Design of Multimode Microwave Cavity for Materials Processing

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Abstract

This paper presents design and simulation of a multimode microwave cavity at 2.45 GHz for materials processing. Microwave cavity with dimensions 305mm x 203mm x 305mm has been modelled with two waveguide ports to couple two generators using CST Microwave Studio 2012® commercial software. Adding one more microwave input to a multimode cavity can result in increased heating power and field uniformity if designed properly. The Design goal of microwave cavity is to couple two low power microwave generators to generate more heat power. The waveguide port arrangement is done so as to obtain uniform field distribution and low coupling between two generators. Different locations of waveguide ports were simulated and cavity was optimized to obtain low coupling and uniform field distribution. Simulation results show that a minimum -38.3db mutual coupling was achieved with two waveguide ports arranged perpendicular in cross current polarization. Simulated results show that Electric field distribution inside the microwave cavity with this waveguide port arrangement is well uniform.

Keywords: Applicator, multimode, cavity, waveguide.

1 Introduction

Application of microwave heating to materials processing offers advantages of reduced processing times and energy savings. Microwave processing equipment mainly consists of three major components: Source for electromagnetic field generation, Applicator where field interacts with material and Transmission line (Waveguide) for delivering the microwave energy to applicator. Design of the applicator is critical as it determines the electromagnetic field distribution for interaction with the load material. Uniform wave distribution and efficient absorption of the set energy by load material are desirable for effective material processing.

Design of industrial microwave oven is complicated due to several considerations such as load type, heating uniformity and hot/cold spots. Varith J. et al. (2007) presented a design of multimode circular microwave cavity at 2.45 GHz as a section of multimode microwave oven. Industrial microwave ovens are available both at 915 MHz and 2.45 GHz frequencies. Microwave oven at 915 MHz has an advantage of higher penetration depth than that of 2.45GHz. The potential application of microwave bandwidth of 2.45 GHz is increasing because it is not limited to application of the industrial microwave generator but also available for household microwave generator modification. Thostenson E.T. et al. (1999) has given an overview of microwave applicators and processing systems. The design of the applicator is critical to microwave heating because the microwave energy is transferred to materials through the applicator. The temperature fields within the material undergoing microwave heating are inherently linked to the distribution of the electric fields within the applicator.

Common microwave applicators include waveguides, traveling wave applicators, single mode cavities, and multi-mode cavities. For heating and material processing applications, resonant applicators, such as single mode and multi-mode applicators and non-resonant waveguides are most popular. Resonant cavities are commonly used because of their high field strengths. The type of applicator used in a microwave processing system depends on the application and type of material to be processed. Single mode, multi-mode, and variable frequency multi-mode processing systems are commercially available and are being used for different microwave processing applications. Single mode applicators are being used in specific applications such as joining of ceramics and laboratory-scale study of microwave/materials interactions. J.Asmussen et al. (1987) presented a detailed description of single mode or controlled multimode microwave cavity applicators for precision materials processing. Multimode cavities can be used for processing large sized objects and are suitable for batch operations and therefore most industrial microwave processing systems employ multimode cavity. Srinath M.S.et al. (2012) presented
simulation and analysis of microwave heating in a multimode microwave applicator.

Multimode cavity is widely used as an applicator in microwave processing because of low cost, simple construction and adaptability to wide range of heating loads. To achieve more uniform electric field distribution and higher heating power multiple microwave inputs can be added in a microwave cavity. That means it is possible to couple two or more low power microwave generators (< 1 kW) in series to generate higher heating power in a multimode microwave cavity. The objective of this work was to design a multimode microwave cavity with two waveguide microwave inputs to couple two low power microwave generators to generate more heat power. The waveguide port arrangement is done so as to obtain uniform field distribution and low coupling between two generators. Different locations of waveguide ports were simulated and cavity was optimized to obtain low coupling and uniform field distribution.

2 Theory of microwave cavity

The wavelength of a resonant frequency in a rectangular cavity with dimensions a, b, and c is given by

\[ \frac{2}{\lambda} = \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{c}\right)^2} \] (1)

Where \( \lambda \) is the wavelength of the microwave in the oven chamber and m, n, and p are zero or positive integers, called mode set numbers. If the dimensions of the oven chamber match the resonant frequency, then three-dimensional standing waves are formed. The dimensions a, b, and c of the chamber are proportional to the wavelength in each of the corresponding directions as given by

\[ a = \frac{m \lambda_x}{2}, b = \frac{n \lambda_y}{2}, c = \frac{p \lambda_z}{2} \] (2)

And

\[ \frac{1}{\lambda} = \sqrt{\frac{1}{\lambda_x^2} + \frac{1}{\lambda_y^2} + \frac{1}{\lambda_z^2}} \] (3)

Kamol S. et al. (2010) demonstrated three dimensional standing waves in microwave oven complying with theoretical calculation of the electric field distribution in the oven chamber. The electric fields in an empty microwave oven can be obtained by solving Maxwell’s equations, which yield solutions for the electric fields in terms of the coordinates x, y, and z and time t as

\[ E_x = E_1 \cos k_1 x \sin k_2 y \sin k_3 z e^{-j\omega t}, \]
\[ E_y = E_2 \sin k_1 x \cos k_2 y \sin k_3 z e^{-j\omega t}, \]
\[ E_z = E_3 \sin k_1 x \sin k_2 y \cos k_3 z e^{-j\omega t}. \] (4)

Where \( E_x, E_y, \) and \( E_z \) are the components of the electric fields in the x, y, and z directions. \( E_1, E_2 \) and \( E_3 \) are the amplitudes of the electric fields in the x, y, and z directions, \( k_1 = \frac{m \pi}{a}, k_2 = \frac{n \pi}{b}, \) and \( k_3 = \frac{p \pi}{c}, \) and \( t \) is the time.

3 Model Simulation

In the present work a multimode cavity has been modelled to couple two generators using CST Microwave Studio 2012® commercial software. Three dimensional (3D) microwave heating geometry has been created. The microwave cavity is a metallic box with two 1 kW, 2.45 GHz microwave sources via rectangular wave guides ports operating in the TE10 mode.

The dimensions of modelled cavity are 305mm x 203mm x 305mm and it has two rectangular waveguide ports for coupling two microwave sources as shown in figure 1. The wave guide port allow the microwaves to pass through and enter into the applicator. Two ports can be configured in two configurations: (a) in crosscurrent polarization (b) in concurrent polarization as shown in figure 1. At an excitation frequency of 2.45 GHz, the generator is assumed to provide effective voltage supply of 1V.

![Figure1: 3D model of Microwave cavity with two waveguide ports for coupling two generators (a) in crosscurrent polarization (b) in concurrent polarization](image-url)
Background material of model is set as PEC (Perfect Electric Conductor). The model approximates wall of cavity and waveguides as perfect conductors with boundary conditions as Electric field intensity E=0 V/m for all dimensions. Finite integral Method is applied to simulate the model in frequency range of 2.4 to 2.5 GHz with mesh of 10 lines per wavelength. The Design goal of microwave cavity was to couple two low power microwave generators to generate more heat power. Different locations of waveguide ports were simulated and cavity was optimized to obtain low coupling and uniform field distribution.

4 Simulation results and discussion

Figure 2 shows scattering parameters S12 and S21 graph for type (a) cross-current waveguide port arrangement and Figure 3 shows same parameters graph for type (b) con-current waveguide port arrangement. Type (b) configuration (concurrent polarization) resulted in higher coupling than that of type (a) configuration (cross-current polarization) of the two waveguide ports. Results are tabulated in Table I showing scattering-parameter in range of 2450±50 MHz. The averaged S-parameter for both 1-2 and 2-1 coupling (-12.4 dB) of type (b) configuration were higher than those of 1-2 and 2-1 coupling (-18 dB) in type (a) configuration. Table also shows coupling at 2450MHz, maximum and minimum coupling values for two configurations. It is clear from table that in the frequency range of 2450±50 MHz in which two coupled microwave generator's frequency can fluctuate, arrangement of type (a) provides low coupling and is more suitable. Low coupling means less returned wave between port and therefore less risk for microwave generator to be damaged than that of type (b).

<table>
<thead>
<tr>
<th>Table I: S-parameters of waveguide port arrangements</th>
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<td>Type of polarization</td>
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<tr>
<td>(a) Cross-current</td>
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<td>(b) Concurrent</td>
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Simulation results show that a minimum -38.3dB mutual coupling was achieved with waveguide ports arrangement of Figure 1(a) showing two perpendicular ports in cross current polarization at 2.45 GHz. Figure 4 shows simulated Electric field distribution inside the microwave cavity with this waveguide port arrangement and it is well uniform field distribution. Thus, arrangement of type (a) seems to be the ideal design to obtain uniform wave distribution.
5 Conclusions

Electric field distribution inside the microwave cavity depends on the arrangement of input waveguide ports in cavity. Arranging two ports of waveguide on adjacent faces and in cross-current polarization offered low coupling. This work provided basic information for the multimode microwave cavity design and simulation explored the electric field distribution inside the microwave cavity and port arrangement for optimum design of two input microwave cavity.

References