DECREASING MOISTURE CONTENT OF EPOXY AFTER HIGH TEMPERATURE STRESS, BY ALTERING PRE-SEAL BAKE TIMES.

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ABSTRACT: A correlation has been determined between die attach cure processes, pre-seal bake processes and sealed package moisture content after high temperature stress. While pre-seal bake times may be reduced to 4 hours and resisdual gas analysis, RGA, through mass spectroscopy shows a dry package after assembly, << 0.5 percent of moisture, results after a high temperature bake can be markedly different. A part with a 4 hour pre-seal bake will show up to 3.0 percent of moisture content after 24 hours at 175°C, after a 48 hour pre-seal bake it will only show 0.2 percent moisture. With the decomposition of the epoxy other gases are produced besides water such as methane, carbon dioxide, and hydrocarbons any and all of which can cause corrosion or create charged particles in the package, changing device performance characteristics.

KEYWORDS: Packaging; Reliability; Die Attach; Design

1. INTRODUCTION

With the increasing power dissipation and stress sensitivity of semiconductor mixed signal devices, a low cure temperature, low die stress die attach with a high decomposition temperature is necessary for hermetic packaging. Currently, new parts are producing upwards of 2 Watts which in a hermetic package can translate to a 60 to 70 degree Celsius internal junction temperature rise above the package temperature. Combined with small packages and constrained placement on PC boards with little heat extraction, a chip could easily see 150°C at the silicon junctions in a 70°C ambient. Any moisture in a package could cause a failure by introducing charged particles at a surface junction, gate oxide area, or corrosion on a metal interconnect line.

At Harris a cross functional team from Process Reliability, Packaging and Analytical Services has recently been working to reduce the moisture content and improve the reliability of a high power dissipation, stress sensitive and assembly temperature restrictive hermetic packaged devices which uses an epoxy as its die attach medium. Work was specifically aimed at a new package, product, process development effort. The epoxy die attach studied meets the requirements of having a low cure temperature, ~200°C and produces low die stress while having a sufficiently high stud pull values.

The purpose of this work was to establish the reliability implications of the out gassing of moisture from the epoxy under expected operating conditions and to investigate ways to reduce it. Of particular interest was the cure cycle and the pre-seal bake time and temperature.

2. PROCEDURE

Work includes RGAs before and after storage bakes at different temperatures, with different pre-seal bake times, thermal gas analysis (TGA) weight loss for a simulated cure and pre-seal bake cycle, and die stud pulls to determine the strength of the epoxy before and after stress. All package testing was done with the same die size, 0.200 X 0.280 mils, in the same 40 pin dip package type. TGAs were performed on epoxy from the same batch as was used during the packaging experiments.

The first design of experiments, DOX, was a three way split in stress temperatures, 125°C, 150°C, 175°C using cure cycle A, which is a three step cure with a final cure temperature of 200°C. The results show that at sustained temperatures above 125°C a significant amount of outgassing can occur, graph 1. At low temperature, 125°C, there is an initial outgassing of moisture but it quickly saturates and does not seem to increase over time indicating a very stable package environment. At higher temperatures, 150°C and 175°C there seems to be a fairly constant increase in moisture over time that continues to increase even after 1600 hours. It is reasonable to assume that the outgassing will saturate before the epoxy completely breaks down since the stress temperature is lower than the cure or pre-seal bake temperature. Methane, carbon dioxide, CO_2 and hydrocarbons, HC_x were measured along with H_2O and the changes over time are listed in table 1. For low temperature stress, 125°C, methane, CO_2 and HC_x are stable after an initial increase mimicing what was seen for moisture while for higher stresses, 150°C and 175°C all gasses continue to increase with time. The rise in organics and moisture indicates a decomposition of the epoxy.

In conjunction with the first DOX a high temperature operating lifetest, HTOL, was conducted on the same product @ 100°C. The product dissipates approximately 2 Watts leading to an internal temperature of 160°C and the results for moisture outgassing are shown in graph 2. The results correlate well to what was expected if the data from DOX 1 was extrapolated to 160°C. Even with the high moisture content after HTOL stressing for 3000 hours no parts failed due to device shift that could be attributed to moisture. Visual inspection also showed no corrosion of the metal at the bondpads or internal to the circuitry.

DOX two was a three way split in pre-seal bake time of 4, 24, and 48 hours. It was started to answer some of the questions raised by DOX 1, about the complete curing of the epoxy in the pre-seal bake oven and to find out if there is a saturation point for the epoxy when stressed at 150°C. The initial RGA showed no difference in moisture, methane, CO_2 or HC_x for virgin units out of packaging assembly. The units where then stressed at 150°C or 175°C. The results in table 2 shows significant outgassing of moisture for short pre-seal bake times, 4 hours, after stress at 175°C or 150°C. A long pre-seal bake time, 48 hours, significantly reduces moisture content after the part has been stressed but the epoxy still continues to outgas H_2O, methane, CO_2 and HC_x. The results from DOX 2 confirm the findings of DOX 1, the epoxy is breaking down at a stress temperature of 175°C, and while longer pre-bake times help in reducing moisture content, it does not cure the problem.

At 150°C the results are not so clear. The moisture, methane, CO_2 and HC_x content peaks at 1500 hours and then decreases at 2000 hours. The ceramic package, lead frame, the die and/or even the epoxy may be absorbing some of the moisture and the other gases leading to the decrease in outgassing. The data is inconclusive but a peak in moisture seems to occur after 1500 hours of high temperature stress. [1]

The epoxy while degrading and outgassing at 150°C and 175°C, still has significant bonding strength since no apparent degradation was found in stud pull testing even after 2000 hours of stress and a pre-seal bake time of 48 hours, table 3.

A TGA was also performed to simulate the outgassing of cure cycle A and the pre-seal bake, graph 3. The problems with the epoxy can clearly be seen here with outgassing continuing for the entire pre-seal bake time and not stabilizing even after 48 hours confirming results seen with RGAs in DOX 2.

A second cure cycle, cycle B, was tried with a four hour vacuum pre-seal bake that showed a significant increase in outgassing during the cure cycle but a decrease in the pre-seal bake. The TGA is shown in graph 4 of the outgassing during a simulated pre-seal bake. Stressing it at 150°C the moisture outgassing is comparable to the 48 hour pre-seal bake of DOX 2 at 150°C, graph 5. Increased amounts of CO2 and hydrocarbons are visible probably due to the reduction of oxygen in the cavity package itself due to the vacuum pre-seal bake, table 4, although the packages are backfilled with nitrogen during seal.

3. CONCLUSIONS

The outgassing process is very temperature dependant leading to a moisture saturation limit which for very high operating temperatures, 160°C and above, can have several percent water in a die cavity. At lower stress temperatures, 125°C, a low level of moisture saturation is quickly reached.

To reduce outgassing at higher temperatures, the cure cycle can be changed along with lengthening the pre-seal bake time or pre-seal method. A suitable cure and pre-seal bake combination could not be reached in this case unless, the ambient temperature of the package or the Θ_{ja} is lowered. A nitrogen pre-seal takes a longer time to ensure low moisture levels and leads to lower levels of CO_2 or HC_x than vacuum. A vacuum pre-seal method leads to lower moisture level than nitrogen but has increased levels of CO_2 and HC_x.

The effect of lengthening the pre-seal bake time in nitrogen has little effect on the die stud pull strength of the epoxy and does not increase the stress on the die significantly.

4. REFERENCES

1. J. H. Linn and J. Daar, RL/NIST Workshop on Moisture Measurement and Control for Microelectronics, 1993.

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Table 1: DOX 1, Two Temperature Stress versus Time for Cure Cycle A.1

Time (hours)	**Temp.**	**H_2O**	**Methane**	**CO_2**	**HC_x**
0 hrs	N /A	< 0.010 < 0.010 0.017 0.021 < 0.010 < 0.010	< 0.010 < 0.010 < 0.010 < 0.010 < 0.010 < 0.010	< 0.010 0.012 < 0.010 < 0.010 < 0.010 < 0.010	< 0.010 < 0.010 < 0.010 < 0.010 < 0.010 < 0.010
192 hrs	125°C	0.020 0.044	< 0.010 < 0.010	< 0.010 < 0.010	< 0.010 < 0.010
	150°C	0.045 0.068	< 0.010 < 0.010	0.028 0.062	< 0.010 < 0.010
	175°C	0.820 0.345	0.079 < 0.010	0.849 0.436	0.298 0.043
500 hrs	125°C	0.037 0.036	< 0.010 < 0.010	0.116 0.075	< 0.010 < 0.010
	150°C	0.306 0.237	0.019 < 0.010	1.086 0.252	0.066 0.034
	175°C	1.921 1.070	0.275 0.115	2.103 0.768	0.580 0.406
1000 hrs	125°C	0.041 0.033	< 0.010 < 0.010	0.090 0.045	< 0.010 < 0.010
	150°C	0.075 0.243	< 0.010 < 0.010	0.487 1.037	< 0.010 0.070
	175°C	4.398 1.553	0.679 0.246	3.274 1.074	1.273 0.323
1600 hrs	125°C	0.021 0.038	< 0.010 < 0.010	0.030 0.026	< 0.010 < 0.010
	150°C	0.961 0.543	0.065 0.052	1.092 0.804	0.227 0.162
	175°C	3.104 2.672	0.479 0.508	1.606 2.129	0.899 0.791

1. Three step cure with final temperature at 200°C.

Table 2: DOX 2, Pre-Seal Bake Time vs. Stress Time at Two Temperatures.[1]

Stress Time	Stress Temp	Pre-Seal Bake Time	H_2O	Methane	CO_2	HC_x
0	N / A	4 hrs	0.038 0.185	< 0.010 < 0.010	< 0.010 < 0.010	< 0.010 < 0.010
		16 hrs	0.703 < 0.010	< 0.010 < 0.010	< 0.010 < 0.010	< 0.010 < 0.010
		48 hrs	0.189 < 0.010	< 0.010 < 0.010	< 0.010 < 0.010	< 0.010 < 0.010
24 hrs	175°C	4 hrs	3.332	0.022	0.221	0.166
		16 hrs	0.726	< 0.010	0.710	0.026
		48 hrs	0.210	< 0.010	0.206	< 0.010
96 hrs	175°C	4 hrs	2.762	0.079	2.956	0.234
		16 hrs	1.161	0.040	0.535	0.200
		48 hrs	0.919	0.037	1.061	0.082
196 hrs	175°C	16 hrs	1.545 1.570	0.070 0.063	1.783 1.362	0.140 0.187
		48 hrs	0.449 1.560	< 0.010 0.054	1.034 1.588	0.050 0.124
832 hrs	150°C	16 hrs	4.612 1.179	0.086 0.042	0.865 0.699	0.255 0.164
		48 hrs	0.297 0.228	< 0.010 < 0.010	0.713 0.377	0.015 0.018
	175°C [2]	16 hrs	3.342 6.411	0.576 0.707	4.791 2.983	0.980 1.190
		48 hrs	2.323 1.385	0.339 0.231	2.434 2.632	0.573 0.372
1500 hrs	150°C	16 hrs	1.135	0.061	1.651	0.199
		48 hrs	0.911	0.053	0.460	0.162
	175°C [2]	48 hrs	3.099 4.019	0.978 0.714	5.771 2.297	1.542 1.146
2000 hrs	150°C	16 hrs	0.718 0.591	0.060 0.068	1.748 3.173	0.224 0.325
		48 hrs	0.422 0.095	0.019 < 0.010	1.035 0.875	0.074 0.021

1. Three step cure with final temperature at 200°C.
2. Elemental Oxygen starts appearing in RGA, possibly a secondary peak due to H_2O.

Table 3: Stud Pull Results from DOX 2.

Time (hrs)	**Temp.**	**Pre-Seal bake** **4 hours**	**24 hours**	**48 hours**
0 hrs	N / A	30.0	38.5	24.4
2000 hrs	150°C	48.2 38.0	45.5	40.7 22.7
	175°C	39.5		

Table 4: Cure Cycle B vs. Stress Time at 150°C.1

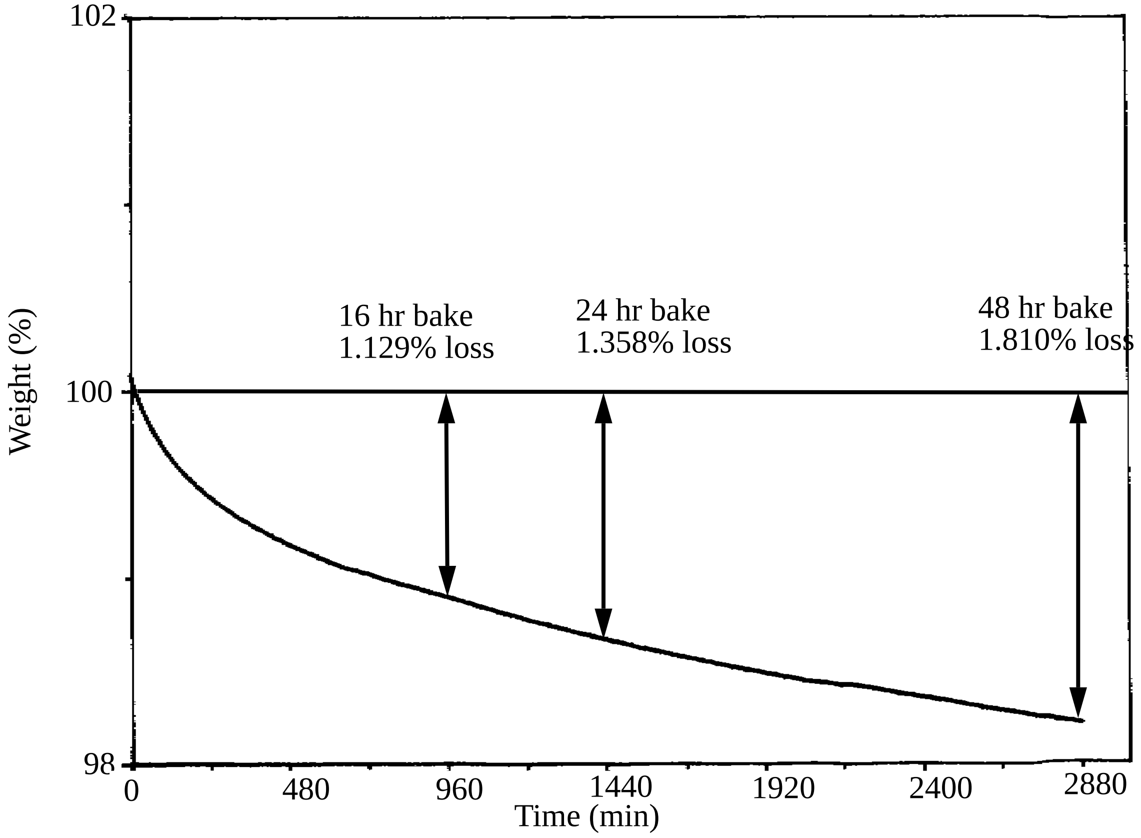
Time (hrs)	**H_2O**	**Methane**	**CO_2**	**HC_x**
0 hrs	< 0.010 0.025	< 0.010 < 0.010	0.012 0.014	< 0.010 < 0.010
280 hrs	0.361 0.263 0.262	0.071 0.064 0.056	0.312 0.323 0.271	0.354 0.277 0.212
500 hrs	1.298 0.787 0.356	0.090 0.106 0.051	0.558 0.609 0.949	0.472 0.622 0.222

1. Cured at 200°C.

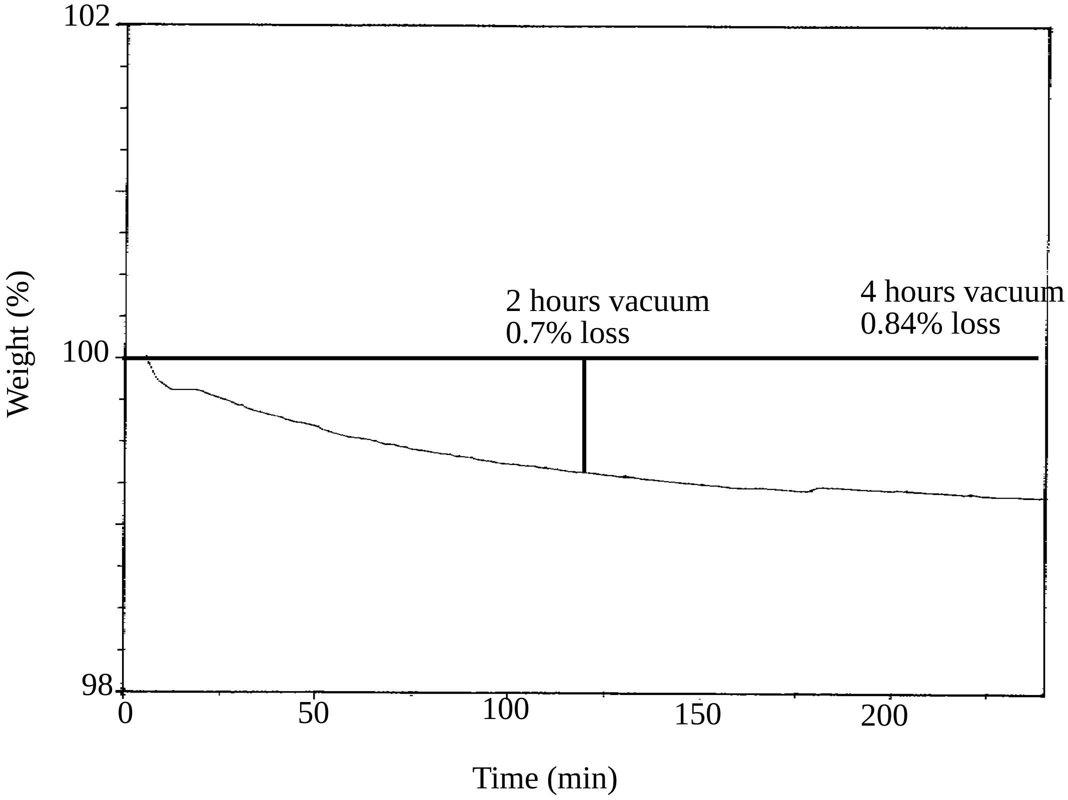
Graph 1: Moisture versus Time for Different Stress Temperatures with Cure Cycle A.

Graph 2: Moisture versus Time for HTOL Testing with Cure Cycle A.

Graph 3: Time versus Percent Weight Loss for Nitrogen Pre-Seal Bake with Cure Cycle A.



Graph 4: Time versus Percent Weight Loss for Vacuum Pre-Seal Bake with Cure Cycle B.



Graph 5: Time versus Percent H_2O for Pre-Seal Bake Cycle.