Microwave Materials Processing Activities at the Karlsruhe Institute of Technology

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Karlsruhe Institute of Technology (KIT) as "The research university in the Helmholtz Association" is a pioneer in the German science system which maximized the synergies by the merger of a national large-scale research center and a state university. A major activity of KIT is allocated in the Helmholtz Research Field Energy.

The working group on microwaves materials processing, which is part of the Institute for Pulsed Power and Microwave Technology is active in the Helmholtz Program Materials and Technologies for the Energy Transition (MTET). Actual microwave applications of interest are motivated by the need to electrify process heat, to increase resource and energy efficiency. The group started by Guido Link more than 30 year ago has gathered broad expertise in various fields of applications and has acquired knowledge on dielectric characterization, on system and process design and simulation as well as experimental validation and process control. Based on many years of work in this field and several public funded joint R&D projects with partners from research and industry, a considerable infrastructure of measurement and testing facilities is available. This can be offered to interested partners from industry and science for feasibility studies of new application ideas.

Actually, the main activity of the microwave groups within the Helmholtz MTET program is on the development of power-to-X technologies to convert renewable electricity into chemical energy carriers. A major focus is plasma-based activation of CO_2 using atmospheric microwave plasmas sustained with pulsed high-power solid-state microwave generators [1]. Various plasma torches and nozzle designs for plasma quenching have been investigated to further optimize the conversion and energy efficiency of the CO_2 dissociation process.

$$CO_2 \rightarrow CO + 1/2\ O_2 \qquad + 283\ kJ/mol$$

Latest results are presented in Fig. 1.

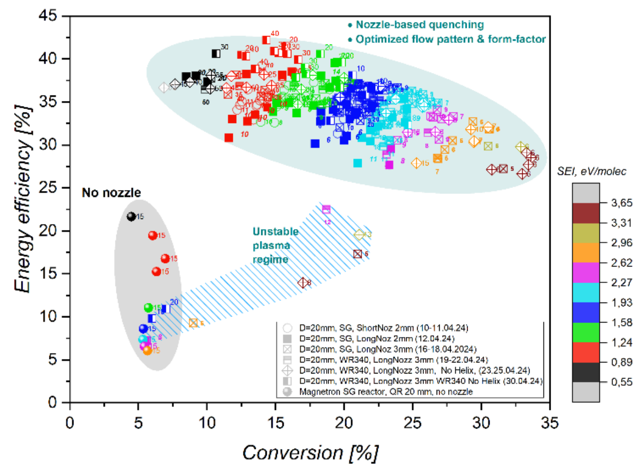

Fig. 1: Energy efficiency vs. conversion of CO2 for different nozzle designs. Specific energy input (SEI) is color coded.

In addition to this activity, there are several very diverse and public-funded joint research projects in which KIT is supporting innovative microwave ideas. Recently completed and still ongoing projects include the following:

TOMOCON

The European Marie Skłodowska-Curie Training Network "Smart tomographic sensors for advanced industrial process control" (TOMOCON – www.tomocon.eu) joined 12 international academic institutions and 15 industry partners, who worked together in the emerging field of industrial process control using smart tomographic sensors. In close collaboration with Chalmers University of Technology and the University of Eastern Finland, the KIT was engaged in the development of a microwave tomography (MWT) and its application in microwave drying of porous materials.

This microwave tomography (MWT) system was integrated in a high-power hybrid heating system to determine the moisture distribution inside wet polymer foam. The microwave drying system is equipped with a conveyor belt that enables a continuous drying process. The objective was a uniform drying of the foam to a specific moisture content. This requires in-situ and non-invasive measurements of the unknown moisture distribution inside the foam. Therefore, the developed MWT was installed next to the HEPHAISTOS oven (see Fig. 2). Various models and algorithms to solve the inverse problem have been developed and investigated [2].

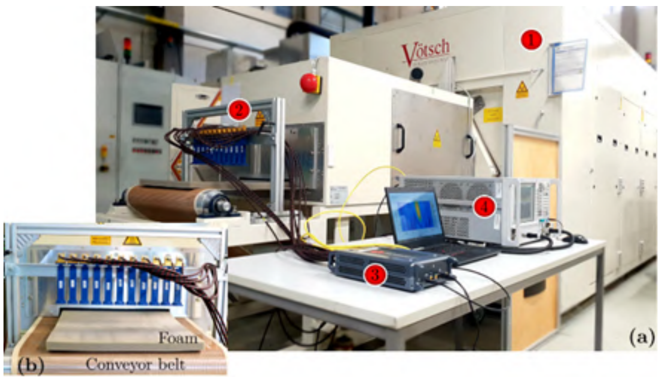

Fig. 2: (a) MWT system and its integration with the HEPHAISTOS is shown. The numbers 2, 3, and 4 shows the MWT system, Solid state switch, and VNA respectively. (b) shows the enlarged view of the MWT antenna array.

IMPULS

IMPULS was a national funded project related to microwave assisted pultrusion of carbon fiber reinforced composites. The IMPULS Project mitigates the limitation of state for the art pultrusion technology with contact heat. As microwave heating allows to selectively heat the profile in the otherwise cold tool, the degree of cure of the profile can be changed instantaneously by changing the microwave power. By alternating between fully cured and uncured segments, the profile can be locally deformed in a subsequent process step, opening the process to a variety of new applications. Within the scope of the project proper microwave heated forming tools were built and tested. Successful test ware performed and the desired transitions between cured and uncured segments, with small transition lengths, was demonstrated. [3]

MWPrint4ReCon

The MWPrint4ReCon project is a Helmholtz Technology Transfer and Validation project to validate the KIT patented microwave assisted 3D printing technology [4, 5] on a meter scale, for the production of continuous carbon fiber reinforced spatial lattice structures (CCFSLS) and those structures will be used for the reinforcement of concrete. Concrete is used in most of the world's buildings and constructions. Forecasts predict that the annual production of cement, which is an essential component of concrete, will increase by 50% by 2050 which today is responsible for more than 8% of the global anthropogenic CO_2 emissions. The usage of (CCFSLS) instead of conventional steel reinforcement is a potential solution for a significant reduction in concrete consumption and thus improvement of its carbon footprint. The MWPrint4ReCon project is to validate the idea with CCFSLS reinforced precast concrete elements. The microwave assisted printing head is already designed and built. The robot-based printing cell as well as the printing process itself is still under development.

CORAERO

The Helmholtz CORAERO project (www.coraero.de) brings together a multidisciplinary group of scientists from virus biology, medicine, applied physics, chemistry, and engineering to understand virus spreading through aerosols and designing technical and administrative measures for mitigation, detection and virus control. The COVID-19 pandemic, caused by SARS-CoV-2, led to over 774 million cases and seven million deaths globally by January 2024, highlighting the continuing need for the development of innovative and effective technologies to prevent virus transmission and manage future pandemics effectively. The IHM microwave group supports CORAERO with R&D on air purification systems that utilize microwave radiation to reduce virus load in enclosed spaces, targeting airborne viruses in public and private ventilation systems. First tests with virus laden aerosol in biosafety level 3 laboratory with CORAERO project partner show promising results. Further experiments are planned and will be published.

PAMICO

In farming, weeds compete with crops for sunlight, space, nutrients, water, and CO_2 and can significantly impact crop products worldwide.

Even though an estimated 3 billion kg of pesticides is currently applied worldwide, it is estimated that 37% of global crop production is still lost. Controlling and demolition of the distribution of weeds in a crop field is vital to increase the production rate. Weed control by microwaves is supposed to be an environmentally friendly method for replacing chemical and pesticide methods, which are no longer acceptable from an ecological point-of-view.

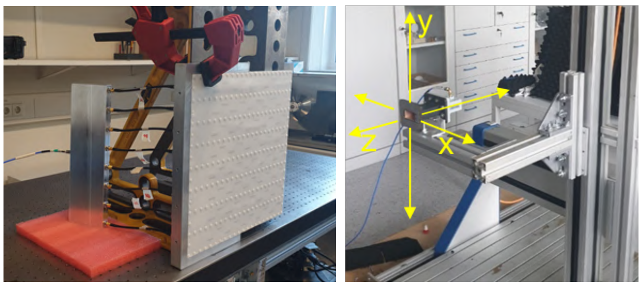

Fig. 3: Test stand for measuring antenna characteristics using a power divider connected to the slotted waveguide array antenna (left) and a WR159 receiving antenna fixed to a xyz positioning stage.

As part of an IraSME funded project, IHM is in charge of development and demonstration of a novel phased-array 5.8 GHz microwave antenna, which will allow to focus the microwave power installed to the weed location which was identified before by optical methods and AI technology [6]. The volumetric and selective heating by microwaves, can lead to the bursting of cells inside the plant at high power densities. The test stand for the validation of the designed and developed slotted waveguide phased array antenna is shown in Fig. 3. In a next step, phase shifters will be installed to each antenna port to demonstrate the beam steering capabilities prior to the setup being prepared for testing on the field.

Acknowledgement

I kindly acknowledge the working group consisting of 2 senior scientist, 2 engineers and a number of PhD students acting as project engineers, continuously solving all microwave-specific problems with great enthusiasm and motivation. The group is well supported by a competent in-house mechanical and electronic workshop. Those projects listed are supported by national and European funding programmes within the support codes: ZF4204604BL8; KK543301DF1; HGF contract numbers KA1-Co-06 and KA-TVP-11 and Marie Skłodowska-Curie Innovative Training Networks grant agreement number 764902.

For further readings

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About the author

Guido Link received the Dipl.-Phys. and Dr. degree in physics from the Technical University Karlsruhe (now KIT), Germany in 1990 and 1993, respectively. His diploma thesis and graduate research was devoted to the frequency and temperature dependent dielectric characterization of low loss ceramics and ionic crystals. Since 1993, he has been working at the Karlsruhe Institute of Technology, Germany in the field of high-power microwave and millimeter-wave processing of materials as a team leader at the Institute for Pulsed Power and Microwave Technology. His research interest includes dielectric measurements, design and simulation of microwave systems and processes, microwave assisted sintering, curing of polymer composites, additive manufacturing and plasma chemistry.