Medical Device Wafer Singulation

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Abstract:

Singulation can be the most damaging step in electronic manufacturing where individual dice are freed from a brittle silicon wafer. So much torque and force is applied to the silicon during this process that if precautionary steps are not taken, the freed die may exhibit low strength due to chipping damage. For medical devices, this is particularly a problem because medical devices must be specially shaped and assembled so that they can fit into small implantable or insertable units for the human body. Insertable medical products require that dice have unusually high aspect ratios in order to fit into tubular shaped instruments.

For this paper, we have emulated a medical device using blank silicon wafers cut to $\geq$3.60 mm long 0.36 mm wide and 0.100 mm thick. The aspect ratios of 10:1 will be compared with lower as well as high aspect ratios for dicing quality and die integrity. With standard dicing parameters with standard blades, the singulation yield would be as low as zero. Even the use of step cut which in most cases would alleviate chipping, but for such high aspect ratio dice, the yield improved to only 50%.

This paper will present comparative yield results of various dicing setups to find the process with the best yield on singulated dice. 100% yield for singulation resulting in higher strength devices can be obtained using properly selected blades with the correct dicing parameters. Newer, stronger and narrower blades are allowing dice with high aspect ratios to be sawn without chipping yield loss. Also special dicing programs are required to produce chip-free dies without resorting to laser saws.

Background on high yield dicing

Semiconductor wafer dicing has come a long ways since the days of diamond scribe and break before 1970. Since then, the predominant method of dicing silicon wafers has been with rotary saws and diamond embedded metal blades. Dicing machine and blade technology have become extremely sophisticated and precise with the proliferation of electronic products and the manufacturers' demand for high yields and low cost. Newer, stronger blade materials and designs have kept the rotary dicing technology quite robust despite the introduction of laser dicing technology in the last several years. Led by a pair of major players in dicing and blade technology, saw kerfs of 20 micrometers can be achieved consistently with no chipping. This is particularly true for square or rectangular tile shaped dies for consumer product applications. There are other options such as laser dicing in achieving [1,2] damage free singulation for medical devices but at a much higher cost of ownership and lower return on investment compared to the blade method.

Figure 1. An implantable medical device product called Bion Microstimulator made by Advanced Bionic Corp. [3] The device is a miniature, self-contained, rechargeable implantable neurostimulator intended to treat a wide variety of diseases through direct electrical stimulation of peripheral nerves and muscles.

For medical devices which require device modules to be insertable or implantable into the human body, the dies are designed with high aspect ratios. The reduction of the level of invasiveness for the patient must be considered as well as high device reliability. System-in-package or SIP modules for medical applications require extreme aspect ratios of up to 20 to maintain slim fit into the human body and into the medical instrument. An example is the rod shaped Bion Microstimulator [3] shown in Figure 1. This device is intended to be inserted into organs such as the bladder to prevent incontinency. With the requirement for high aspect ratios, the device now becomes bar shaped or stick shaped.

One of the widely published solutions is to use step cut to prevent die chipping and to increase die fracture strength [4, 5, 6]. Step cutting which usually controls sidewall chipping in tile shaped dies have been found to produce severe chipping on bar shaped dies. Bar shaped dies have sidewall chipping (Figure 2) despite using step cutting as has been recommended. The photograph in Figure 2 shows sidewall of die with the characteristic delineation of wide blade and narrower blade passes which did not control chipping. The dimension of sidewall chipping on this die extends beyond the mid point of die thickness and is considered unacceptable.

Figure 2

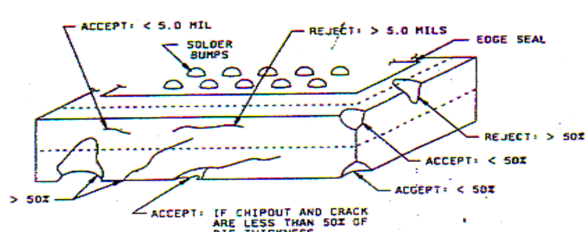
Long bars are vulnerable to torsion or twisting during dicing as the blade abrades the sidewall of the dies. This torsion chipping shows up along the sidewalls of the long edge of the die on regular intervals. Torsion chipping cannot be seen from the top of the die but can be seen on the bottom by a trained eye. When the die is viewed from the sidewall, the chipping is usually triangular with a "shark fin" or "saw tooth" profile. The torsion related chipping shown in Figure 3a and Figure 3b adversely affect dicing yield and device reliability.

Figure 3a

Figure 3b

Publications on wafer singulation generally use fracture strength and environmental testing as a gauge for chipping reliability [1, 7]. Instead, this paper uses measurements of sidewall chipping damage size from high power optical microscope to determine yield, dicing-related quality and dicing-related reliability. This optical monitoring method using sidewall chipping data is direct and accurately predicts fracture strength of die as well as reliability of die during environmental testing. This method eliminates excessive handling of the fragile silicon bars for fracture testing which can corrupt fracture test results. Additionally, it is a simple and useful statistical process control tool as it provides feedback on the dicing quality of a wafer immediately after saw. This method is not destructive because wafer edge or inked dies can be used as monitors without destroying any functionally good dies on the production wafer.

Figure 4



It has been found that small sample sizes provide high confidence levels for wafer chipping integrity as long as adequate sidewall lengths are inspected. It is however a manual process requiring operator intervention to the automated wafer loading and unloading system of the saw machines.

The pass and fail criterion for sidewall chipping is based on Mil-Std. 883 [8] for flip-chip as shown in Figure 4. The criterion states that a visible crack extending from the backside of the die upwards to a height higher than the mid point of the die is rejectable irrespective of its absolute length. Cracks on the die sidewall always originate from the bottom side of die. Sidewall cracks do not originate from top side in general due to the forward feed direction of blade as well as the rotary blade spin direction. As shown in the schematic in Figure 5, this blade forward feed direction with respect to blade rotation axis where the leading blade edge cuts downwards while the trailing edge cuts upwards is widely adopted in the manufacturing industry. The configuration is responsible for the tendency of sidewall chipping to originate from the wafer bottom-side or backside.

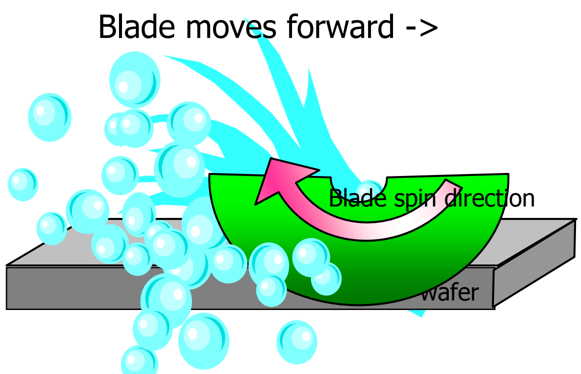


Figure 5. Schematic of the dicing blade axis and feed direction in a wafer.

EXPERIMENTAL SETUP

The experimental set-up here is to develop a dicing process where no rejectable level of chipping is observed on bar shaped dies with very high aspect ratios. Starting with blank 200mm diameter 0.780mm thick silicon wafers mounted on backgrind tape. The wafers are background with 2000 grit wheel to thicknesses of 0.250mm or 0.100mm. The final few micrometers of the wafer surface are removed / smoothened by lapping with an approximately 4000 grit wheel. This fine surface finish has an almost mirror finish with grind marks visible only under high power microscope. The wafer total thickness variation (TTV) is checked on a contact gauge. The TTV is measured on 4 edge locations and 1 central location on the wafer. Background silicon wafers are extremely uniform in thickness with TTV measured at less than 1 micrometer. The thinned wafers are carefully mounted onto UV sensitive dicing tape framed by rigid metal frames for easy handling.

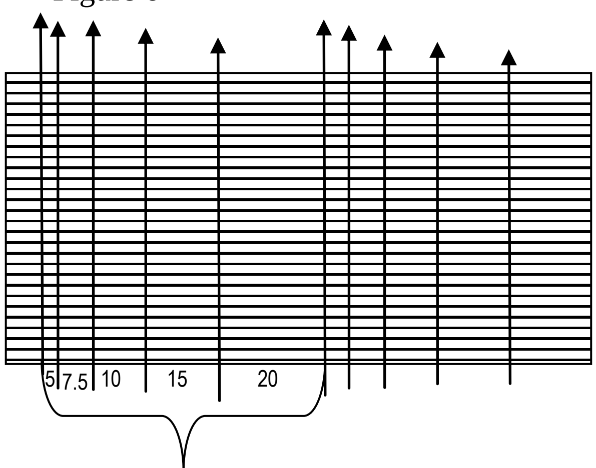
All non-product wafers in this study are processed identically to minimize errors. Machine set-up with the same optimized dicing condition variables are tightly controlled for wafers in this study because chipping results are extremely sensitive to dicing parameters and machine set-up, All wafers are cut to produce dies with aspect ratios from 5.0, 7.5, 10.0, 15.0 to 20.0 with a fixed 0.36mm width. Multiple aspect ratios are created to compare chipping vulnerability with bar length. The experimental groups are listed in the Table 2.

Table 2. Experimental Set-up for determining damage-free highly thinned silicon bars.

Wafer thickness	Blade thickness	Speed mm/s	Set-up No.
.250mm	.100 mm	15	No. 1
.250mm	.020mm	25	No. 2
.250mm	.020mm	25	No. 3
.100mm	.020mm	62.5	No. C
.100mm	.020mm	62.5	No. D
.100mm	.020mm	62.5	No. E

Each wafer is diced on a dual spindle Disco Saw with bars parallel to the flat of the wafer. The Disco dicing machine is programmed to dice bars from the lowest aspect ratio to the highest aspect ratio in a reticular pattern as shown in Figure 6. This will allow the bars of the same aspect ratio to be sourced from the entire wafer minimalizing effects of the radial backgrind marks on wafer backside. It should be noted that with the finer grit backside finish for thinner wafers, this effect is much lower than the standard 2000 grit finish for thicker wafers.

Figure 6



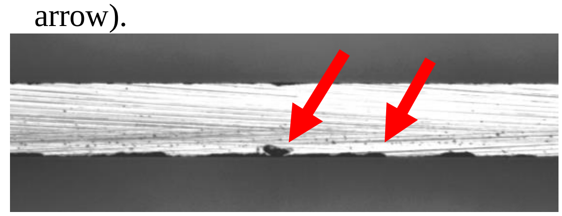
A cluster or reticule of bars with aspect ratios increasing from left to right. The cluster repeats across the wafer automatically.

The selected blade type and machine set-up is adopted from manufacturer recommendations. Multiple set-up parameters are used and they are identified as Groups 1, 2 and 3, C, D and E. Wafers are sawn a Disco dual spindle saw plumbed with de-ionized water for cooling and surfactant for cleaning. The post diced wafer is automatically loaded into a cleaning station to be spin rinsed and dried. The silicon bars which are laminated on ultraviolet sensitive dicing tapes are then exposed to UV light so that they can be easily lifted off with tweezers. Since these dies are quite fragile, they can be quite challenging to handle without damage. Great care was taken while handling these dies as they are very vulnerable to scratches and cracks.

INSPECTION METHOD

A sample size of around 25 dies from each experimental group was picked off from random locations of wafer. Samples from each aspect ratio were grouped together in rows for optical measurement. Die picking was manual and done extremely careful to prevent introducing damage from the tweezers that were used. Each bar was placed sideways on the microscope stage so that the chipping size on both sides of the bar could be recorded. For each side, only the largest chipout along the entire length of the bar or crack was recorded. 0 indicates die with no chipping, whereas 0.5 indicates dies with chipping size reaching to the midpoint of the die thickness. Chipping caused by handling is not “shark fin” shaped but rather “scallop” shaped such as shown in Figure 7. The latter is disregarded to eliminate introducing errors in this study.

Figure 7. Chipping from handling (left arrow) and chipping from dicing (right arrow).



RESULTS

Table 3. Silicon bars with aspect ratio of 10 and thickness of .250mm.

Silicon Bar number	GROUP 1 front	GROUP 1 back	GROUP 2 front	GROUP 2 back	GROUP 3 front	GROUP 3 back
1	0.500	0.000	0.000	0.000	0.300	0.000
2	0.000	0.000	0.000	0.000	0.100	0.000
3	0.300	0.000	0.200	0.000	0.000	0.000
4	0.400	0.000	0.000	0.000	0.100	0.000
5	0.300	0.000	0.000	0.000	0.000	0.000
6	0.400	0.000	0.000	0.000	0.100	0.000
7	0.300	0.000	0.000	0.000	0.100	0.000
8	0.400	0.000	0.200	0.000	0.100	0.000
9	0.700	0.000	0.000	0.000	0.100	0.000
10	0.200	0.000	0.200	0.000	0.000	0.000
11	0.400	0.000	0.000	0.000	0.000	0.000
12	0.100	0.000	0.000	0.000	0.000	0.000
13	0.100	0.000	0.200	0.000	0.000	0.000
14	0.200	0.000	0.000	0.000	0.000	0.000
15	0.200	0.000	0.200	0.000	0.000	0.000
16	0.200	0.000	0.100	0.000	0.000	0.000
17	0.600	0.000	0.000	0.000	0.000	0.000
18	0.600	0.000	0.100	0.000	0.000	0.000
19	0.300	0.000	0.200	0.000	0.000	0.000
20	0.300	0.000	0.000	0.000	0.100	0.000
21	0.400	0.000	0.000	0.000	0.000	0.000
22	0.300	0.000	0.000	0.000	0.000	0.000
23	0.400	0.000	0.100	0.000	0.000	0.000
24	0.100	0.000	0.000	0.000	0.000	0.000
25	0.200	0.000	0.000	0.000	0.000	0.000
Failure rate(size > 0.5)		4/25		0/25		0/25
Largest chipping size in group		0.7		0.2		0.3

The effect of various blade types and dicing setup on the size of the sidewall chipping of silicon bars of aspect ratio 10 is presented in Table 3. The number represents the height of the side wall chipping with respect to die thickness. Pristine dies are indicated by 0.0 or 0.1 level chipping whereas reject dies are 0.5 and higher. 4/25 dies fail in the Group 1 set-up whereas 0/25 or no failure is observed in Groups 2 and 3. All 25 dies pass with less than 20% or 30% chipping size. This applies to the front sides of the bars only. The opposite sides of the bars are usually pristine. It is safe to predict that there will be negligible rejectable dies present in the rest of the wafer. Group 3 may have a higher chance of failing as the largest chipping size is bigger than that in Group 2. This is to be expected as the dicing feed-rate in Group 3 is much faster than Group 2. Each wafer can yield thousands of these small size silicon bars therefore sample size must be increased if a higher level of confidence is needed.

The same higher throughput dicing parameter in Group 3 was used on bars which were thinned down to 0.100 mm. The lower silicon bar thickness reduces the fracture strength making the dicing optimization process even more critical. The wafer was diced to obtain die dimensions from 5 times to 20 times the aspect ratio as shown in Figure 6.

The raw data as observed under the microscope is presented here in Table 4.

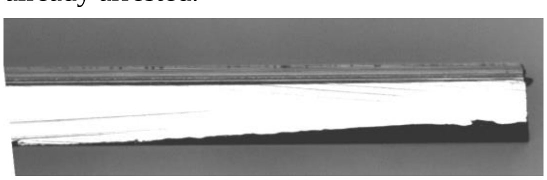
Table 4. 0.100mm thick silicon bars

	Group C					Group D					Group E				
Aspect ratio L:W	5	7.5	10	15	20	5	7.5	10	15	20	5	7.5	10	15	20
Chipping size 0.0	2	7	4	12	2	4	3	10	9	8	4	n/a	n/a	11	6
0.1	17	5	11	12	17	1	15	8	2	11	12	n/a	n/a	9	6
0.2	5	3	5	5	5	1	5	7	3	4	0	n/a	n/a	3	2
0.3	0	0	2	0	1	15	3	6	7	2	1	n/a	n/a	9	4
0.4	1	1	3	0	0	5	1	2	3	0	6	n/a	n/a	0	2
0.5	0	0	0	0	0	0	0	0	1	2	3	n/a	n/a	0	0
>0.5	0	0	0	0	0	0	0	0	0	0	0	n/a	n/a	0	0
total quant	25	16	25	29	25	26	27	33	25	27	26	n/a	n/a	32	20
Reject quant	0	0	0	0	0	0	0	0	1	2	3	n/a	n/a	0	0
% reject	0	0	0	0	0	0	0	0	4	7	12	n/a	n/a	0	0

DISCUSSION

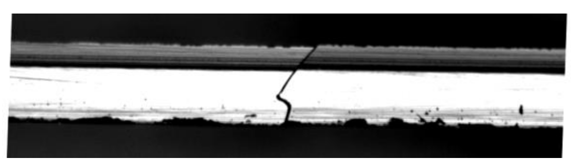
The results show that even with bars that have an aspect ratio of 20 and a thickness of 0.100 mm, crack free dicing can be achieved with the proper dicing parameters. Of the 3 groups C, D and E with thickness of 0.100mm, Group C shows the best overall result. This group is diced using the same blades as Group 3 but with different setting, the chipping result is satisfactory with no failures on all aspect ratio dies including the longest bar with aspect ratio of 20. The largest size chipping from Group C is 40% of the side wall which is surprising found on the lower aspect ratio dies. It turns out that this chipping is at the corner of the die where the crack has been arrested as shown in Figure 8.

Figure 8. Largest chipping of 0.4 size from the best group (Group C) is found on smaller aspect ratio dies with corner crack that is already arrested.



Such corner chipping is not a reliability concern for the device during environmental testing. With the die being only 0.100mm thick, each sidewall crack is at or lower than 0.040 mm in height. Group D which is performed with dual pass or step cut surprisingly produced higher levels of chipping. Failures with chipping that is ≥50% of sidewall thickness occurred on the higher aspect ratio bars of 15 and 20. Also these 2 failed high aspect ratio groups showed high incidence of bar breaking (Figure 9) when handled in the same manner as Group C. Such ease in breakage indicates very low fracture toughness and strength. The singulation process which allows this to happen would not be acceptable in the manufacturing line.

Figure 9. A pinched area with 100% die break. Such artifacts are disregarded and discarded from results.



Group E is also a step cut process but produced rejectable chipping levels on the low aspect ratio dies in the form of corner chipping. This corner chipping extending beyond the midline of the die thickness is rejectable per criteria mentioned in Figure 4. Normal examples of acceptable sidewall condition with $\leq$ 20% crack size from Groups C, D and E are revealed in Figure 10.

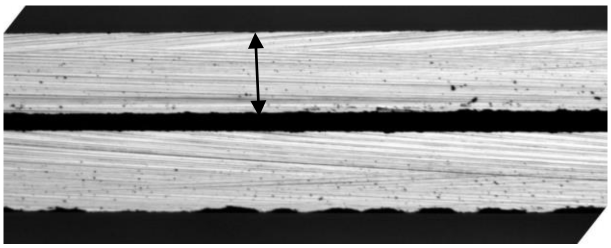


Fig.10A. Sidewall of two dies with 10% chipping size from Group C.

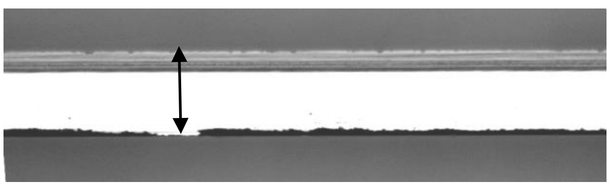


Fig.10B. An example of a die with 10% sidewall chipping size from Group D. The chipping level is normal and is acceptable.

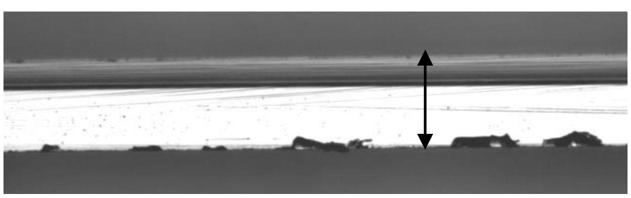


Fig.10C. An example of a die with 20% sidewall chipping size from Group E. Arrow indicate full die thickness.

Additionally Group D showed high incidences of breakage during handling indicating poor fracture strengths. This is an example of the fragility of thin silicon bars and their tendency to succumb to die breakage during pick and place (Figure 9). Fracture occurs in an area where the die was pinched with no correspondence to damage caused by the dicing process. It is evident from this study that the dicing process may not be the limiting factor for high aspect ratio die assembly but instead picking / placing is.

CONCLUSION

For silicon bars of aspect ratio as high as 20 with varying thicknesses as low as 0.100mm, high quality dicing can be obtained with very acceptable levels of die chipping on conventional saw machines. 100% yields can be achieved using high quality blades and high precision saws with proper machine set-ups. For medical devices, this is particularly important because of zero field failure requirements. Also the implants must be small and long creating a challenge for singulation unlike that for the consumer electronic devices which are mostly "tile shaped". Long bars are susceptible to torsion if not controlled during dicing resulting in rejectable chipping and cracking of the bars. Without having to adopt newer singulation technologies such as laser dicing or dice before grind, the work here has shown that 0.3 maximum chipping size can be achieved for silicon bars that are 0.1mm thick, 0.36mm wide and 7.2mm long.

Acknowledgments

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