Microwave Plasma”

Microwave generated plasmas excel in low-pressure processes because of high attainable plasma densities and low ion energies. Important applications are surface modifications like scratch resistant polymer surfaces, e.g., or coatings for solar cells. For these large

area applications, plasma sources are necessary. The high costs of test-types make further upscaling difficult with current concepts. We have developed a simulation model which can be used for flexible design of large-scale plasma devices. A coupled system of Maxwell's, transport and heat equations for microwave plasma is solved self-consistently and time resolved by a finite element software package. We present the simulation results for the Plasmaline, a very flexibly extendable source. First experimental verification of our model by measurement of plasma parameters is also shown. Applications of the model towards the design of new microwave plasma sources for upscaling several industrial processes are finally discussed.

8. Vadim V. Yakovlev, Worcester Polytechnic Institute, Worcester, MA, USA
“Efficient Techniques of ANN-Based Microwave Imaging in Closed Systems”

This contribution presents a new modeling-based technology of microwave imaging for non-destructive evaluation (NDE) of materials in closed cavities. The approach based on artificial neural network (ANN) optimization and backed by FDTD data is shown to be capable of reconstructing the internal structure of the samples from measured S-parameters. Three techniques designed for a waveguide fixture are considered: first determines complex permittivity of the sample; second reconstructs 2D permittivity profiles; third detects a position and size of a spherical object in a dielectric body. Demonstrated efficiency of these techniques are conditioned by architectures, training mechanisms, and other special features of the employed RBF ANNs. Due to their capabilities of providing accuracy satisfactory for practical needs and orientation on elementary measurements, the presented techniques appear to be attractive NDE technologies serving various needs/applications of microwave power engineering.

9. Yoshio Nikawa, Kokushikan University, Tokyo, Japan
“Microwave Power Applications to Metamaterials and Measurement of Complex Permittivity under NMR Temperature Mapping”

Microwave power is a very efficient source to heat wide-ranging lossy material. In this study, to obtain temperature dependent complex permittivity of low loss homogeneous material, cylindrical cavity resonator of TM₀₁₀ mode and heating system in a frequency of 2.45 GHz band has been designed. The characteristics of composite material and metamaterial are also measured and evaluated using this technique. Furthermore, to measure temperature depending complex permittivity of lossy material, phase shift of T₁ signal in magnetic resonance (MR) has been observed using 0.3T open-type nuclear MR equipment to measure the temperature in the material with measurement of complex permittivity using open ended coaxial probe to apply microwave power with obtaining reflection coefficient. By such methods discussed here, complex permittivity of material in wide temperature range can be obtained.

10. Lambert Feher, Forschungszentrum, Karlsruhe, Germany
“Microwave Quantum Interactions for Polymer and Composite Curing”

Polymer materials exposed to microwave field undergo the thermal Brownian motion and rotational resonances originated uniquely by microwaves. This talk presents a new quantum representation that explains the behavior of the assigned classical electric conductivity. It can be applied for processing ceramics, composites, polymers, nano materials, and many others. It also forms the basis for refined descriptions for energy conversion and absorption mechanisms, leading to new processes and enhanced material properties. Microwave coupling can be much more diversified due to correlation effects than the traditional classical approaches are capable to describe. These results give rise to innovative approaches for energy efficient polymer processing for automotive and aerospace applications with microwave technologies. Such technologies are currently investigated in industrial projects at FZK and will be presented at the Workshop.