Application Report
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Use of Polystyrene for Bare-Die Carrier-Tape Shipping Applications

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ABSTRACT

The packing and shipping of bare-die product is relatively new, especially in the tape-and-reel packing format. Bare-die format assumes that the devices will be handled in a clean-room-type environment and that the packing materials used to ship the dies will be as clean as possible. Texas Instruments has developed a plan for testing multiple carrier-tape materials from multiple suppliers. The objective was to prove or disprove that polystyrene carrier tape could meet the same cleanliness requirements as those materials used to ship finished wafers to internal and external customers. The tests performed indicate that the polystyrene tape exceeds TI requirements for materials used for shipping wafers and bare dies.

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1 Introduction

The semiconductor industry ships devices to customers in many packing configurations. Most of the devices have been ceramic- or plastic-encapsulated dies. The newest form of device is the Wafer Scale Chip Scale package (WCSP). These devices are either bumped or unbumped dies singulated from the wafer. Bare dies are shipped to end users using several packing methods. For some time, conductive plastic trays with individual compartments to hold each die or special packing material containing tacky surfaces to hold the die in place was the dominant method, but tape-and-reel packing is becoming the norm (see Figure 1).

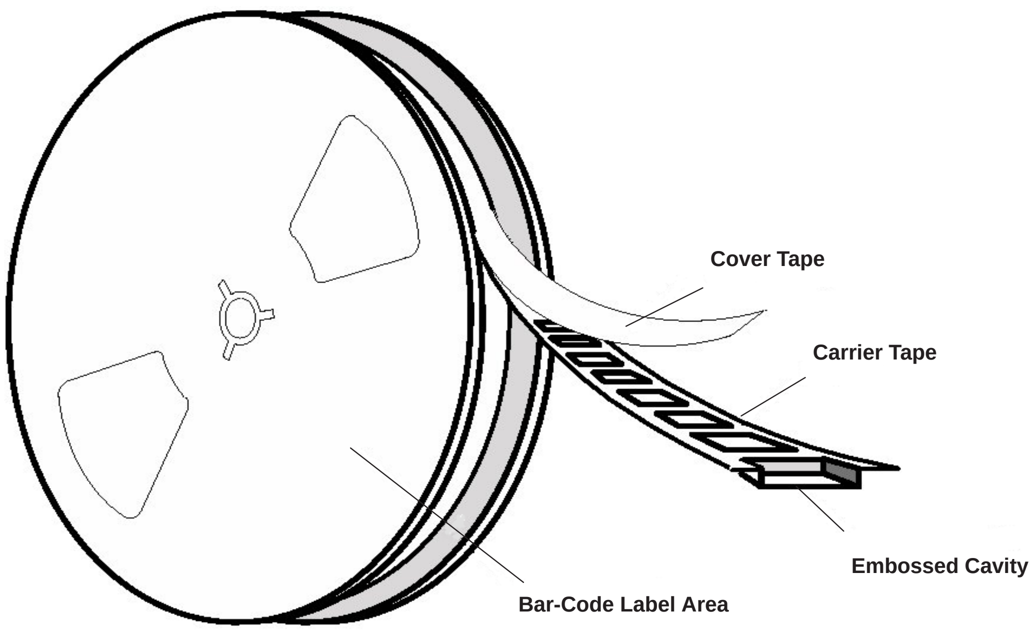

Figure 1. Tape-and-Reel Packing Components

Bare-die format assumes that the devices are handled in a cleanroom-type environment and that the packing materials used to ship the dies will be as clean as possible. Clean in the context of handling the bare die means clean from ionic contaminants and clean from particles. The industry-accepted cleanest carrier-tape base material is polycarbonate; however, the most widely used carrier-tape base material is polystyrene. Due to cleanliness concerns, all bare-die carrier-tape requirements at TI are being met with polycarbonate carrier-tape material.

In early 2000, TI began a concerted effort to determine whether switching from polycarbonate carrier tape to polystyrene carrier tape for bare-die shipments was feasible. The objective was to prove or disprove that the polystyrene carrier tape could meet the same cleanliness requirements as those materials presently used to ship finished wafers to internal and external customers.

2 Test Plan

Multiple groups of carrier tape from two suppliers were tested. Each supplier submitted samples of polycarbonate and polystyrene tapes from their normal (standard tape format) process and their clean process. The clean process has an additional air shower, and the tape is shipped to TI on a reel enclosed in a clean plastic bag.

- Supplier A polycarbonate carrier tape material
- Supplier A standard polystyrene carrier tape material
- Supplier A proposed cleaner polystyrene carrier tape material
- Supplier B standard polycarbonate carrier tape (not cleaned)
- Supplier B cleaned polycarbonate carrier tape
- Supplier B standard polystyrene carrier tape

Overall, the objective was to determine if a significant difference in particle counts existed between polycarbonate carrier tape and polystyrene carrier tape. Tapes with no dies in them were evaluated, as well as tapes that had dies in them. Steps in the test plan were:

1. Analyze samples of empty carrier tape for cleanliness using ion chromatography, liquid particle counting, and outgas analysis
2. Examine bare dies in a loaded carrier tape for cleanliness using visual examination
3. Examine bare dies in a loaded carrier tape by completing water extraction on samples
4. Perform statistical analysis on test results

The test methods used follow accepted industry standards:

- Ion Analysis: Samples were soaked in deionized (DI) water for 1 hour at 80°C. The water extract then was analyzed by ion chromatography.
- Liquid Particle Count (LPC): Samples were soaked in DI water for 1 hour at 80°C, and a liquid particle counter then was used to analyze the extraction.
- Outgassing: Sample was packed in an airtight vial and baked for 16 hours at 85°C. The resulting vapor then was analyzed by using gas chromatography/mass spectrometry (GC-MS).
- Visual Inspection: Sample was inspected manually at 40× magnification using a stereomicroscope.

All tests were performed by a certified outside laboratory.

3 Test Results and Conclusions

3.1 Ionic-Contamination Data

The first data to be evaluated was from water extraction to determine ionic contamination. These data show type and quantity of contaminants present on the carrier tape. It is important to minimize these ionic contaminants to prevent potential corrosion. Supplier A data is shown in Table 1, and the Supplier B data is shown in Table 2.

Table 1. Ionic Contamination Results From Supplier A

Contaminant	Supplier A Normal Polycarbonate ($\mu g/cm^2$)	Supplier A Clean Polycarbonate ($\mu g/cm^2$)	Supplier A Normal Polystyrene ($\mu g/cm^2$)	Supplier A Clean Polystyrene ($\mu g/cm^2$)	TI Specification Limits† ($\mu g/cm^2$)
Fluoride	<0.01	<0.01	<0.01	<0.01	0.02
Chloride	<0.01	<0.01	<0.01	<0.01	0.28
Nitrate	<0.01	<0.01	<0.01	<0.01	0.01
Phosphate	<0.01	<0.01	<0.01	<0.01	0.01
Sulphate	<0.01	<0.01	<0.01	<0.01	0.01
Sodium	<0.01	<0.01	<0.01	<0.01	0.1
Potassium	<0.01	<0.01	<0.01	<0.01	0.02

† Specification limits reflect TI specifications for plastic wafer shipping boxes.

Table 2. Ionic Contamination Results From Supplier B

Contaminant	Supplier B Normal Polycarbonate ($\mu g/cm^2$)	Supplier B Clean Polycarbonate ($\mu g/cm^2$)	Supplier B Normal Polystyrene ($\mu g/cm^2$)	Supplier B Clean Polystyrene ($\mu g/cm^2$)	TI Specification Limits† ($\mu g/cm^2$)
Fluoride	<0.01	<0.01	<0.01	<0.01	0.02
Chloride	<0.01	<0.01	<0.01	<0.01	0.28
Nitrate	<0.01	<0.01	<0.01	<0.01	0.01
Phosphate	<0.01	<0.01	<0.01	<0.01	0.01
Sulphate	<0.01	<0.01	<0.01	<0.01	0.01
Sodium	<0.01	<0.01	<0.01	<0.01	0.1
Potassium	<0.01	<0.01	<0.01	<0.01	0.02

† Specification limits reflect TI specifications for plastic wafer shipping boxes.

Ionic-contamination results show that both normal and cleaned tapes of both materials (polystyrene and polycarbonate) from both suppliers show no contaminants. Because these data are well below specification limits for packing materials, this test was eliminated as a distinguishing factor between the tape materials. From an ionic contamination point of view, either tape material could be used.

3.2 Outgassing Data

The second group of tests that was completed and data evaluated was for outgassing. Again, the goal is to minimize outgassing characteristics. Supplier A data is shown in Table 3, and Supplier B data is shown in Table 4.

Table 3. Outgas Test Results From Supplier A

Contaminant	Supplier A Normal Polycarbonate (μg/g)	Supplier A Clean Polycarbonate (μg/g)	Supplier A Normal Polystyrene (μg/g)	Supplier A Clean Polystyrene (μg/g)
Acrylate	ND	ND	ND	ND
Siloxane	ND	ND	ND	ND
Chlorinated solvent	ND	ND	ND	ND
Hydrocarbons	ND	ND	28.8	83.56
Total outgas†	0.58	5.69	28.8	85

ND = none detected
† Total outgas is slightly higher due to detection of gases not listed in the table.

Table 4. Outgas Test Results From Supplier B

Contaminant	Supplier B Normal Polycarbonate (μg/g)	Supplier B Clean Polycarbonate (μg/g)	Supplier B Normal Polystyrene (μg/g)	Supplier B Clean Polystyrene (μg/g)
Acrylate	ND	ND	ND	ND
Siloxane	ND	ND	ND	ND
Chlorinated solvent	ND	ND	ND	ND
Hydrocarbons	14.38	13.07	5.14	6.72
Total outgas†	14.38	13.07	5.14	6.72

ND = none detected
† Total outgas is slightly higher due to detection of gases not listed.

The carrier-tape materials (polystyrene and polycarbonate) are petroleum based. This explains the existence of hydrocarbons in all cases. This test also was eliminated as a possible distinguishing criteria between polystyrene and polycarbonate carrier-tape materials.

3.3 Visual Inspection Data

A sample of bare dies encased in carrier tape by cover tape was taken from three different tape samples:

- One from Supplier A normal polystyrene tape
- One from Supplier A clean polystyrene tape
- One from Supplier B clean polycarbonate tape

Sample size in each case was 32 dies.

One die at a time, the cover tape was removed from the samples and the die inspected under a microscope at 40x magnification to look for evidence of contamination. If contamination was seen, it was documented, its size checked to see if it was large enough to bridge between bonding pads, and it then was verified as either loose or attached by using a low-pressure air blow while holding the die in place. Results are shown in Table 5.

Table 5. Visual-Inspection Results From Suppliers A and B

Supplier and Tape Composition	Sample Size	Contamination Seen (Yes/No)	Amount of Contamination Seen (Particles)	Contamination Type	Large Enough to Bridge Bond Pads? (Yes/No)	Removal With Air Blow? (Yes/No)
Supplier A Normal Polystyrene	32	Yes	4	Loose particle	No	Yes
Supplier A Clean Polystyrene	32	Yes	4	Loose particle	No	Yes
Supplier B Clean Polycarbonate	32	Yes	4	Loose particle	No	Yes

Visual inspection did not reveal any overt contamination that might cause bridging or significant contamination during the solder process. This test also was eliminated as a distinguishing factor.

3.4 Liquid Particle-Count Data

The overall conclusion from evaluating and examining the unloaded carrier tapes is that no difference exists between the polycarbonate and polystyrene materials with respect to cleanliness. Additionally, tapes loaded with dies also were evaluated to see if one carrier-tape material generated more particles than the other during normal shipping and handling.

Samples of Supplier A normal polystyrene (not cleaned) carrier tape and Supplier A clean polystyrene carrier tape were analyzed. As a control, samples of Supplier B clean polycarbonate carrier tape also were analyzed.

Particle-count data collected by a certified outside laboratory is listed in Table 6.

Table 6. Liquid Particle-Count Data Used for ANOVA and Duncan's Multiple-Range Calculations

Supplier and Tape Composition	Particle Size ≥0.5 μm
Supplier A Normal Polystyrene, Bottle 1	361
Supplier A Normal Polystyrene, Bottle 2	701
Supplier A Normal Polystyrene, Bottle 3	372
Average	478
Std. Dev.	193
Supplier A Clean Polystyrene, Bottle 1	467
Supplier A Clean Polystyrene, Bottle 2	608
Supplier A Clean Polystyrene, Bottle 3	356
Average	443
Std. Dev.	79
Supplier B Clean Polycarbonate, Bottle 1	447
Supplier B Clean Polycarbonate, Bottle 2	369
Supplier B Clean Polycarbonate, Bottle 3	416
Average	410
Std. Dev.	40

To help understand the particle-count data, statistical analyses, such as analysis of variance (ANOVA) and Duncan's multiple-range test were performed. The ANOVA test is used to determine if there is a significant difference between the sample means. Duncan's test complements the ANOVA test and shows the relationship between mean pairs.

3.4.1 ANOVA Analysis of Liquid Particle-Count Data

Results of the ANOVA test are shown in Table 7. This test is not explained in detail because it is a straightforward computation. This procedure can be found in any statistical-analysis handbook. Data used to perform these tests are shown in Table 6.

Table 7. Single-Factor ANOVA Liquid Particle-Count Data

Data Summary					
Groups	**Count**	**Average**	**Variance**		
Supplier A, Normal Polystyrene	6	478	29905.6	172.9324	
Supplier A Clean Polystyrene	6	443.3333	4988.667	70.63049	
Supplier B Polycarbonate	6	410.3333	1310.267	36.19761	
ANOVA Results					
Source of Variation	**SS**	**MSe**	**F**	**P-Value**	**$F_{critical}$**
Between Groups	13739.11	6869.556	0.569229	0.577722	3.682317
Within Groups	181022.7	12068.18			
Total	194761.8				

Because $F_{critical} > F$, it can be concluded that there is no significant difference in the manufacturing processes between the carrier tapes with respect to particle count for normal polystyrene production, clean polystyrene production, and normal polycarbonate production.

3.4.2 Duncan's Test of Liquid Particle-Count Data

Duncan's test, as previously mentioned, is used to determine if a significant difference exists among the three carrier tapes. This test is explained in detail in steps 1 through 4 below for the ≥0.5-μm-particle test because it is not as well-known as the ANOVA test.

1. Linearly order the means such that $\bar{u}_1$ = 410.33 (counts/cm^2), $\bar{u}_2$ = 443.33 (counts/cm^2), and $\bar{u}_3$ = 478.00 (counts/cm^2). $\bar{u}_1$ is the mean for Supplier B's process, $\bar{u}_2$ is the mean for Supplier A's clean process, and $\bar{u}_3$ is the mean for Supplier A's normal process.
2. Determine the value of the least-significant studentized range, r_p, for each p value or pairs of unique data sets greater than 1. In this case, p can equal 2 or 3. The r_p value is determined by the table in Appendix A. In this table, $\alpha = 0.05$, or 95% confidence level, and $\gamma = 15$, which is the degrees of freedom associated with the error mean square in the analysis of variance or MSe. From the table, $r_p = 3.014$ for two sets of adjacent data sets and $r_p = 3.16$ for the one nonadjacent data set, based on the linearly ordered means.
3. For each p value, the shortest significant range, SSR_p, must be calculated. For equal sample sizes with n = 6 values,

   $$SSRp = r_p \times \sqrt{(MSe/n)}$$

   The SSR_p values are shown in Table 8.

Table 8. SSR_p Values

	P = 2	P = 3
SSR_p (α= 0.05), 0.5-μm liquid particle-count test	135.1725	141.7204

4. Analyze adjacent sample means. Any two population means are considered to be significantly different if $|\bar{u}_i - \bar{u}_j| > SSR_p$ for equal sample sizes. Results are in Table 9.

Table 9. Results of Duncan's Multiple-Range Test

Supplier and Process	Adjacent-Sample Means		Conclusion
	$\lvert\bar{u}_i - \bar{u}_j\rvert$	SSR_p	
Supplier B and Supplier A Normal	67.67	141.7204	All mean differences $<SSR_p$, which means that all of the processes are not significantly different, is the same conclusion as the ANOVA test.
Supplier B and Supplier A Clean	33.00	135.1725	
Supplier A Clean and Normal	34.67	135.1725	

With regard to the data listed in Tables 8 and 9, the statistical analyses show no statistical difference between any of the three groups. Therefore, one could conclude there is no difference in particle cleanliness between the carrier-tape materials.

4 Summary

Polystyrene and polycarbonate carrier-tape materials from different suppliers and different production processes were evaluated by several methods. Carrier tapes, with and without dies, were evaluated. All of the data show results well within identified TI specification limits and results that are not statistically different. Based on these evaluations, polystyrene is an acceptable carrier-tape material for packing bare dies for shipment to customers.

5 Acknowledgments

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Appendix A Least-Significant Studentized Ranges r_p

Table XI Least significant studentized ranges r_p

least significant studentized ranges r_p, $\alpha = 0.05$

r	p = 2	3	4	5	6
1	17.97	17.97	17.97	17.97	17.97
2	6.085	6.085	6.085	6.085	6.085
3	4.501	4.516	4.516	4.516	4.516
4	3.927	4.013	4.033	4.033	4.033
5	3.635	3.749	3.797	3.814	3.814
6	3.461	3.587	3.649	3.680	3.694
7	3.344	3.477	3.548	3.588	3.611
8	3.261	3.399	3.475	3.521	3.549
9	3.199	3.399	3.420	3.470	3.502
10	3.151	3.293	3.376	3.430	3.465
11	3.113	3.256	3.342	3.397	3.435
12	3.082	3.225	3.313	3.370	3.410
13	3.055	3.200	3.289	3.348	3.389
14	3.033	3.178	3.268	3.329	3.372
15	3.014	3.160	3.250	3.312	3.356
16	2.998	3.144	3.235	3.298	3.343
17	2.984	3.130	3.222	3.285	3.331
18	2.971	3.118	3.210	3.274	3.321
19	2.960	3.107	3.199	3.264	3.311
20	2.950	3.097	3.190	3.255	3.303
24	2.919	3.066	3.160	3.226	3.276
30	2.888	3.035	3.131	3.199	3.250
40	2.858	3.006	3.102	3.171	3.224
60	2.829	2.976	3.073	3.143	3.198
120	2.800	2.947	3.045	3.116	3.172
∞	2.772	2.918	3.017	3.089	3.146

least significant studentized ranges r_p, $\alpha = 0.01$

r	p = 2	3	4	5	6
1	90.03	90.03	90.03	90.03	90.03
2	14.04	14.04	14.04	14.04	14.04
3	8.261	8.321	8.321	8.321	8.321
4	6.512	6.677	6.740	6.756	6.756
5	5.702	5.893	5.898	6.040	6.065
6	5.243	5.439	5.549	5.614	5.655
7	4.949	5.145	5.260	5.334	5.383
8	4.746	4.939	5.057	5.135	5.189
9	4.596	4.787	4.906	4.986	5.043
10	4.482	4.671	4.790	4.871	4.931
11	4.392	4.579	4.697	4.780	4.841
12	4.320	4.504	4.622	4.706	4.767
13	4.260	4.442	4.560	4.644	4.706
14	4.210	4.391	4.508	4.591	4.654
15	4.168	4.347	4.463	4.547	4.610
16	4.131	4.309	4.425	4.509	4.572
17	4.099	4.275	4.391	4.475	4.539
18	4.071	4.246	4.362	4.445	4.509
19	4.046	4.220	4.335	4.419	4.483
20	4.024	4.197	4.312	4.395	4.459
24	3.956	4.126	4.239	4.322	4.386
30	3.889	4.506	4.168	4.250	4.314
40	3.825	3.988	4.098	4.180	4.244
60	3.762	3.922	4.031	4.111	4.174
120	3.702	3.858	3.965	4.044	4.107
∞	3.643	3.796	3.900	3.978	4.040

least significant studentized ranges r_p, $\alpha = 0.1$

r \ p	2	3	4	5	6
1	8.929	8.929	8.929	8.929	8.929
2	4.130	4.130	4.130	4.130	4.130
3	3.328	3.330	3.330	3.330	3.330
4	3.015	3.074	3.081	3.081	3.081
5	2.850	2.934	2.964	2.970	2.970
6	2.748	2.846	2.890	2.908	2.911
7	2.680	2.785	2.838	2.864	2.876
8	2.630	2.742	2.800	2.832	2.849
9	2.592	2.708	2.771	2.808	2.829
10	2.563	2.682	2.748	2.788	2.813
11	2.540	2.660	2.730	2.772	2.799
12	2.521	2.643	2.714	2.759	2.789
13	2.505	2.628	2.701	2.748	2.779
14	2.491	2.616	2.690	2.739	2.771
15	2.479	2.605	2.681	2.731	2.765
16	2.469	2.596	2.673	2.723	2.759
17	2.460	2.588	2.665	2.717	2.753
18	2.452	2.580	2.659	2.712	2.749
19	2.445	2.574	2.653	2.707	2.745
20	2.439	2.568	2.648	2.702	2.741
24	2.420	2.550	2.632	2.688	2.729
30	2.400	2.532	2.615	2.674	2.717
40	2.381	2.514	2.600	2.660	2.705
60	2.363	2.497	2.584	2.646	2.694
120	2.344	2.479	2.568	2.632	2.682
∞	2.326	2.462	2.552	2.619	2.670

Abridgement of H. L. Harter's "Critical Values for Duncan's New Multiple Range Test." *Biometrics*, vol. 16, no. 4 (1960). With permission from the Biometric Society.

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