IMPROVED OPEN ENDED MICROWAVE OVEN SYSTEM

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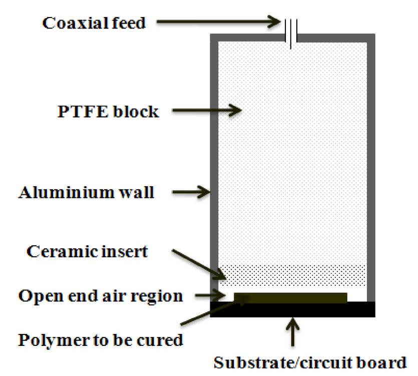
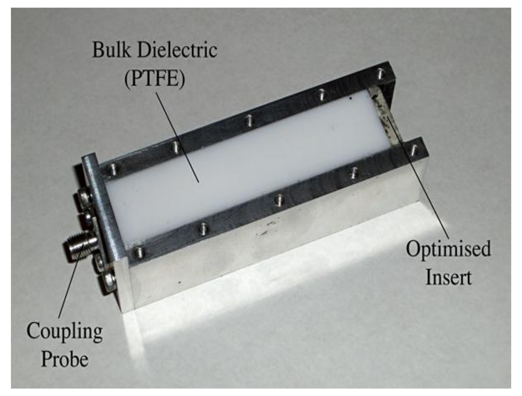
Project Overview

An enhanced open ended waveguide cavity oven is presented with improved uniform heating, heating rates and power conversion efficiency for the microwave curing of bumps, underfills and encapsulants is described. The open oven has the potential to provide fast alignment of devices during flip-chip assembly, direct chip attach (DCA), surface mount assembly (SMA), wafer-scale level packaging (WSLP), MEMS and MOEMS devices with simultaneous curing. The cavity is to be mounted on the arm of a high precision placement machine thereby permitting simultaneous alignment and curing. Combining curing and 'conventional' assembly processes into a single step suggests the open-ended geometry can offer productivity gains and lead to more efficient assembly process.

Cavity Geometry

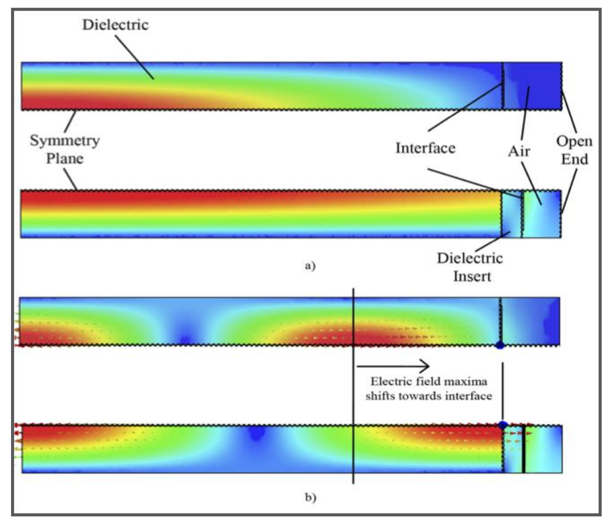




- Cavity resonators are usually formed with short circuit termination at each end and, in turn, form a close metal box. Resonant modes are formed with trapped electromagnetic waves between the short circuit, at one end, and a quasi open circuit formed by the dielectric-air interface at the other.
- If the waveguide is partially filled with a low loss dielectric material (above), a resonant cavity can be formed even if on end is 'open'. Radiation losses can be minimized if, in the air region, the waveguide is cut-off.
- A sample of lossy material, placed in the evanescent fields within the cut-off section of waveguide, will experience heating if sufficient power is supplied. Therefore, the open-ended cavity becomes an open oven.

Optimization of Evanescent Heating Field

- An additional low loss dielectric material is placed within the air region (above-centre).
- Adjustment of the length and permittivity of the 'insert' will change the boundary condition experienced by a the TM (Transverse magnetic) mode wave front impacting from the bulk dielectric.
- Therefore, tuning the length of the insert, with a given permittivity, allows the optimum boundary condition to be found where the normal electric field, within the cut-off section of waveguide, is maximized.



- For the case of the cavity with no insert, the field prior to the dielectric-air interface has the properties associated with an open-circuit boundary condition. The inclusion of an optimized dielectric insert 'shifts' the normal electric field towards the interface.

- The insert effectively acts as a quarter-wave transforming section.
- Adjustment of the permittivity and length of this additional dielectric insert enables the control of the boundary condition at the dielectric-air interface and therefore provides a method for optimising the magnitude of the evanescent fields in the open end region.

TABLE I
MODEL GEOMETRY

Bulk Dielectric	Dimensions	18mm x 18mm x 80mm
	ε_r	2.035
	tan δ	0.0005
Dielectric Insert	Dimensions	18mm x 18mm x 3.5mm
	ε_r	6
	tan δ	0.0005
Encapsulant	Dimensions	15mm x 15mm x 300μm
	ε_r	4
	tan δ	0.08

- An optimized oven has been fabricated based on the dimensions and properties shown in the table above.
- For the second TM mode, an optimized thickness results in a reflection phase of 180º .

Design of Open Ended Microwave Oven System

- To compare the net power input power flow between the optimised and non-optimised ovens, a study has been carried out by exciting both ovens at identical modes and testing the net power flow during the heating cycle. The net power flow for each case is shown below.

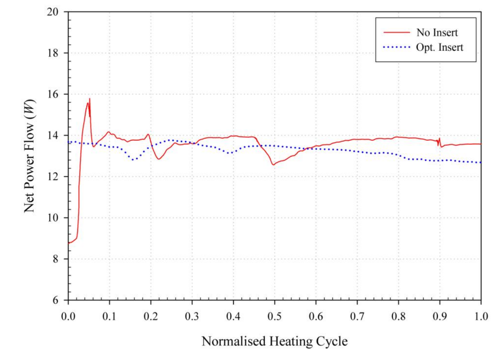
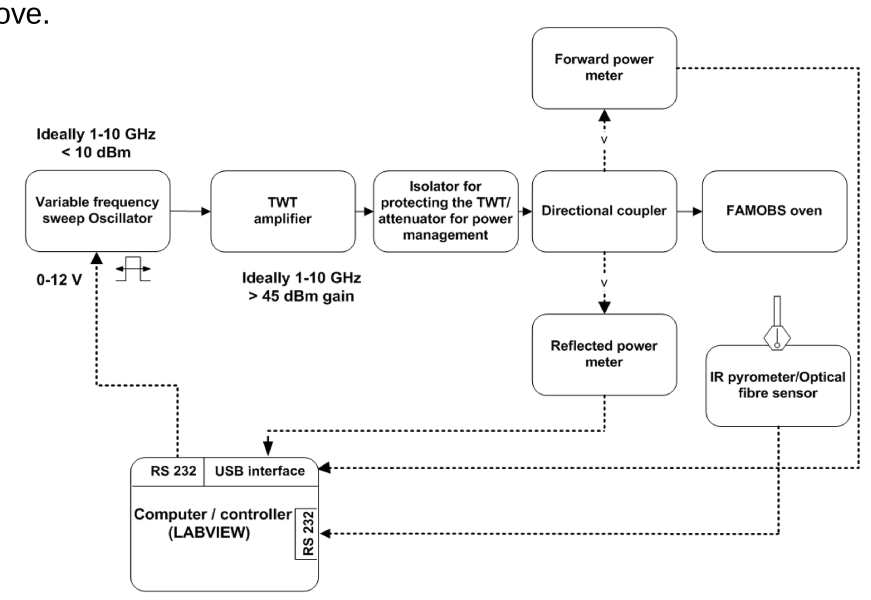


TABLE II
RESONANT FREQUENCY (GHZ)

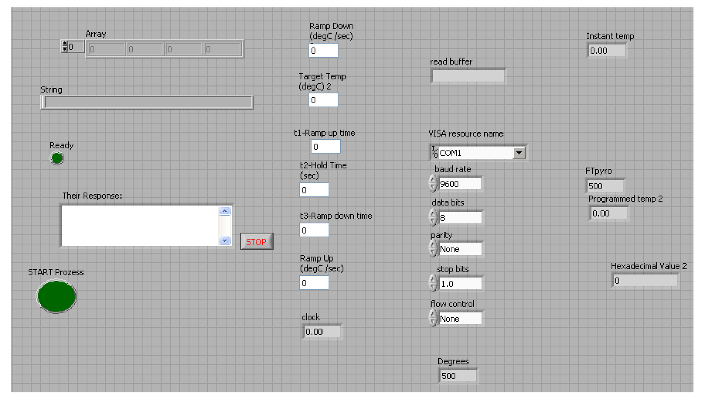
MODE	SIMULATED	MEASURED
1^{st} TM – *No Insert*	8.3502	8.355
1^{st} TM_{11} – *Insert*	8.2648	8.2625
2^{nd} TM_{11} – *No Insert*	8.6295	8.665
2^{nd} TM_{11} –*Insert*	8.4583	8.4825

- A closed loop feedback control block diagram consisting of the necessary standard microwave components, temperature sensor, data interfaces, and computer with a Labview™ program has been developed as shown in below.
- This drive s the open ended oven to achieve efficient EM (electro-magnetic) fields in the heating region. The resonant frequencies for the improved oven are also shown in the table above.



- A fiber optic temperature thermometer, the Neoptix™ Reflex™ signal conditioner, is used to record the temperature distribution within the curing sample and provides the basis for a closed loop control routine.

- The fiber optic sensor is inserted into a ceramic ferrule which is later inserted into the curing material.
- A typical cure profile consists of a ramp up period, a hold period and a ramp down period.
- Monitoring of the curing of the materials can be achieved by (a) measuring the temperature at about 100 millisecond time intervals in the material, (b) comparing this temperature with a programmed temperature profile and (c) pulsing the microwave source accordingly.
- This control feed back system monitors the heating temperature and has the potential to stipulate temperature ramp up and down rates, multiple hold temperatures and curing time intervals. The Labview program user interface is shown below.



- The system is powered using a 25W traveling wave tube (TWT) with in the X-Band frequency range.

Curing Principle

- The amount of heat transferred into the curing material with a microwave oven is given by

$$P = \frac{f\pi\varepsilon''}{V}\int \vec{E}.\vec{E}\,dV$$

- where f_{res} is the resonant frequency of the coupled mode, ε'' is the imaginary component of the complex permittivity, $\vec{E}$ is the electric field and V is the volume of the material.
- In order to maximise the dielectric power loss and therefore the heating potential, the target sample should have a high dielectric loss tangent relative to the dielectric filling (bulk) materials within the cavity.

Integration in a Robotic Placement Machine

Open ended microwave oven system

a) PC with Lab view interface

b) Sig. Gen.

c) TWT (30W)

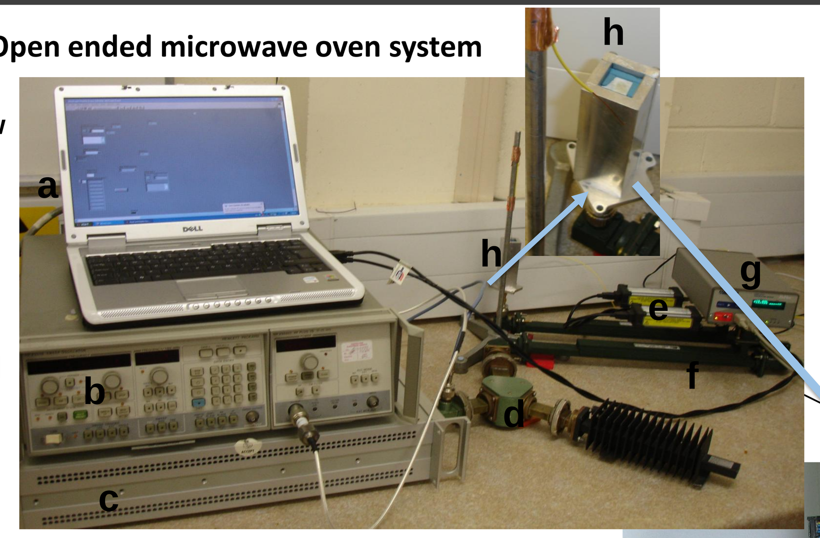
d) Isolator with load

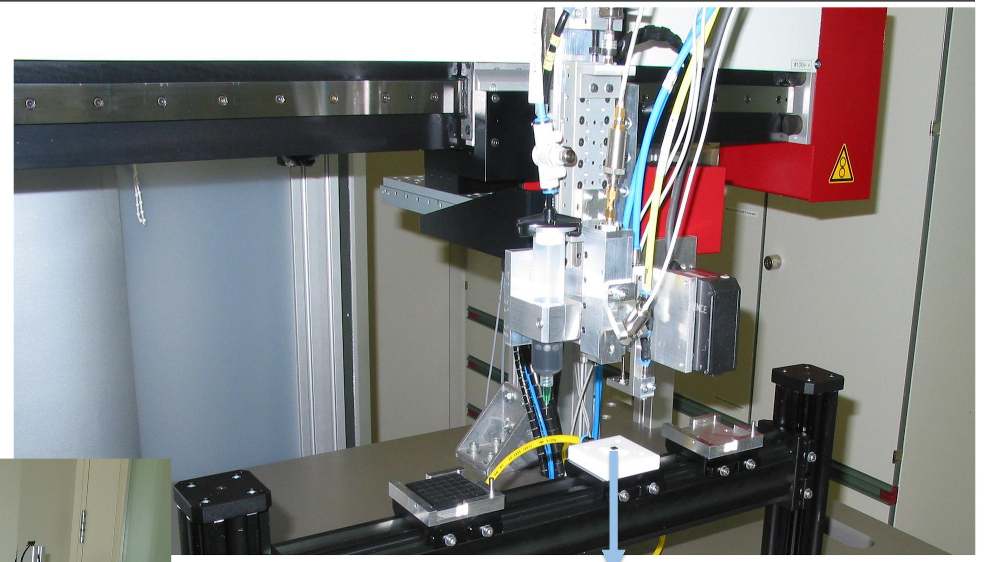
e) USB power sensors

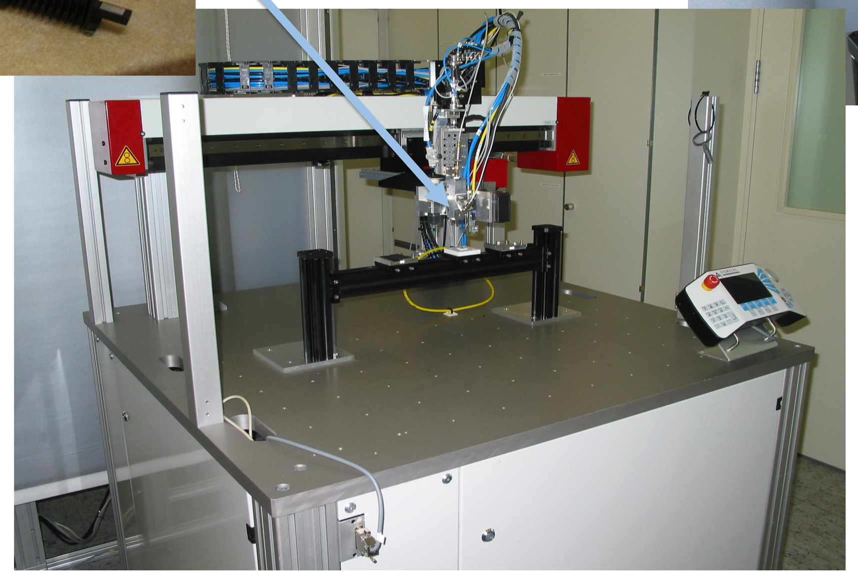
f) Directional couplers

g) Fibre optic temperature sensor

h) FAMOBS oven with a temperature probe





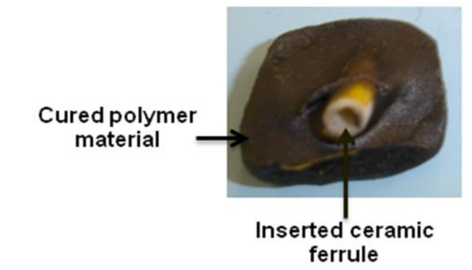


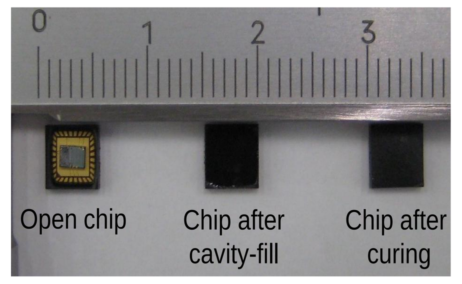
Dies, Adhesives, Underfills, Encapsulants etc

- The improved open ended oven system is integrated with a robotic placement machine.
- The robotic system is based on a portal placement machine by Sysmelec™.
- The robotic placement machined also posses a time-pressure dispensing system, a vacuum gripper, a laser triangulation sensor and a high resolution camera to aid in complete automated encapsulation process.

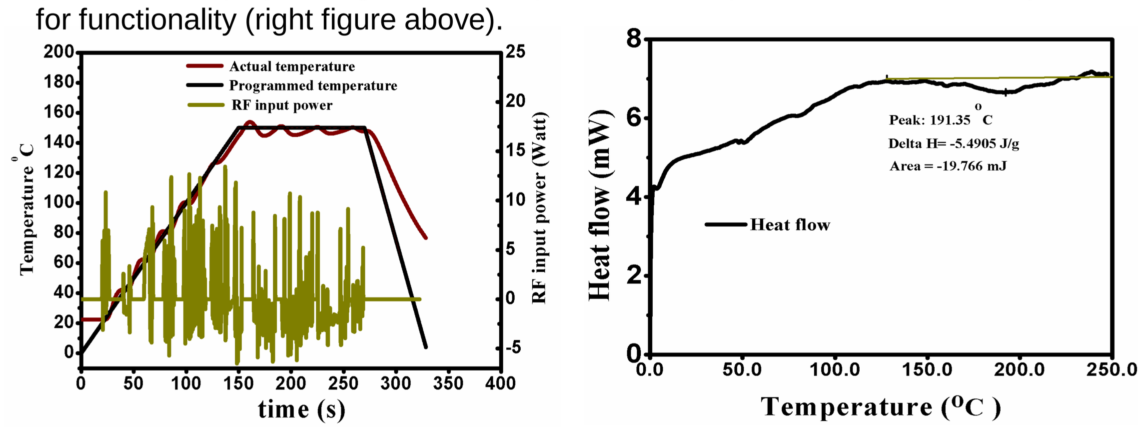
- A Labview program as described above is setup to achieve full automation of the curing and pick and placement process.
- To achieve this, the program has a curing control loop and a TCP communication loop for the pick and placement program.

Experimental Results

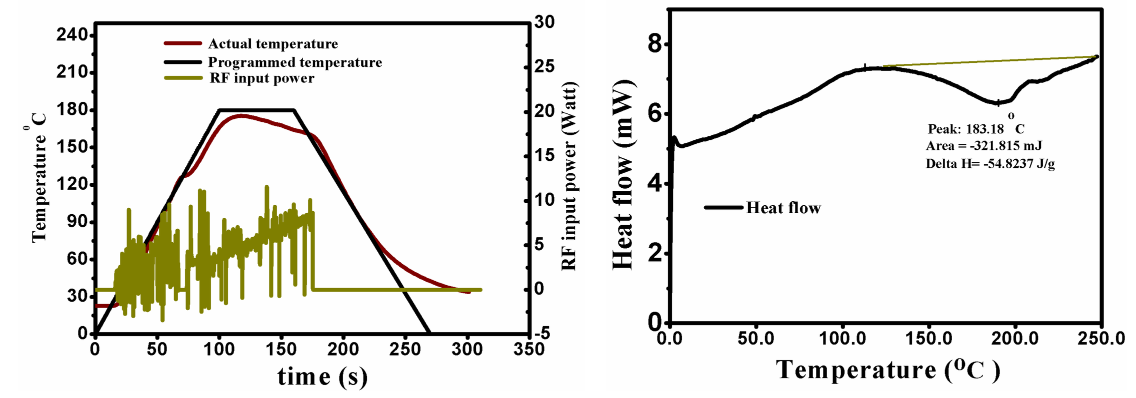




- The encapsulant used in the experimental study is EO1080 manufactured by the Company Henkel.
- Modulated DSC analysis was performed using a Perkin Elmer DSC-7 device to study the curing behaviour of the no-flow encapsulant polymer material.
- The test specimen consists of an adhesive injected on to the cover slips or PTFE film of 8 mm × 8 mm dimensions and a thickness of about 1 mm. The overall thickness of the sample varies between approximately 1 mm and 1.5 mm.
- A temperature profile has been specified according to the recommended datasheet of the paste manufacturers for curing tests. A cured specimen is shown above (left).
- An LM2940C-12 voltage regulator chip has been encapsulated in a QFN package (shown above) by curing with the improved oven system and successfully tested for functionality (right figure above).



- A two stage pulsing method is employed in order to follow the set programmed temperature profile.
- The microwave source is pulsed at a rate of about 12.5 Hz during the ramp up period for 100s and a pulse rate of about 5.5 Hz during the hold period from 100s to 160s of the curing cycle.
- Figure above shows the measurement results of the microwave power input into the encapsulant and the temperature profile for a 150 ºC curing cycle.
- The DSC curve for a microwave cured EO1080 encapsulant specimen with a 98% degree of cure for the 150 ºC cure cycle is also shown above (right).



- Figure above shows the measurement results of the microwave power into the encapsulant and the measured temperature curves for an 180 ºC curing cycle.
- The DSC curve for a microwave cured EO1080 encapsulant specimen with an 81% degree of cure for the 180 ºC cure cycle is shown above (right).
- The lower degree of cure of the polymer material for the 180 ºC cure cycle can be attributed to the smaller hold period of 60s as opposed to 120s for the 150 ºC cure cycle.

Conclusions

- An improved open end oven system that can assist in the thermal processing of various MEMS, MOEMS and microelectronic encapsulation processes is presented.
- Implementation of this oven for MEMS and microelectronics device packaging requires reliable control over the frequency, power, temperature and uniformity of EM fields combined with an understanding of cure models for the different materials involved.

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