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Adaptive Control of Microwave Power During Microwave Sintering

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Summary

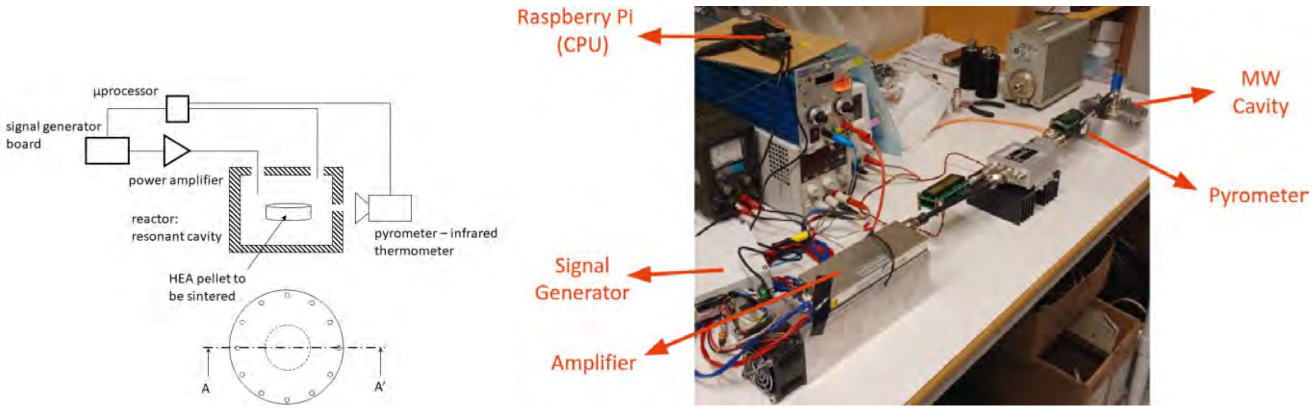
This paper establishes a novel technique to control microwave power in order to sinter materials placed within a microwave cavity resonator (MCR). MCRs separate the magnetic and electrical fields allowing the interaction of these fields with any target material placed within the cavity. The material properties can be evaluated based on S-parameters i.e., the ratio between the incident and reflected power. Thus, with reliable measurements of S-parameters this opens the possibility to track changes in material properties as temperature increases. This is facilitated by an adaptive control algorithm that helps guide energy efficient solutions while simultaneously maintaining desired temperatures of the target material. In this paper we introduce the experimental setup and present initial results of a heat profile (HP) i.e., desired temperatures over time intervals, that is followed by the adaptive algorithm.

1. Introduction

Microwave (MW) sintering is a technique that consists of heating of material through absorption / coupling of the microwave energy followed by the heating of the material through the conversion of the electromagnetic energy into thermal energy. This volumetric heating ability of the microwave results in sintering of powder compacts with enhanced diffusion, short processing time and lower energy cost. Therefore, this has allowed for rapid heating of common metals [1] and fabricating bulk amorphous alloys [2] using microwave heating. As the material properties change with the temperature, the resonance frequency of the cavity resonator is also changing. An active feedback algorithm that tracks the operating frequency can help drive amplifiers to optimize the power injected in the resonator and maintain sintering temperatures. One of the key prospects of such a technology is that, the same machine can be used to sinter different materials efficiently with little to no reconfiguration. This flexibility and reproducibility are driving elements of "Industry 4.0" or the fourth industrial revolution.

2. Experimental setup

The microwave set-up is composed of a cavity resonator, operating in the ISM band 2.4 - 2.5 GHz. The material to be sintered can be inserted in its center, where the electrical field amplitude is the maximum. The cavity is also provided with an opening for the temperature readout using a pyrometer as shown in Figure 1.a. A pyrometer is a contact-less infrared thermometer. This is used as input of a feedback loop, controlled by a microprocessor (Raspberry Pi) that is connected to a signal generator (SG) board which is controlling the MW power, frequency at the time of operation (Figure 1.b).



(a) (b)

Figure 1. (a) Cross section of TM_{010} cavity with a center slot to insert material held by a test tube. (b) Experimental setup.

3. Experimental results

Graphite powder is used as the target material due to its high thermal resistance. Approximately 500mg of graphite powder is introduced into a quartz test tube that is placed inside the cavity as shown in Fig. 1.a. The Amplifier and SG that are controlled by the microprocessor runs a frequency sweep of the cavity to establish the maximum resonant frequency of target material based on the S_{11} measurements. The highest coupling for the material is initially established at 2.452 GHz as shown in Fig 2. The algorithm now begins to deliver power into the cavity and follows the heat profile (HP) suggested for the target material. The HP suggests the algorithm to maintain 640º C across 5 mins, excluding ramp up and ramp down times. The Figure 3.a. highlights the performance of the algorithm in maintaining high temperatures. When we get to temperatures greater than 600º C we observe the graphite glowing within the cavity as observed in Figure 3.b.

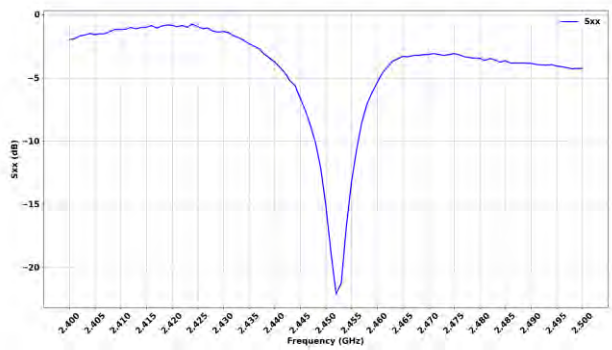
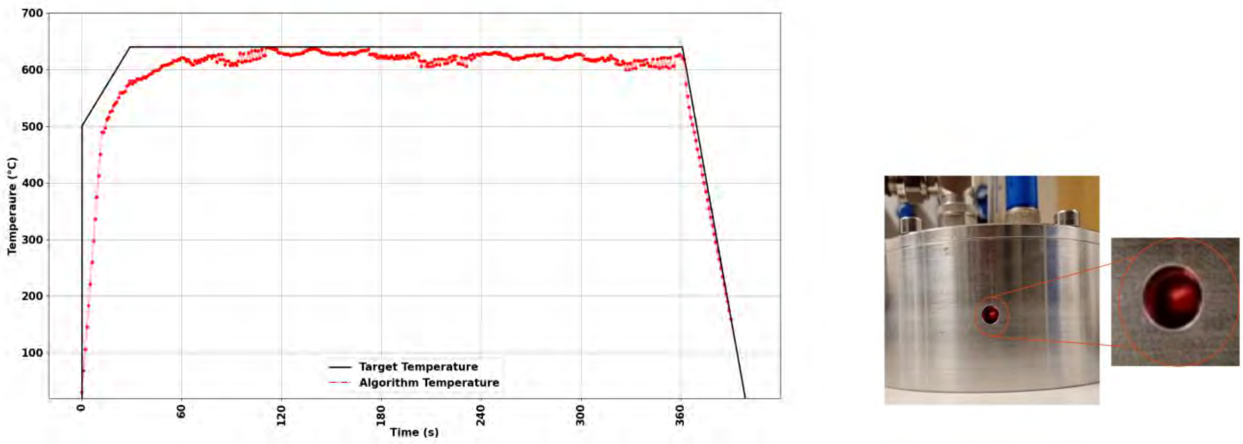


Figure 2. Reflection coefficient S_{11}, obtained in real time, in a frequency sweep between 2.4 - 2.5 GHz directly from the amplifier readout of forward and reflected power. The TM_{010} cavity is loaded with 0.5 g of graphite, placed in its center.



(a) (b)

Figure 3. (a) Performance of algorithm (red) in the defined heat profile (black) for graphite. (b) Graphite glowing at 600C.

6. Acknowledgements

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References

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