Multiphysics Modelling of a Microwave Furnace for Efficient Silicon Production

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Introduction: The JPM Silicon GmbH presents a novel method for the production of solar grade silicon in the microwave oven. This method can specially reduce the energy costs and increase the efficiency of the process. A numerical model is developed which depicts the physical, chemical and electromagnetic phenomena of silicon production process. In order to increase the efficiency of the system, it is important to identify the relevant influencing parameters and estimate their uncertainties.

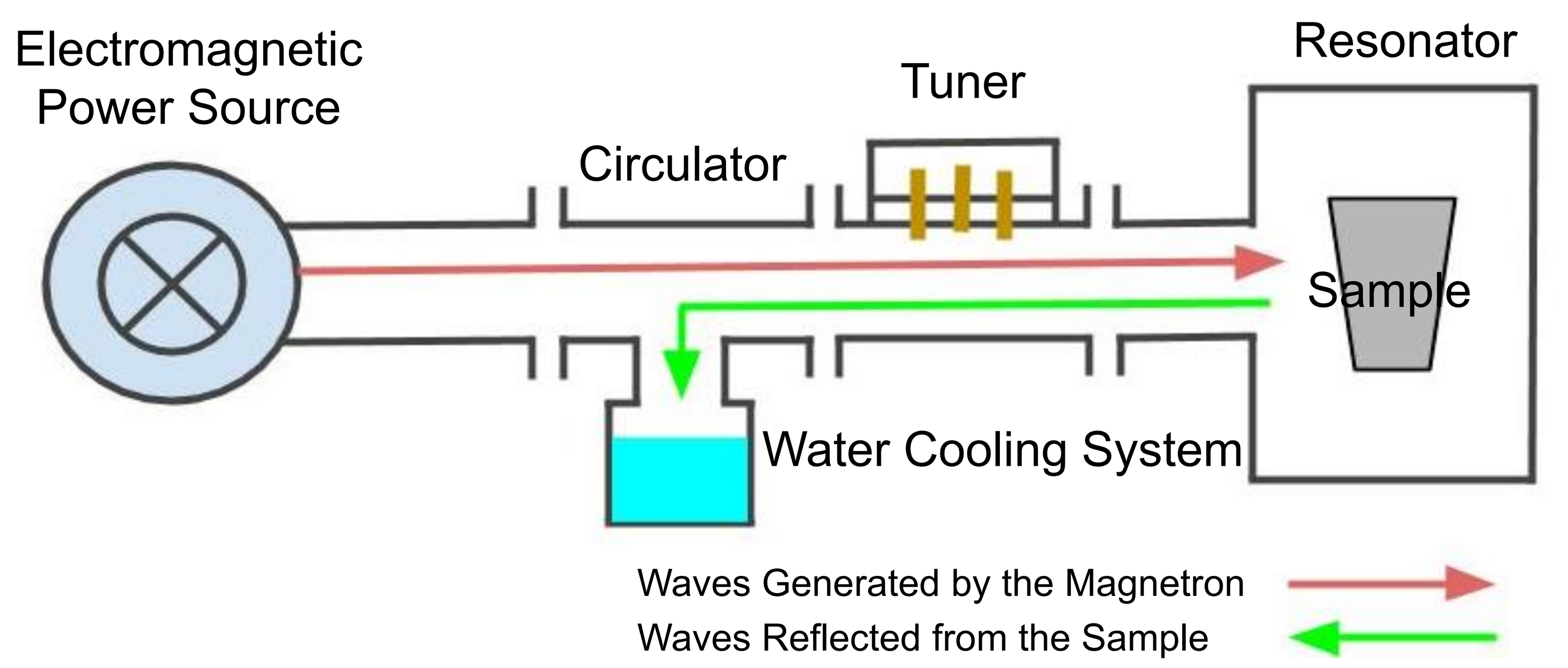

Figure 1. Schematic representation of the microwave system of JPM Silicon GmbH

Computational Methods: For illustration of relevant processes within the microwave oven, the Heat Transfer (HT) module, the Radio Frequency (RF) module, and the Computational Fluid Dynamics (CFD) module are used. In RF module, the calculation of the electromagnetic field intensity and distribution is carried out, which is originated from the intended port power (p) and the electromagnetic boundary conditions are set according to the Maxwell-equations. The total dissipated heat through polarization effects is interpreted as volumetric heat source in the HT module. The HT module forms the heat transfer mechanisms in different material types. This constitutes the thermal conduction in solids, the convective heat transport in gaseous media, and the electromagnetic radiation in the form of photons in both transparent and opaque media. The CFD module solves the Navier-Stokes Equations, obtaining the gas velocity profile, which will be used by HT module for the calculation of convective thermal losses.

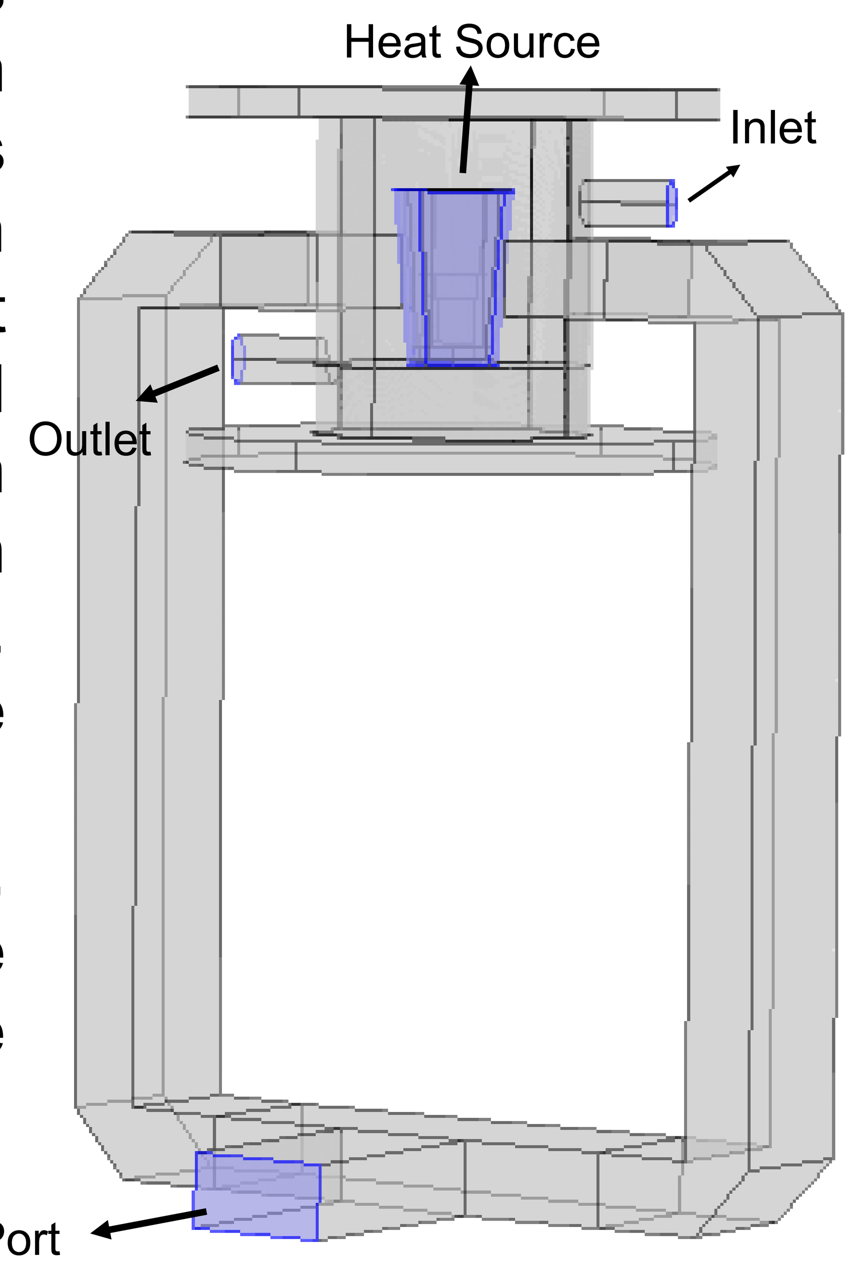

Figure 2. Overview of the Geometry Used for the Simulation

Results: At the height of the waveguide ports, the electric field is increased relative to the rest of the resonator. Moreover, a field enhancement at the core of the simulated sample is also observed. This is the ideal height, where the crucible can be located to be heated (Figure 3). However, the electric field strength alone cannot be used as a measure of the heat input in the system. yet, the hottest point is expected to be the center of the heated sample and this is confirmed by the Figure 4, which shows the resulting temperature distribution throughout the resonator chamber.

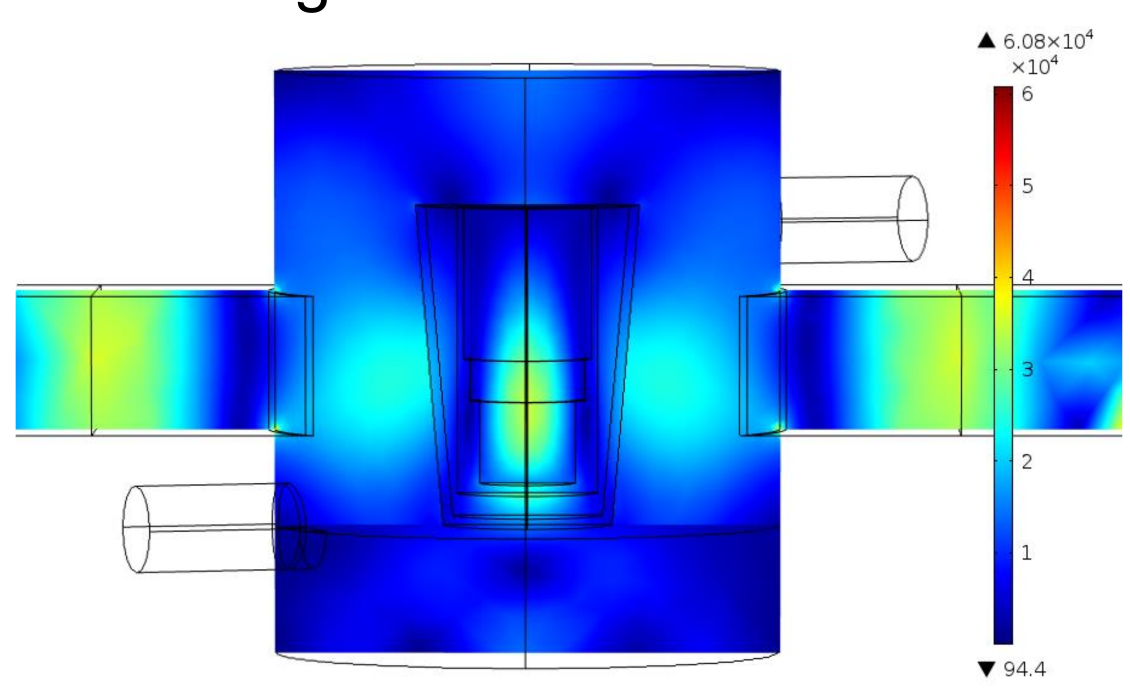

Figure 3. Electric Field Distribution in Resonator

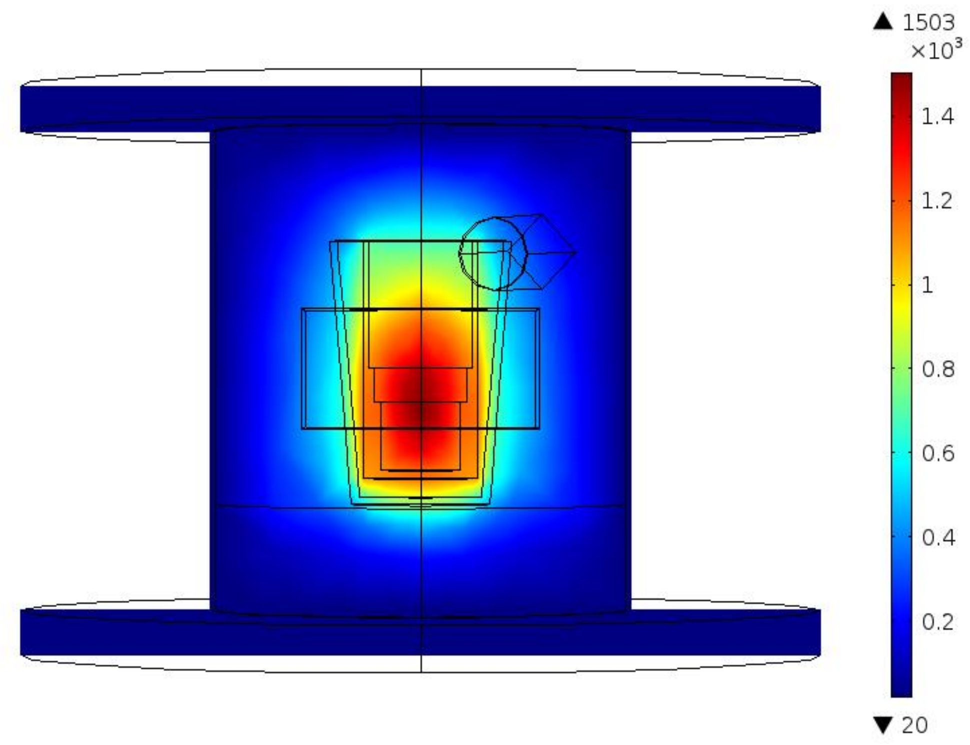

Figure 4. Heat Distribution in Resonator

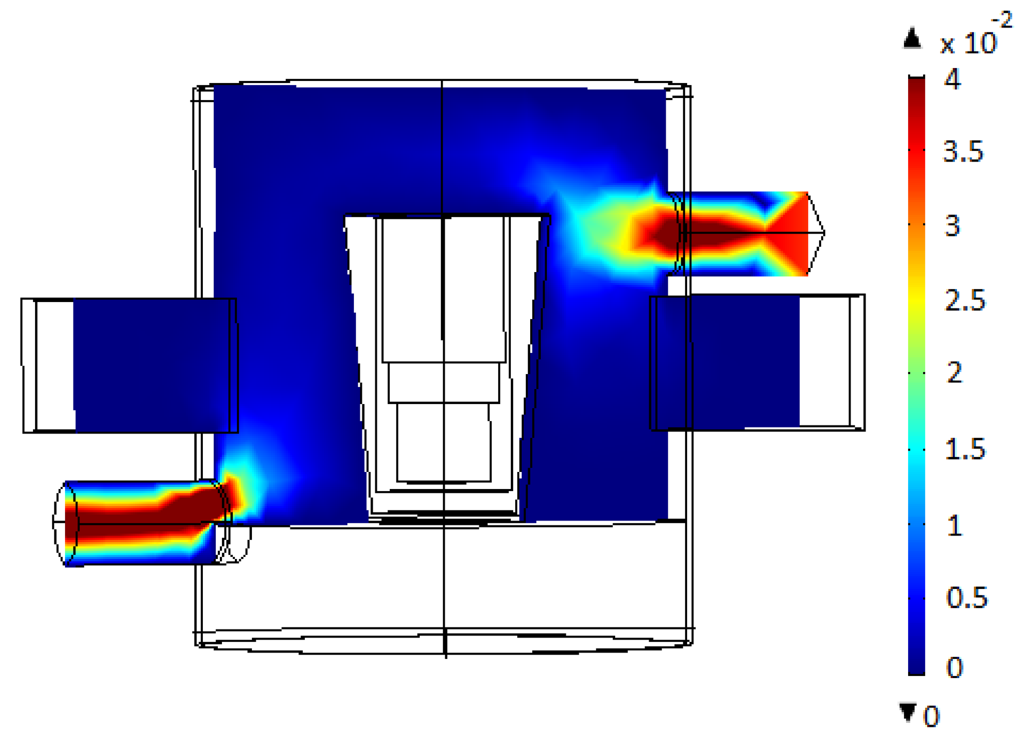

Figure 5. Gas Velocity Distribution in Resonator

Conclusions: COMSOL Multiphysics made it possible to simulate the internal processes within the microwave furnace. The simulation results could mainly help to identify the optimum design and appropriate materials in order to reach a high-efficiency system.

References:

1. S. Pielsticker, Simulationen zum Temperaturprofil im Reaktionsgemisch der carbothermischen Reduktion von Quarz im Mikrowellenofen, JPM Silicon GmbH, Germany (2014)
2. H. Ziebold, Wärmetechnische Auslegung eines Hochtemperatur-Mikrowellenreaktors, JPM Silicon GmbH, Germany (2012)