TECHNICAL NOTE

UNDERSTANDING THE QUALITY AND RELIABILITY REQUIREMENTS FOR BARE DIE APPLICATIONS

INTRODUCTION

With the advent of multichip modules (MCMs) and system in a package (SiP) applications, customer demand for known good die (KGD) has increased. In many cases, meeting the demand for KGD includes educating customers about quality and reliability, as well as how the number of parts per system can impact the performance. A common understanding of quality and reliability enables bare die suppliers to provide bare die solutions that meet customers' expectations.

QUALITY

DEFINITION

For the purpose of this technical note, quality is defined as meeting the customer's expectations and ensuring that the parts work when assembled in the final product. Quality can be measured in many ways, but in general it is represented as the number of defective parts per the number of good parts. For example, the quality of the product coming out of wafer probe is measured in terms of yield: the lot yielded 97 percent (or 3 percent were defective). This can be easily translated into three failures out of 100 tested (or 30/1,000, or 300/10,000, or 3,000/100,000, or finally 30,000/1,000,000). The ratio most commonly referenced is defective parts per million (DPM), which in this case would be represented as 30,000 DPM. DPM is often interchanged with parts per million (PPM), where the term "defective" is simply implied. Very small failure rates are most easily expressed in DPM, as shown in Table 1.

It is important to note that the same group of devices used in more than one application could have entirely different quality levels. An example of this is design marginality to a given specification. If design "A" runs its application close to the specification, the assembled devices would result in a low quality level. If design "B" does not run its application close to the specification, the assembled devices would result in a higher quality level. This is a very important point because, as this technical note describes, the quality level relates directly to the cost associated with producing KGD.

Table 1
Defects per Million

YIELD	DEFECTS PER MILLION
90%	100,000
95%	50,000
99%	10,000
99.9%	1,000
99.99%	100
99.999%	10

Memory manufacturers rely on the device data sheet as the quality metric. The effectiveness of the manufacturing and test process is measured by monitoring the outgoing quality levels to a set of tests that use the data sheet as a reference. Manufacturers spend a large amount of test time looking at every conceivable electrical specification from the data sheet. Historically, this testing is performed after assembly on individual units so the manufacturer can take advantage of parallel test systems.

In some cases, manufacturers test as many as 8,192 units at one time in the burn-in ovens. High-speed test equipment typically runs 256 devices at a time. For KGD, where 100 percent of the testing must be done at wafer level, this parallelism drops to 64 parts at a time. It is easy to see that the cost of performing the same level of testing on a wafer is, at a minimum, four times as expensive and, at the maximum, 128 times as expensive.

Referring back to the example about design marginality, customer "A" may be willing to pay for the extra testing at wafer level, but customer "B" would receive no benefit from this added cost. This leads to the first critical point:

- **Cost-effective KGD requires application-specific testing.**

PARTS PER SYSTEM

The number of parts per system affects the quality level. For example, in a system with a single die, the customer will experience an initial test failure rate equal to the DPM for the application. If the DPM is 10,000, the customer will see a yield loss of 1 percent due to component-related quality (assembly defects will be above and beyond this). However, as the number of parts per system increases, the failure rate increases.

The initial test failure rate will be the product of all of the yields of the various die on the module:

$Yt = Y1*Y2*Y3.....Yn$
Where: Yt is the overall yield
Y1 is the yield for component 1
Y2 is the yield for component 2
Y3 is the yield for component 3
Yn is the yield for component n

If all the components on the module are the same type of die, the formula is simplified to:

$Yt = Y1^N$
Where: Yt is the overall yield
Y1 is the yield for component 1
N is the number of parts per system

Table 2 shows how the number of parts per system and the quality level affects the yield of a system.

RELIABILITY

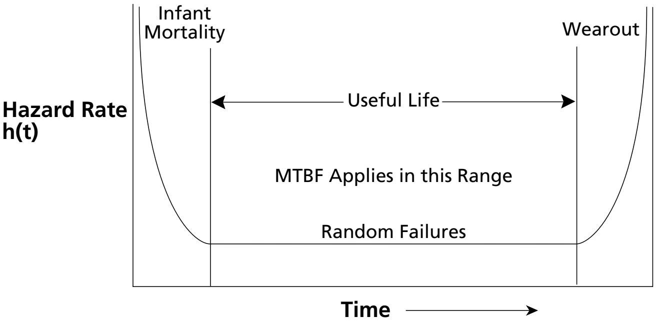
DEFINITION

For the purpose of this technical note, reliability is defined as *how long* the device continues to meet the customers' expectations. Note the reference to time (how long) versus quality, which is measured one time at initial test only. Reliability is typically expressed in failures in time, or as a FIT rate. A FIT is a failure per billion device hours. If a group of devices has a FIT rate of 100, the customer should expect there to be 100 failures per billion device hours.

To complicate matters, the FIT rate of a group of parts is not constant. Many studies have shown that the reliability failure rate starts high and eventually drops to a constant level (see Figure 1). Manufacturers use burn-in to remove the devices that make up the early failures before the product is shipped. Even with the early failures removed from the population, the failure rate is reduced, but never eliminated. This leads to the second critical point:

- **No amount of burn-in can reduce the failure rate to zero.**

Figure 1
Hazard Rate Curve



As previously mentioned, manufacturers use burn-in to remove the early failures from the population. However, with KGD, the ability to burn-in product is significantly hampered. The industry (including Micron) is spending a great deal of time studying wafer-level burn-in, discrete die burn-in, as well as various types of stress testing. While these methods remove the early failures from bare die populations, they are

Table 2
System Yield

YIELD	DPM	NUMBER OF PARTS PER SYSTEM						
		1	2	4	8	16	32	64
90%	100,000	90.00%	81.00%	65.61%	43.05%	18.53%	3.43%	0.12%
91%	90,000	91.00%	82.81%	68.57%	47.03%	22.11%	4.89%	0.24%
92%	80,000	92.00%	84.64%	71.64%	51.32%	26.34%	6.94%	0.48%
93%	70,000	93.00%	86.49%	74.81%	55.96%	31.31%	9.81%	0.96%
94%	60,000	94.00%	88.36%	78.07%	60.96%	37.16%	13.81%	1.91%
95%	50,000	95.00%	90.25%	81.45%	66.34%	44.01%	19.37%	3.75%
96%	40,000	96.00%	92.16%	84.93%	72.14%	52.04%	27.08%	7.33%
97%	30,000	97.00%	94.09%	88.53%	78.37%	61.43%	37.73%	14.24%
98%	20,000	98.00%	96.04%	92.24%	85.08%	72.38%	52.39%	27.45%
99%	10,000	99.00%	98.01%	96.06%	92.27%	85.15%	72.50%	52.56%
99.90%	1,000	99.90%	99.80%	99.60%	99.20%	98.41%	96.85%	93.80%
99.99%	100	99.99%	99.98%	99.96%	99.92%	99.84%	99.68%	99.36%

not yet able to match the cost effectiveness of burn-in on packaged parts. By understanding a customer's requirements, the proper amount of screening can be applied at the wafer or discrete die level to meet the customer's expectations at a reasonable cost. This leads to the third critical point:

- **Reliability levels as high as those of packaged parts can be achieved with KGD, but the cost is much higher.**

PARTS PER SYSTEM

The number of parts per system affects the required reliability level. For example, if a system has one part, the system will accumulate one device hour every hour. If the system has 10 parts, it will accumulate 10 device hours every hour, etc. This leads to the fourth critical point:

- **The level of reliability required depends directly on the number of parts per system.**

To present FIT rates in a way that makes sense to the end user, manufacturers often convert the value to a mean time between failures (MTBF). The MTBF can be calculated after the FIT rate and the number of parts per system are known. The MTBF predicts the average time before the first failure occurs. MTBF is sometimes referred to as mean time to failure (MTTF). Table 3 summarizes the effect on the MTBF by the number of parts per system and the failure rate of the population. The data in Table 3 indicates the estimated number of *years* before the average system will fail. As the table clearly indicates, most MCM or SiP applications with very few die can get by with failure rates much higher than applications with many die.

The MTBF is useful from a consumer, or end customer point of view. For example, if a consumer buys a system with 16 devices that have a FIT rate of 100, the consumer would expect an average life of 71.35 years. If the manufacturer of that system sold 32 units, the manufacturer would expect the first failure to be seen in 2.23 years because the entire population is 512 parts. Some unfortunate consumer will always have the first failure. If enough units are sold, the first failure will occur very early, but the *average* consumer will still see a 71.35 year MTBF. Although this point is slightly confusing, the fact is that the failure rate is not zero; and if enough parts are used, the first failure will occur early. What is important is that the *average* system will more than exceed the consumer's expectation.

SUMMARY

The following key points are essential to understanding the quality and reliability requirements for bare die applications:

1. Cost-effective KGD requires application-specific testing.
2. No amount of burn-in can reduce the failure rates to zero.
3. Reliability levels as high as those of packaged parts can be achieved with KGD, but the cost is much higher.
4. The reliability level required depends directly on the number of parts per system.

Table 3
Mean Time Between Failures (in Years)

FIT		NUMBER OF PARTS PER SYSTEM								
	1	2	4	8	16	32	64	128	256	512
1	114155.25	57077.63	28538.81	14269.41	7134.70	3567.35	1783.68	891.84	445.92	222.96
10	11415.53	5707.76	2853.88	1426.94	713.47	356.74	178.37	89.18	44.59	22.30
100	1141.55	570.78	285.39	142.69	71.35	35.67	17.84	8.92	4.46	2.23
1,000	114.16	57.08	28.54	14.27	7.13	3.57	1.78	0.89	0.45	0.22
10,000	11.42	5.71	2.85	1.43	0.71	0.36	0.18	0.09	0.04	0.02

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