Variable Frequency Microwave
For Chip-On-Board Glob Top Curing

Binghua Pan
(Phone: 65-4508629 Fax: 65-4565422 e-mail: binghua.pan@delphiauto.com)
Chih Kai Nah
(Phone: 65-4508629 Fax: 65-4565422 e-mail: chih.kai.nah@delphiauto.com)
Su Liang Chan
(Phone: 65-4508337 Fax: 65-4565422 e-mail: su.liang.chan@delphiauto.com)

Delphi Automotive Systems Singapore Pte Ltd
501 Ang Mo Kio Industrial Park 1
Singapore 569621

J. Billy Wei
(Phone: 919-462-1919 Fax: 919-462-1929 e-mail: bwei@microcure.com)

Lambda Technologies Inc.
860 Aviation Parkway, Suite 900
Morrisville, NC 27560, USA

ABSTRACT

VFM for COB glob top curing has been successfully demonstrated to be rapid, selective and reliable. Glob top cured by VFM yielded equivalent curing extent, Tg and CTE properties to that of convection oven curing. It is also confirmed that VFM has no effect on wire bonding integrity, including wire pull force, ball shear force and resistance. Adhesion study showed that all three glob top GT-A, GT-B and GT-C in this study by VFM processing exhibited very strong adhesion on die surface, however lower adhesion strength on substrate, especially GT-C, as compared with that of convection curing. Further optimization of VFM parameters and adhesion improvement is required. All the test vehicles of both GT-A and GT-B processed by VFM and control samples by convection oven have passed automotive reliability test requirements with no failure. C-SAM findings further confirmed that there is no delamination at the interfaces of glob top to substrate, glob top to die surface and die attach layer even after long time extreme reliability test. It is proposed to verify the feasibility and performance of VFM curing process using functional samples for real world applications.

Key Words:

Variable Frequency Microwave, Chip On Board, Glob Top, Convection Oven Curing, Wire Bonding

1. INTRODUCTION

Chip-On-Board (COB) [1] refers to a configuration in which a bare, unpacked semiconductor is attached directly onto the printed circuit board (PCB), wire bonded and then encapsulated. This technology is driven by the miniaturization trend of electronic packaging that demands for higher density, lighter weight, upgraded performance, higher reliability and lower cost. COB is widely applied and utilized in automotive, computers and office automation products.

Glob top encapsulants [2], as advanced packaging materials for COB, are used to protect semiconductor chips and bonded wires from adverse environment and increase the long-term reliability in COB applications. Commonly, glob top materials are cured by convection oven thermal heating, which utilizes the flow of hot air. Glob top conducts the thermal energy from the surface into the bulk through intrinsic thermal transport mechanism, which depends on the specific heat and thermal conductivity. The thermal conductivity of most glob top is low, leading to poor and slow heat transfer from the hot air environment to COB body. The typical glob top curing time is 2 to 4 hours by convection oven to establish full properties, which results in long process cycle time, higher energy consumption and more work-in-process.

Variable Frequency Microwave (VFM) [3-6] has been developed as an alternative to convection oven curing for the purpose of processing many of advanced materials, with particular applications in the area of advanced polymer-based electronic packaging materials. VFM curing is direct and volumetric at molecular level, hence is rapid and selective. Advantages of using this process are lower product cycle time, lesser energy consumption and floor space required, hence it is cost effective. Major VFM parameters include central frequency, frequency bandwidth, sweep time and incident power. VFM process utilizes swept frequencies and is different from traditional microwave processing, which uses a fixed microwave frequency. During an adhesive cure, like glob top in this case, the computer cycles through 4096 frequencies consecutively, with each cycle corresponding to the sweep rate input, typically 0.1 sec. Through this very fast sweeping process, the energy distribution is uniform, the problems with non-uniformity in temperature and arcing observed in most microwave oven are avoided. Moreover, VFM irradiation leads to damage-free processing because the dynamics of charge buildup are never reached when sweep rates less than 1 second are used. The microwave incident power can be automatically adjusted to provide control over the heating profiles of the workpieces.

In recent work [5-8], VFM has been shown to significantly reduce the curing time of advanced packaging materials, such as underfill, polyimide passivation coating and post mold cure. Little work can be seen on COB glob top curing application. In this study, three commercially available and production intent glob top encapsulants, GT-A, GT-B and GT-C respectively, from three different suppliers were chosen for the assessment. Comprehensive approaches have been conducted to evaluate and compare the glob top properties and reliability performance using both convection oven and VFM curing processes. Objectives are to establish VFM curing process for COB and eventually to assess its real world applications on functional products. Effect of VFM on wire bonding integrity was also studied and further improvement and suggestions are provided.

2. EXPERIMENTAL

A Lambda Technologies MicroCure2100-700 model VFM oven with Auto-Ramp control software was used in this project. VFM oven requires smaller floor space and much lesser energy consumption. The VFM operating parameters for all these experiments in this paper were frequencies between 5.85 and 7 GHz, a sweep time of 0.1 sec and incident power automatically varied up to maximum 500 Watts. Both single step and double step curing profiles were applied for the study. A convection Oven, WTB-binder FED model, was used to provide control samples with established base properties.

Three glob top encapsulants (GT-A, GT-B and GT-C) were acquired from three different suppliers to be included in the study matrix. All are epoxy-based pastes with different thixotropic behaviors that can be easily applied to encapsulate chip and bonded wires.

Differential Scanning Calorimeter (DSC, TA Instrument Model 2910), Thermomechanical Analyzer (TMA, TA Instrument Model 2940) and Electronic Balance (Model AEG-120G) were used for glob top curing profile study, glassy transition temperature (Tg) and Coefficient of thermal expansion (CTE) measurement. Dage tester and Instron tensile tester were used for die shear and lap shear test to study the adhesion of glob top to die passivation and substrate.

COB test vehicles were designed, fabricated and built to assess the long-term reliability performance as per automotive requirements. A daisy chain chip MSFB was used as test die. SRT pick and place machine was used to attach the MSFB on the test vehicles, die attach adhesive was a Delphi qualified material and cured by oven. Then ESEC wire bonder was used to conduct the 1.2mil Au wire bonding after plasma cleaning, and glob top encapsulants were applied by Asymtek dispenser or stencil printing followed by degassing. Finally all the test vehicles with COB assemblies were sent to both convection oven and VFM oven for curing. All completely processed samples were then divided into two groups for both temperature cycling and temperature humidity tests. Full chain resistance was measured to monitor the long-term performance.

3. RESULTS AND DISCUSSION

3.1 DSC Study

DSC was used to identify the glob top curing profiles and resultant curing extent. For each glob top, six VFM curing profiles were selected for this study, including four single-step and two double-step options, with different temperature and time at the temperature. Convection oven curing option was included as the Control to provide base properties for comparison.

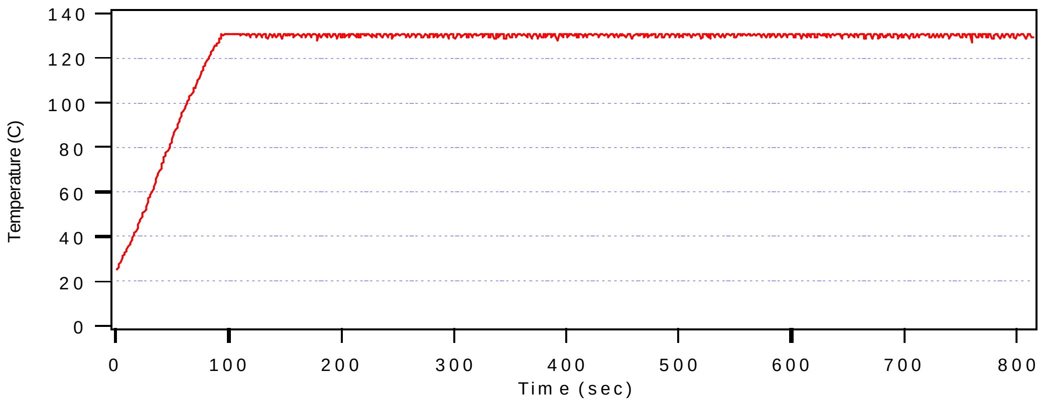


Figure 1. A typical VFM single-step curing profile

Figure 1 shows the typical VFM curing single-step profile at 130°C for 15 minutes, the ramping rate is about 1°C/sec, which has been preset and programmed. All the different curing profiles were programmed using Auto-Ramp control software, and then the samples were put into the VFM oven for curing, with the IR sensor monitoring the temperature. Closed loop electronic system of the VFM system can control the temperature very well as per the programmed curing steps, by the means of adjusting the power level rapidly. It can be seen from Figure 1 that the temperature variation is within +/- 2°C.

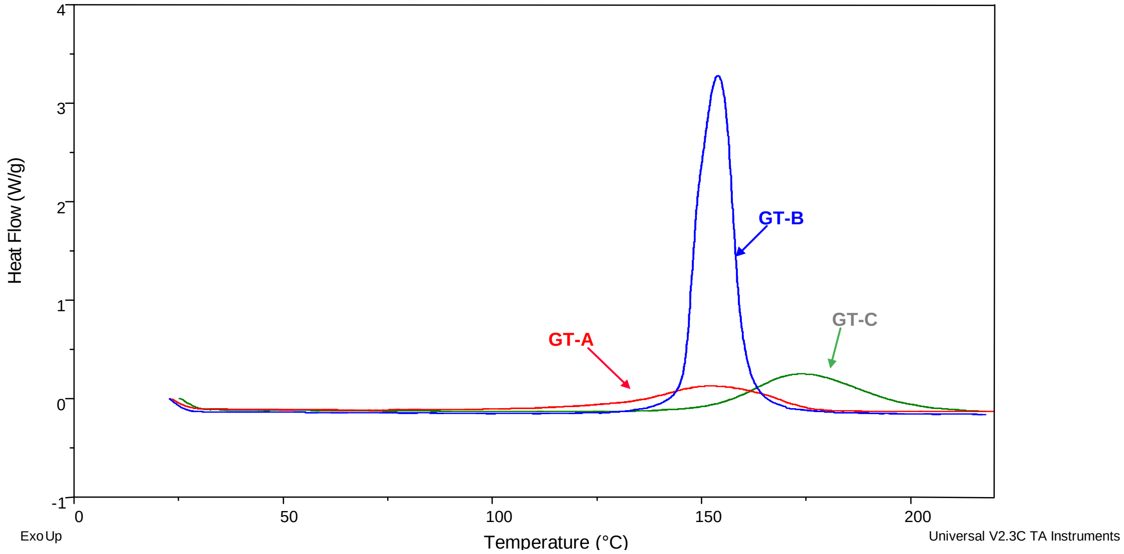


Figure 2. DSC dynamic curves of flesh glob top with 10°C/min scan rate

DSC was then used to study the curing extent of glob top. Figure 2 is the DSC curves of all the three glob top flesh samples with 10°C/min scan rate. The heat generated by GT-A is lowest, followed by GT-C, very great of heat was released during GT-B curing, that means GT-B polymerization reaction is very drastic. From the onset and peak point temperatures, it is obvious that GT-C curing is slower, it requires higher temperature or longer time for curing, on the other hand, GT-A and GT-B have similar peak points. In this study, since the emphasis is focused on VFM curing, only one convection oven curing profile, 2 hours at 130°C, was used as control for comparison with that of different VFM curing options.

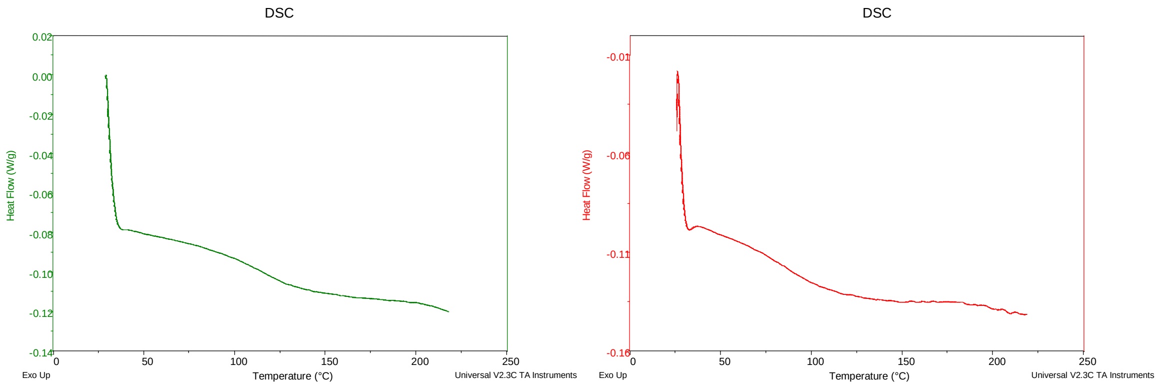


Figure 3. DSC curve of typical GT-A after convection curing (left, 2hrs/130°C) and VFM curing (right, 3min/130°C+7min/150°C)

Determination of glob top curing extent by different curing profiles is very important for material development as well as production process quality control. DSC is widely used and accepted to determine curing schedule and extent. Glob top samples after both convection and VFM oven curing were prepared and tested by DSC to verify the curing completeness. 5-20 mg of specimen was heated from room temperature to 220°C at a rate of 10°C/min. Figure 3 shows the DSC results of GT-A after convection curing (left, 2hrs/130°C) and VFM curing (right, 3min/130°C+7min/150°C). Glob top by both curing techniques exhibited equivalent results, there is no residual peak observed, which means that GT-A was completely cured by these two options. Curing extent of glob top was calculated as dividing the value of total heat flow minus residual heat by total heat. By doing this, all the three glob top by different curing options were characterized and the results were summarized as Table 1.

Table 1. Summary of glob top curing profiles and curing extents

Glob Top	Curing Options	Curing Profiles	Curing Extent
GT-A	Convection	2hrs/130°C	100%
GT-A	VFM-1	13min/130°C	96%
GT-A	VFM-2	15min/130°C	100%
GT-A	VFM-3	5min/150°C	99%
GT-A	VFM-4	8min/150°C	100%
GT-A	VFM-5	3min/130°C+7min/150°C	100%
GT-A	VFM-6	3min/130°C+5min/150°C	100%
GT-B	Convection	2hrs/130°C	97%
GT-B	VFM-1	15min/130°C	97%
GT-B	VFM-2	10min/130°C	96%
GT-B	VFM-3	5min/150°C	100%
GT-B	VFM-4	8min/150°C	100%
GT-B	VFM-5	3min/130°C+5min/150°C	100%
GT-B	VFM-6	2min/130°C+4min/150°C	100%
GT-C	Convection	2hrs/130°C	95%

GT-C	VFM-1	15min/130°C	90%
GT-C	VFM-2	8min/150°C	97%
GT-C	VFM-3	10min/150°C	98%
GT-C	VFM-4	12min/150°C	100%
GT-C	VFM-5	3min/130°C+7min/150°C	97%
GT-C	VFM-6	5min/130°C+10min/150°C	100%

From Table 1, we can see that the curing time by means of VFM is much shorter as compared to that by convection oven curing to reach same curing extent, although different glob top curing phenomena are different, which is in agreement with the results shown in Figure 2. It concludes that VFM curing is rapid.

3.2 TMA Study

TMA was used to determine the Tg and CTE values of glob top after convection and VFM oven curing. Again, the results from convection curing control sample were compared with that of different VFM curing. Samples were carefully prepared and heated from room temperature to 220°C at a rate of 10°C/min. Typical TMA curves of GT-A were plotted as shown in Figure 4.

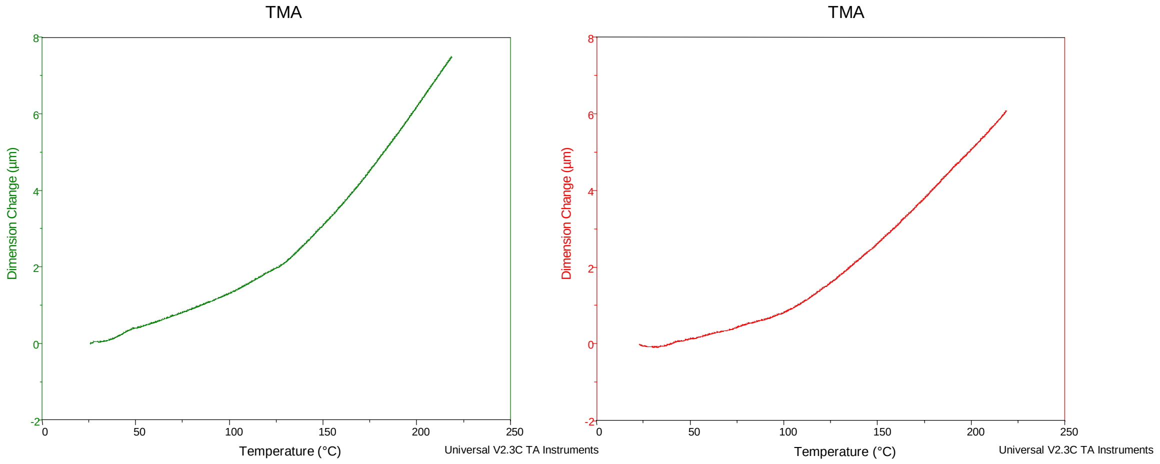


Figure 4. TMA curve of typical GT-A after convection curing (left, 2hrs/130°C) and VFM curing (right, 3min/130°C+7min/150°C)

Figure 4 shows the TMA results of GT-A after convection curing (left, 2hrs/130°C) and VFM curing (right, 3min/130°C+7min/150°C). Apparently, glob top by both curing techniques exhibited equivalent TMA results. Tg and CTE values were determined by thermal analysis software and showed to be comparable. By doing this, all the three glob top by different curing options were characterized and the Tg and CTE-1 results were determined and summarized as in Table 2.

Table 2. Summary of glob top Tg and CTE-1 vs curing profiles

Glob Top	Curing Options	Curing Profiles	Tg (°C)	CTE-1 (ppm/°C)
GT-A	Convection	2hrs/130°C	120	13
GT-A	VFM-1	13min/130°C	108	12.6
GT-A	VFM-2	15min/130°C	115.4	13
GT-A	VFM-3	5min/150°C	119.5	17.3
GT-A	VFM-4	8min/150°C	118	16.5
GT-A	VFM-5	3min/130°C+7min/150°C	120.6	11
GT-A	VFM-6	3min/130°C+5min/150°C	121.4	17.8
GT-B	Convection	2hrs/130°C	156	45

GT-B	VFM-1	15min/130°C	169.4	45.2
GT-B	VFM-2	10min/130°C	162.2	66.1
GT-B	VFM-3	5min/150°C	169.4	47
GT-B	VFM-4	8min/150°C	165.7	45.9
GT-B	VFM-5	3min/130°C+5min/150°C	177	45.3
GT-B	VFM-6	2min/130°C+4min/150°C	171.5	45.8
GT-C	Convection	2hrs/130°C	143	14
GT-C	VFM-1	15min/130°C	101	15.7
GT-C	VFM-2	8min/150°C	156	17.9
GT-C	VFM-3	10min/150°C	155.2	16.7
GT-C	VFM-4	12min/150°C	156	15.7
GT-C	VFM-5	3min/130°C+7min/150°C	146	14.6
GT-C	VFM-6	5min/130°C+10min/150°C	153.4	16.5

From Table 2, we can see that the curing schedule is very important and associated with the resultant thermal properties like Tg and CTE of glob top. Certainly, under different glob top curing phenomena, Tg and CTE values are different, which is similar to the results as indicated in Table 1. For individual glob top, in general, Tg and CTE values are comparable by both convection and VFM curing as long as the samples are fully cured and then tested within the TMA equipment accuracy range. Under certain curing profiles, samples are not completely cured, resulting in lower Tg and higher CTE, which is well agreed with the results of Table 1. To achieve more representative Tg and CTE results, it is recommended to test more samples under each same curing conditions. In summary, all the previous results in Sections 3.1 and 3.2 confirm that glob top by much rapid VFM curing can generally achieve equivalent curing extent and hence Tg and CTE values to that of convection curing, efforts were then put on actual application study and evaluation.

3.3 Adhesion Study

In COB application, it is paramount that glob top must be applied and cured to provide good adhesion strengths on both die passivation surface and substrate, so as to achieve COB assemblies with good reliability. Both lap shear and die shear tests were conducted with five repeating units for each process condition and then averaged. Adhesion of glob top on substrate was studied by means of lap shear test. In this study, only three VFM curing profiles were used to compare with convection oven curing. The lap shear test results are shown in Table 3.

Table 3 Lap shear test results indicating adhesion of glob top on substrate

Glob Top	Curing Option	Curing Profile	Strength (M Pa)	Failure Mode
GT-A	Convection	2hrs/130°C	13.7	Cohesive failure
GT-A	VFM-1	15min/130°C	9.5	Cohesive failure
GT-A	VFM-2	8min/150°C	9.3	Cohesive failure
GT-A	VFM-3	3min/130°C+7min/150°C	9.4	Cohesive failure
GT-B	Convection	2hrs/130°C	15.4	Cohesive failure
GT-B	VFM-1	15min/130°C	14.4	Cohesive failure
GT-B	VFM-2	8min/150°C	12.6	Cohesive failure
GT-B	VFM-3	3min/130°C+5min/150°C	13.4	Cohesive failure
GT-C	Convection	2hrs/130°C	9.0	Adhesive failure
GT-C	VFM-1	15min/130°C	1.4	Adhesive failure
GT-C	VFM-2	12min/150°C	5.3	Adhesive failure
GT-C	VFM-3	5min/130°C+10min/150°C	3.1	Adhesive failure

GT-A and GT-B glob top possessed higher adhesion strength on substrate by convection oven curing, in case of VFM curing, the strength is relatively lower, but they still maintained high and enough strength according to MIL-STD-883D, which calls for 6.9M Pa strength. And all specimens exhibited cohesive failure. For GT-C, the strength by convection curing is acceptable, however, the strength by VFM is poor and inconsistent with adhesive failure mode. Since the chemistries of the material are proprietary and not disclosed by supplier, further parameter fine-tuning and working together with supplier is required.

It is well known that adhesion is material, temperature and time dependent for specific material interface. In the case of VFM curing, only glob top absorbs most of the microwave power, organic FR-4 substrate is almost transparent to microwave, heat only transfers from glob top to substrate and let the substrate to reach to certain temperature level, which is much lower than that of glob top. Much shorter curing time and much lower substrate temperature resulted in lower adhesion. On the other hand, by convection oven curing, both glob top and substrate were exposed and reached to same curing temperature for 2hrs of long curing time, leading to higher adhesion established.

Adhesion of glob top on die surface was then conducted by means of die shear test. All the three glob top exhibited very good and comparable die shear force by both convection curing and VFM curing options. All samples showed die shear strength of greater than 15 M Pa, which again is much higher than the MIL-STD-883D requirements. Silicon chip is a very good microwave absorber, it can be easily heated and reached the same temperature as glob top, hence, equivalent adhesion of glob top on die surface by VFM curing can be achieved to that of convection curing. These findings are correlated with and supported by the C-SAM results after long-term aging exposure, which is covered in later Section 3.5.

3.4 Effect of VFM on Wire Bonding Integrity

In this study, 1.2mil fine gold wire was used to connect the test die to substrate. Attempts have also been done to assess the effect of VFM on the wire bonding integrity, including wire pull force, ball shear test and full chain resistance. Wire bonded samples were exposed to 1 and 2 time VFM irradiation and then compared with samples without VFM exposure. All the results indicated that there is no VFM effects on the wire pull and ball shear force as well as chained circuit resistance. Here, wire pull force test was typically taken for instance, as shown in Figure 5.

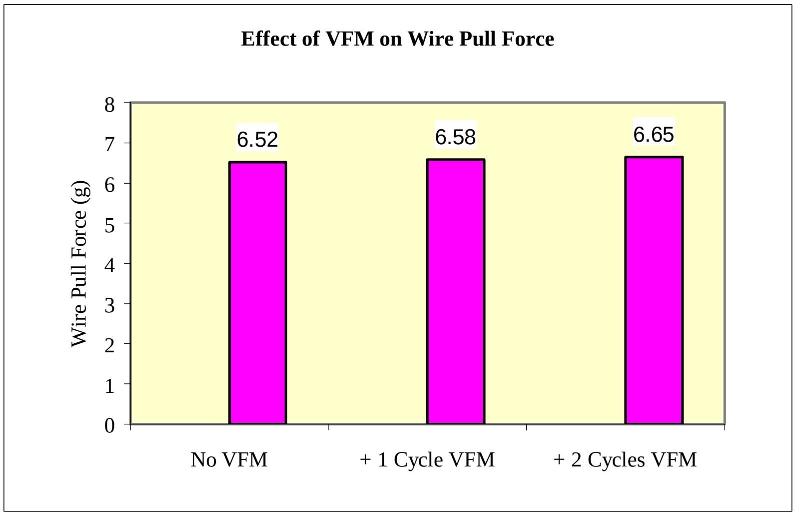
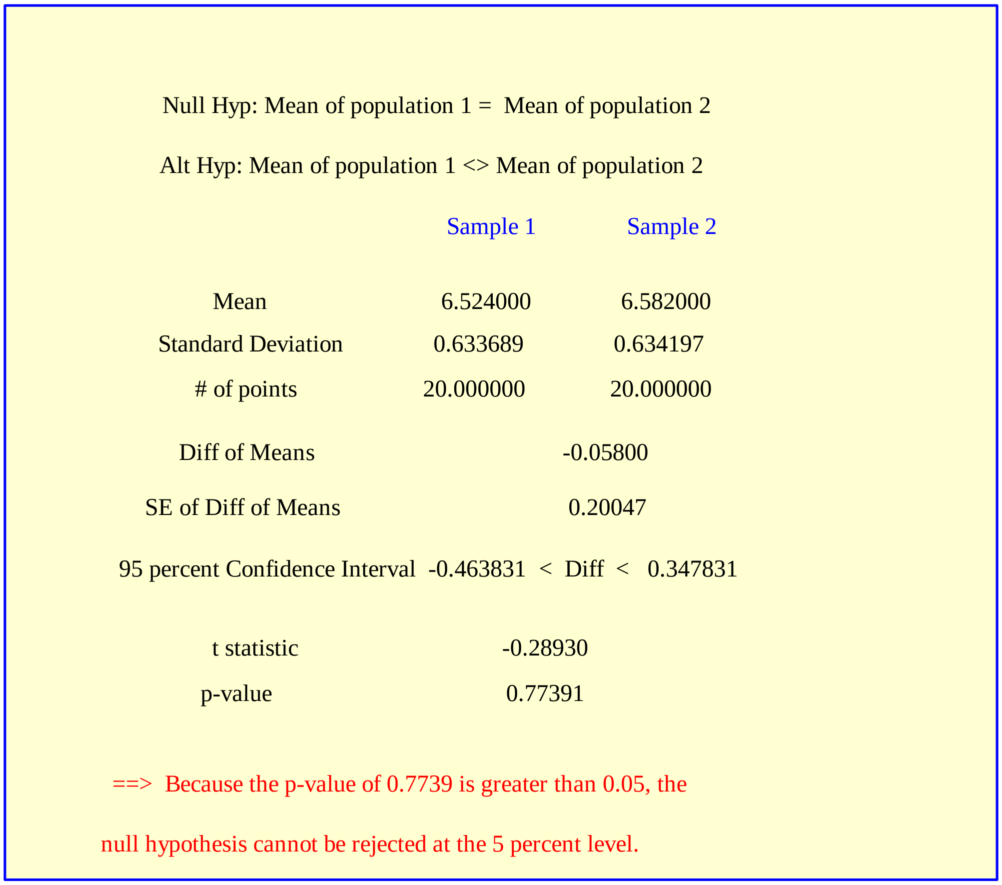


Figure 5. No effect of VFM on wire pull force

Figure 5 shows that there is no change of wire pull force after VFM exposure, which was conditioned as 3min/130°C + 7min/150°C for 1 to 2 times. Same results were derived from ball shear and resistance test. All these findings were also verified by T-test using RS1 statistical tool, which again confirmed these conclusions. Detailed T-test results are shown in Table 4. For 95% confidence level, the null hypothesis can not be rejected, which means no effect of VFM on wire pull force, same conclusions were also derived from this T-test for ball shear and resistance. It is then concluded that VFM has no impact on wire bonding integrity.

Table 4. Effect of VFM on wire pull force verified by RS1 Comparison



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          Null Hyp: Mean of population 1 =  Mean of population 2

          Alt Hyp: Mean of population 1 <> Mean of population 2

                                   Sample 1          Sample 2

             Mean                  6.524000          6.582000
          Standard Deviation      0.633689          0.634197
            # of points          20.000000         20.000000

           Diff of Means                     -0.05800

         SE of Diff of Means                 0.20047

      95 percent Confidence Interval  -0.463831  <  Diff  <  0.347831


             t statistic                -0.28930
            p-value                     0.77391


       ==>  Because the p-value of 0.7739 is greater than 0.05, the

      null hypothesis cannot be rejected at the 5 percent level.
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3.5 Reliability Assessment

After studying and comparing the properties and adhesion of glob top by VFM and convection curing, and confirming that VFM has no impact on wire bonding integrity, test vehicles were built for reliability assessment. All test vehicles, with 2 COB assemblies on each, were built by following internal standard assembly flow. Besides those usual processes, glob top were applied and then cured by both convection and VFM oven with different profiles.

As mentioned previously, the microwave absorption of fresh glob top and silicon die is much higher than that of organic substrate. As a result of this variance in energy absorption, the temperature profiles established during VFM irradiation are selective in nature. In order to testify this characteristic of VFM curing, that is selective heating, IR images of test vehicles were taken after VFM processing. Figure 6 is a typical IR image of test vehicle after VFM curing. There are 2 COB assemblies with different fan-out designs on each PCB. It is clear that microwave selectively heats glob top most, the temperature of glob top is much higher than that of substrate, the temperature gradient from glob top to surrounding area is due to heat transfer. Therefore, besides rapid curing characteristic, VFM curing is also selective.

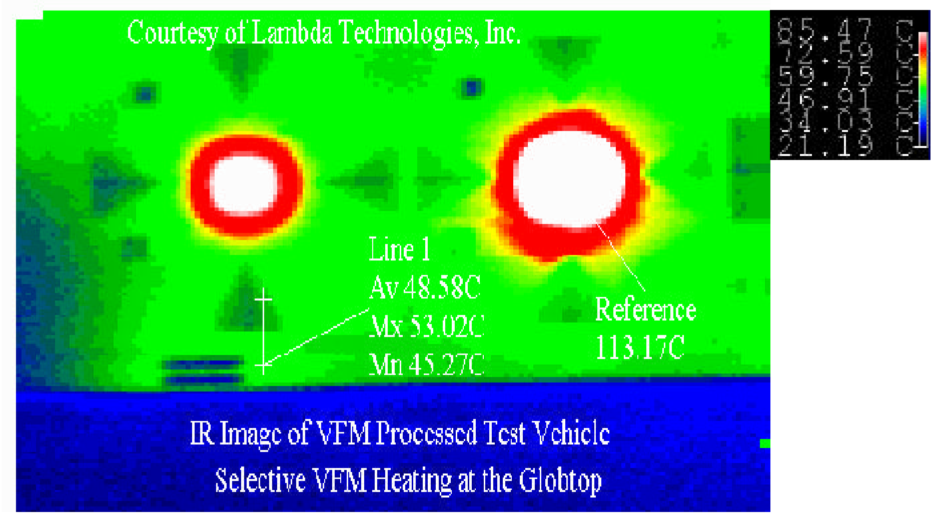

Figure 6. A typical IR image of test vehicle with 2 COB assemblies after VFM processing

In this reliability performance assessment, GT-C was out from matrix because of low adhesion, only GT-A and GT-B were used. The detailed reliability test matrix is shown as Table 5.

Table 5. Reliability test matrix

Group	Glob Top	Curing Option	Curing Profile	Temperature Cycling	Temperature Humidity
1	GT-A	Convection	Control: 2hrs/130°C	12 units	12 units
2	GT-A	VFM-1	15min/130°C	12 units	12 units
3	GT-A	VFM-2	10min/150°C	12 units	12 units
4	GT-A	VFM-3	3min/130°C+7min/150°C	12 units	12 units
5	GT-B	Convection	2hrs/130°C	12 units	12 units
6	GT-B	VFM-1	15min/130°C	12 units	12 units
7	GT-B	VFM-2	10min/150°C	12 units	12 units
8	GT-B	VFM-3	3min/130°C+7min/150°C	12 units	12 units

As indicated in Table 5, both GT-A and GT-B were cured by same conditions accordingly, there are totally 8 groups of samples with different glob top curing profiles, including one control curing by convection oven and three VFM options. 12 repeating units were included and tested for each combination. All test samples were sent for both temperature cycling and temperature humidity test according to automotive test conditions. For temperature cycling test, the condition is from –40°C to +125°C with minimum requirement of 1,000 cycles, for temperature humidity test, the condition is 85°C/85%RH for minimum of 1,000 hours. Over 10 % change in full chain resistance is considered failure.

Reliability test results confirmed that for both GT-A and GT-B, all of the VFM processed samples and convection cured control samples have passed temperature cycling test 1,000 cycles and temperature humidity test 1,000 hours of minimum requirement with no failure. For COB technology, it is well understood that temperature humidity test is not a concern in most cases, failure will occur when samples are sent for long time thermal cycling extreme stress, delamination of glob top from die surface and wire lifts especially at the corners are common failure modes. As mentioned in Section 3.3, in addition to other property criteria, strong glob top adhesion on die surface is paramount to achieve excellent reliability performance. Good long-term aging performance of GT-A and GT-B is in good relation with the adhesion results. C-SAM study was also performed to investigate the interfacial quality of glob top to die surface, glob top to substrate and die attach layer after extreme reliability test. Figure 7 is a typical C-SAM picture of GT-A cured by VFM before (left) and after (right) 1,507 cycles of temperature cycling.

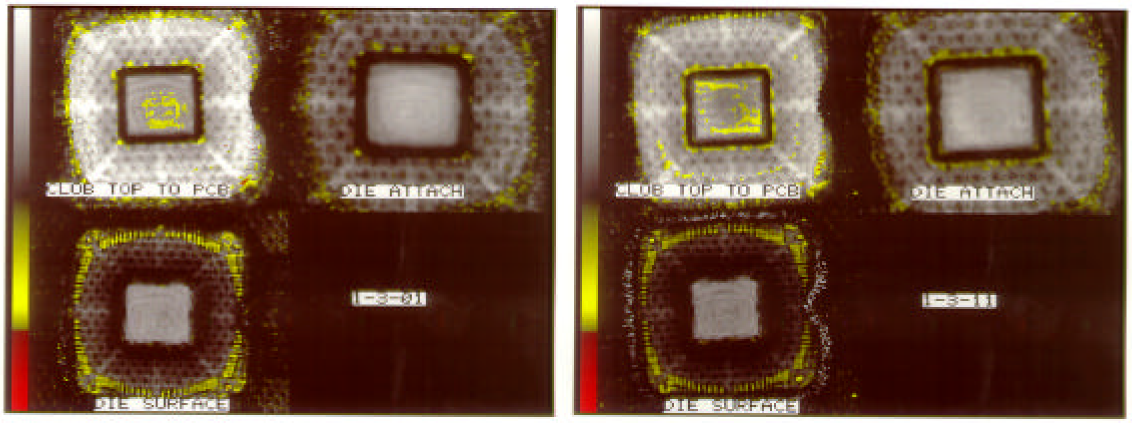

Figure 7. A typical C-SAM results of GT-A cured by VFM before (left) and after (right) 1,507 cycles of temperature cycling test

No appreciable delamination, which is indicated by red spots under C-SAM, was detected at all three interfaces even after 1,507 cycles of temperature cycling test. Same results were observed for GT-B samples as well. C-SAM study results support and confirm further that GT-A and GT-B have good adhesion to die surface and substrate to withstand the conditioned long-term reliability test stress. Application of VFM on functional products is underway to investigate its feasibility and performance in real world application, evaluation and qualification of automatic in-line VFM system is then required.

4. CONCLUSIONS

All the above study and evaluation results have successfully demonstrated that VFM curing for COB glob top is rapid, selective and reliable. Glob top curing time by VFM is much shorter to reach same cure degree and IR images confirmed that VFM heats the glob top in COB assembly most. Single-step and multi-step curing profiles can be programmed and well controlled to achieve equivalent curing extent, Tg and CTE properties of glob top to that of convection oven curing. It is also verified that VFM has no effect on wire bonding integrity, including wire pull force, ball shear force and resistance. The results were also testified by means of statistical T-test using RS1 software. Adhesion study showed that all three glob top by VFM processing exhibited very strong adhesion on die surface, however lower adhesion strength on substrate as compared with that of convection curing. GT-C is then out from matrix due to unacceptable strength on substrate, GT-A and GT-B still maintained high enough strength, which is above military standard requirements, therefore they are used for reliability study.

Test vehicles were built and cured by different VFM profiles to assess and compare their long-term aging performance with the control samples processed by convection curing. All the test vehicles of both GT-A and GT-B processed by VFM and control samples by convection oven have passed all the reliability test requirements according to automotive standards. C-SAM study further showed that there is no delamination observed at the interfaces of glob top to substrate, glob top to die surface and die attach layer even after long time extreme reliability test, this is in agreement with the good adhesion tested. Further optimization of VFM parameters and adhesion improvement of glob top is still required to produce robust COB assemblies. It is then proposed to verify the feasibility and performance of VFM curing process using functional samples for real world applications, fully automatic in-line VFM system is required in this further confirmation.

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