Dicing Improvements: Yield Enhancement, Throughput Increase and Die Size Reduction in M/A-COM's GaAs Fab

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ABSTRACT

A strong wafer dicing operation is vital to the manufacturing process. At the dicing stage the wafer has the highest value. Everyone is aware of the wafer and die yield for the lot and they are counting on the wafers to meet customer commitments. Unfortunately, the dicing process is not trivial with GaAs. Because it is so fragile, GaAs is very sensitive to changes in the dicing tools and to drifts in the dicing machinery. These issues had to be addressed in order to meet the fab-wide drives to increase wafer throughput and increase the die count per wafer.

Over the past year, many improvements have been made in the post-fab area of the Walker building to meet the challenge. Both the saw and scribe / break processes have been streamlined. New materials are being used to dice the wafers in both methods, providing greater speeds as well as reliability. As a result of improvements in the scribe and break operation, we have been able to cut the street size of most die over 50% -- greatly increasing the number of die per wafer. Optimization of the scribing parameters has lead to more predictable separation. There are limitations to the amount of the street reduction and throughput increase that is possible - and our biggest challenge now is to raise the capability of the processing tools to meet our needs. Alignment becomes critical at smaller street sizes, as well as the ability to keep the breaks and chips within the narrow streets. This paper details these processing hindrances as well as the improvements that have been made. In addition, ongoing work with tool designers is described and the opportunities for continuous improvement are presented.

PART I - SAWING

BACKGROUND AND ISSUES

Prior to last year, M/A-COM's saw process at the GaAs facility in Lowell, MA involved dicing wafers with 30-micron-thick resinoid blades. Although the resinoid blades have always produced the highest-quality kerf in our brittle GaAs wafers, they presented availability issues and handling difficulties. Because of the thickness of the blade, they are very fragile and changing them with tweezers can easily break the blades. These blades also have a very short life - few blades made it to 1000 cuts. For reference, the average wafer requires 400 cuts, so the resin blades had to be changed after every one and a half wafers. Blades often blew in the middle of a wafer, damaging die and requiring a mid-wafer change which in turn required a slower processing speed.

The greatest advantage of the resin blades for us -- the quick wear of the resin bonding compound –proved to work against us in another respect. The quick, unpredictable wear makes it very difficult to determine how much of the blade is left. Because of this, wafers had to be monitored frequently and sometimes they were not cut all of the way through. When that happened, the wafers had to be re-cut and die would be damaged due to the difficulty in re-alignment. To make sure the wafers were cut all of the way through, the operators sometimes over-compensated and cut too deeply into the mounting tape causing it to tear.

Throughput using resin blades was very slow due to the blade wear and also the fact that the blades required a two-pass process. For our standard wafers, the entire thickness was too much for the blades to cut through in one pass, so the wafer was cut through partially in each direction and then would go through a second pass in each direction. There was a second reason for doing this two-pass process - when cutting into the adhesive mounting tape, the adhesive would stick to the resin blade and "load" it so that it would not cut properly. If the blade was loaded, and a cut was attempted on the next uncut street, the blade would produce a large amount of chipping.

SAW IMPROVEMENTS MADE

The major improvement to the saw process was a change from resin-bonded diamond blades to electroplated blades. Electroplated blades, which use a nickel compound to bond the diamonds together instead of a resin compound, can be created on a metal hub that can be handled much easier than hubless blades. The manufacturing process for these blades is also more robust and the availability problem is diminished. We found a new blade developed by Disco with a very soft binder compound that allows the blade to wear so that it does not load too much, but it wears slowly enough that the height can be kept constant across the entire wafer. The new blade also has the smallest grit diamond available, which reduces the amount of chipping.

The greatest benefit in using these new blades is the strength over the resinoid blades. Because of this the blades can be made with more exposure (they can cut deeper) while remaining very thin. The blades can also withstand cutting deeper without being damaged, allowing us to go from a two-pass to a single-pass process. The recent purchase of a new saw from K&S with automatic alignment and automatic blade wear monitoring allows us to increase throughput dramatically.

RESULTS OF SAW IMPROVEMENTS

Previously, with a two-pass process and the old resin blades, an average wafer would take just over 2 hours to complete. With our new K&S 980 saw using the new nickel blades and a single-pass process the amount of time per wafer was reduced to 55 minutes. This also produces higher quality cuts as mentioned - the kerf size went from 50 microns with 5 microns of chipping to 30 microns with 1 or 2 microns of chipping. The durability of the blade allows them to routinely last beyond 10,000 cuts per blade. With the handling of the blade being easier as well, the operators are spending much less time changing them.

PART II - SCRIBING

BACKGROUND AND ISSUES

Prior to last year, the scribing process on our Dynatex DX-III machines was limited to only large die (die larger than 1 mm x 1mm). As with sawing, this problem was also related to the diamond dicing tools. Using factory recommendations for scribing parameters, the scribes were unreliable (they were not sufficiently damaging the crystal to allow the GaAs to cleave consistently). The angle of the scribing facet to the wafer surface was determined based on a reference angle that is lapped into the tools. Because the tools are not ground accurately, the reference angle had to be determined for each of the four facets on a tool. In addition to this, the varying quality of the tools required us to scribe a test wafer with each new scribing facet before scribing production wafers. This slowed the operation down and required a large amount of scrap wafers for quals. When a tool failed in production, there was no warning and wafers were easily damaged.

Another opportunity for improvement in the scribing process was in the cover tape required during cleaving. The wafer must be protected because the wafer comes in contact with a polyurethane "anvil". The Gel-Pak cover that was previously used for this purpose was difficult to manage and it left a residue on the wafers that required a solvent clean to remove. Because it was easy to leave bubbles between the tape and the wafer, damage would occur to die or sometimes even whole wafers during cleaving.

SCRIBING IMPROVEMENTS MADE

The first improvement made was to optimize the process to overcome the problem with varying tool quality. A steeper scribing angle is now used so that the point of the facet is used more effectively. Because the new angle is more tolerant to variances in the lapped reference angle, the need for finding the true reference angle went away, removing a subjective 15-minute operation. The scribing angle was then made as steep as necessary to allow small die (die that approach the 2:1 ratio of width to thickness) to be scribed reliably. An additional benefit of the steeper angle is that the scribes no longer fail catastrophically without warning. A small variation in tool sharpness produces uneven breaks as a warning sign. Whenever these warning signs are seen, the tool is rotated to a new facet or changed for the next wafer.

There is a drawback to the steeper angle however. The desirable crystal damage that the scribing tool creates is straight down beneath the sharp point. With a steeper angle, the sides of the tool begin to damage the crystal laterally as well. This lateral damage is seen as what we call "bruising" on the sides of the scribe line. This bruising can be mild, in which case the cleaving process relieves the induced stress, or the bruising may turn into chipouts during cleaving. In order to combat this problem, the downward force must be lowered below the threshold that the manufacturer recommends. The mechanical system that transfers the force from a voice coil to the scribing tool has friction that must be overcome, so the voice coil cannot regulate the force consistently. To fight this problem, time is required to set the servo gains that control the voice coil. In some cases a small amount of weight must be added to the scribing module. Once the correct operating condition is determined, the small ball bearings in the scribe module must be cleaned and re-lubed frequently (every 2-4 weeks) to keep the tool moving smoothly.

Whenever bruising occurs, the scribing force is reduced until the problem goes away. There is frequently a problem where the force must be turned down to the point where it can no longer overcome the friction in the system. In this case, the tool will not follow the contour of the wafer and it the scribe will "skip" over low spots. Any bow in the wafer will exacerbates the problem because the tool, when it reaches the front edge of the wafer, will jump up and skip over the front part of the wafer. This jump at the front edge was limiting the speed that we could scribe with. To fight this problem, the author worked with Dynatex for a software fix that would allow vacuum to pull the wafers flat during scribing. Another problem with our wafers that contributed to skipping and increased tool wear was the PCMs. Most of our PCMs went across the streets putting metal and nitride in the path of the tool. With the help of the CAD and test groups, our PCM structure was changed so that our scribers had a clear path through all of the streets.

The “vacuum pull-down during scribing” fix was finally implemented in a new software release, along with another fix the author requested that allowed us to finally move to a fully automatic process. We now have a more productionworthy process in which the wafers are loaded manually, and the machine automatically aligns, processes, and monitors the wafers with minimal operator intervention. In order to achieve this, we purchased a new Windows-based scribing machine and upgraded an older DOS machine to the Windows platform with a vision system. The Windows platform also gave us control of the individual servo gains needed to optimize the scribe module.

The final improvement to the scribing process was the elimination of the Gel-Pak cover tape for the cleaving process. A mylar cover tape is now used that is more easily applied and removed. The mylar cover also does not produce bubbles that could damage the wafer. The cover is more rigid, and produces much better cleaving results than the thick, soft Gel-Pak. This change had the added benefit of removing a 15-minute solvent clean-rinse-bake cycle that was required to remove Gel-Pak residue from the bonding pads.

Results of Scribing Improvements

With all of these process improvements in place, the throughput increase for scribing was also dramatic. The dicing time for an average wafer was reduced from 52 minutes down to 35 minutes – an elimination of 1/3 of the processing time. The scribing process now consistently delivers a 98% or better yield.

Die Size Reduction

The greatest benefit by far produced by the dicing improvements is the street width reduction. Blank streets on wafers are wasted space. For GaAs that wasted space is expensive so we sought to reduce it as much as possible. For our highest volume wafers, our streets have been reduced by 70%. The reduction in street size can produce savings of 29% in final chip area. With this street reduction alone, the amount of die per wafer can be increased between 10% and 40%. When this shrinkage is included with other die size reduction efforts, the increase can be over 50%. As our die are getting smaller and violating the 2:1 aspect ratio requirement, we have had to make our wafers even thinner. This only makes scribing easier and more robust. Thankfully our grinding engineer, Henry Hendriks, was able to develop a grinding process for the thinner wafers that does not induce any additional breakage or warpage at the thinning step.

Part III – Future Growth Opportunities

For our dicing saws, the potential is still great for the hubbed nickel blades. We are still using them at a comfortable, safe speed to get used to them. We have done experiments that show that the cutting speed may still be increased as much as four times. Dicing lubricant is also being explored to help decrease processing time by increasing the maximum speed. On the equipment side, more fully automatic machine purchases are planned for the future.

For the scribing operation, there are still more improvements to be made with the existing software. Dynatex is reluctant to work on the existing Windows 3.1 software in order to focus on fine-tuning their newly-released machines which use a Windows NT platform. The author is working with Dynatex to resolve this problem. One of the major improvements to be made is in the length of the alignment sweep for the vision system. Currently the machine only has the ability to align a scribe within a street within +/- 6 microns from edge to edge. If this alignment sweep is made longer, this number can be reduced to within 2 microns. We have started experiments with even narrower streets, but we can only go forward with this if the alignment accuracy is increased.

Due to recommendations from the author and a couple of other companies, Dynatex has finally released a beta version of a new scribe module. The new design gets rid of the unpredictable, mechanical force-transfer system and replaces it with a piezo-electric control. The force will be controlled via a closed-loop feedback system so that it can be accurately monitored while processing and it will keep a constant force on the wafer. This new system will create a consistent, repeatable force measured in grams instead of arbitrary counts. This will allow us to optimize the scribing force for our wafers, and it will be portable from scribing system to scribing system. In the past the scribing process has not lent itself to traditional DOE because of the tool use factor and the variable presentation of the force on the wafer.

For the final elimination of the chipping problem, the design of the dicing tool must be optimized. The author has found a diamond grinder that has produced a requested design, and the tool looks promising. Experiments will continue with different designs until the optimum is found.

For the dicing operation in general, we are looking for more efficient tools. K&S is about to release a new fully automatic saw that is more compact at a good price. There is another company that is developing a new scribing machine, something that is sorely needed in an industry where there are only two players. The most promising machine on the horizon is one just developed by Gem City Engineering. They have produced a laser dicing system that they are now marketing to the semiconductor industry. They have overcome the old problem of substrate heating and slag spattering by coupling the laser beam into a thin column of water. The wafers are mounted on a permeable tape that disperses the water, uncoupling the laser beam and therefore preventing the laser from cutting the tape. GaAs wafers are being sent to Gem City for evaluation.

Summary

M/A-COM was able to greatly increase our dicing throughput, quality and repeatability. We accomplished this by optimizing the dicing materials, streamlining the dicing process for both saw and scribe, and by pushing current machines to the limit. Although many improvements have been made, there is much room for growth in the dicing field. Now that the "low hanging fruit" has been picked, we will be able to fine tune the process through statistical methods. We will be working continuously to push the limits of our operation.

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