Enabling Technology in Thin Wafer Dicing

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Abstract
Driven by IC packaging and performance requirements, the die separation process is facing three main trends: Thinner wafers, stronger die and non-Silicon materials. Memory capacity increase, multichip functions and continuous package miniaturization require ultra thin wafer dicing. For IC performance increases, low-K material and other materials (top layers and even substrates) require different dicing methods for efficient and delamination free dicing processes. It is demonstrated that conventional blade dicing has reached the end of its capabilities and does not meet the separation requirements. Particular thin wafer development and the use of Die Attach Film (DAF) have added challenges and restrictions to the dicing technologies. Laser dicing processes have developed and have become the preferred dicing technology. This paper will discuss the various laser dicing technologies introduced for the different segments and will address the specific performances. Using a multibeam laser dicing process add significant advantages to the different solutions.

Background
Advanced Laser Separation International (ALSI) was founded in 2001 as a spin off from Philips Semiconductors. ALSI supplies semiconductor laser dicing systems using its proprietary multiple beam technology. ALSI is recognized by the semiconductor industry as a leading laser dicing technology company. ALSI is a market leader for laser dicing applications in RFIC and has a strong position and is a technology leader in the T&D and LED segment. Working with several “early adapter” semiconductor manufacturers to replace conventional mechanical wafer separation technologies, ALSI has achieved a large installed base and considerable experience in laser dicing and related infrastructures.

Challenges in thin Si applications
New IC technology, packaging as well as performance requirements drive the trend to thinner, more sensitive and complex structures and diversify the requirements in the die separation process. MEMS have fragile structures that do not allow dicing processes with high-pressure water cleaning, nor any dust or particle distribution. With the further shrinking of IC dimensions, low-K material has been widely used to replace the traditional SiO interlayer dielectric (ILD) in order to reduce the interconnect delay. The introduction of low-K material onto silicon has imposed challenges on the dicing saw process. ILD and metal layers peeling and its penetration into the sealing ring of the die during dicing saw are the most common defects. Additionally, the blade costs went up and dicing productivity down for these applications. The drive to more memory capacity per package volume, to enable the development of portable electronics, requires IC packaging with thinner wafers. 3-D packaging, stacked dies, often with Die Attach Film (DAF) are common and proven assembly technologies. Further wafer thickness reductions are needed but require new dicing methods to avoid yield loss at the stage where the wafer value is the highest or even worse when a broken die would yield out a package containing 10 or more dies.

The conventional saw dicing technology is preventing the ongoing trend for thin wafer development due to the following main reasons:
- Mechanical forces and vibration cause die crack and chip-outs
- Short lifetime of saw blades due to inability to self-sharpening on the thin substrates
- Difficulty to cutting through the DAF with high dicing speeds
- Low assembly and die picking yield due to smearing of DAF against the die side wall.

As such major concerns and limitations for the application apply:
- Wafers are extremely sensitive to wafer stress (due to wafer thinning and front end processes)
- Dicing blade selection and exposure to material stacks in the dicing street (polymer, metal, passivation and other test structures)
- Dicing tape material, tackiness
- Dicing speed

Due to these issues and restrictions of conventional saw technology, the thin wafer IC and memory industry are searching for new dicing technologies and have identified laser dicing technology as the new separation technology. This new laser dicing technology has to comply with the demanding specifications.

1. A die strength value high enough to prevent die cracks during assembly and operating conditions
2. Compatibility to cutting through DAF, not influencing the DAF properties and resulting in 100% die pick yield
3. Ability to cut through a stack of different passivation materials and test structures (metals, polymers, oxides and nitrides)

Apart from these challenges, the laser dicing also offers additional opportunities:
1. Reduction of dicing street width
2. High throughput (>12 wafers/hour)

**Laser dicing technologies**

Over recent years, several laser-dicing technologies have been developed each having their specific characteristics for a separation process. The main dicing technologies that have become most common are:

1. **Ablation laser dicing**
   
   In this process the wafer material is removed by irradiation of laser pulses which locally generate a combination of melt and vapor. The vapor pressure drives the molten material out of the wafer generating an opening also referred to as kerf (see figure 1 below). This technology is predominantly used for dicing through the whole wafer substrate thickness, even backside metallization even though the use of backside metallization is not common for IC and memory applications. Depending on the application (wafer material, thickness, throughput, and die size), a certain laser type is chosen. Main laser process parameters that determine the interaction of laser light with the wafer material are wavelength, pulse duration and power. The size of the Heat Affected Zone (HAZ), recast and debris depend on these parameters.

   ![Laser dicing principle](image_url)

   + Ability to dice through top passivation, Si wafer and DAF
   + High removal rate therefore short dicing time

   - Reduces die strength
   - Rougher side wall roughness
   - Possibility of cracks and chip-outs when high power is used

   **Figure 1. Removal principle for ablation**
2. **Subsurface dicing**

This separation process focuses laser pulses inside the wafer substrate generating a polycrystalline structure and therefore weakening the material locally (see figure 2 below). After processing the wafer can be expanded, sometimes with the aid of a breaking device, resulting in die singulation. This process works when there is no top passivation and test structures (specifically metal) within the street. These structures would block the laser radiation from going into the wafer material. In addition, any DAF present on the backside of the wafer is still not singulated and would need to be done in an additional step.

![Figure 2. Subsurface principle](image)

- “zero” kerf width
- smooth side wall surface

Concerns with subsurface technologies:

- low productivity due to low process speed and alignment
- no DAF separation
- not compatible with structures in dicing street

3. **Hybrid laser technologies**

Several hybrid technologies combine laser and the conventional dicing saw or S&B. One typical example is the use of a low power laser to scribe through the top passivation and metal structures within the street, which the mechanical dicing saw has difficulties to cut through. In a subsequent step, the saw is used to cut through the actual Si substrate and possible DAF (see figure 3 below). This process has the advantage of a good interaction of the laser with the passivation and metal layers but still has the negative impact of the dicing saw to the die and the DAF tape (as mentioned above).

![Figure 3. Hybrid principle combination of laser scribing and saw dicing](image)

- removal of passivation out of the dicing street
- typical sawing problems remain

**Multiple beam technology**

When using a laser dicing process to separate the wafer it is always a tradeoff between quality and speed, independent of the above mentioned technology. Nowadays, available industrial lasers can deliver high amounts of power. However, when exerted at such high levels to a thin wafer substrate, the material is not only separated, but may also be damaged severely. To get a good quality (no chipping or cracks) with a small or no HAZ, low laser
power levels need to be used. As a result, material removal rates and therefore dicing speed is low and the laser capability with respect to the available power is far from utilized. To solve this issue Philips and ALSI have developed a proprietary multiple laser beam technology. The basic principle is to split the main laser beam up into a plurality of laser beams, each having a low power level and therefore not compromising the quality, but as a group of beams keeping the material removal rate and thus the dicing speed high.

**Principle of applying a multiple beam in one traverse**

![Diagram of multiple beam principle](image)

**Figure 4. Multiple beam principle**

In figure 4 indicated above the principle is demonstrated. The high power laser beam passes through a beam splitting device, in this example a diffractive optical element (DOE). This DOE splits the main laser beam up into a number of beams (in the situation illustrated above three beams) with a certain distance between them. The number of beams generated and the distance between them is depending on the design of the DOE; any number of beams and distance can be generated depending on the design of the DOE.

Using a multiple beam technology allows the dicing process engineer to tune to the optimal power levels for their application (ensuring minimum HAZ and high quality) and at the same time achieve a high throughput.

Using multiple beams gives the advantage of reducing number of traverses, whether either a laser ablation process is the best to use for an application or a subsurface dicing process. A multiple beam technology can be used for any laser dicing process and for each it brings the advantage of speed. When applying the multiple beam laser technology again significant advantages can be achieved and concerns for laser dicing are eliminated as demonstrated below in graph 1 and 2 for respectively this Si wafers and for low-K wafers.

**Graph 1. Thin wafer separation technology overview**

<table>
<thead>
<tr>
<th>Category</th>
<th>Ablation</th>
<th>Sub-surface</th>
<th>Law</th>
<th>DAF</th>
<th>Die Strength</th>
<th>No Chip-Outs</th>
<th>Productivity</th>
</tr>
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<tbody>
<tr>
<td>Street Width</td>
<td>100</td>
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<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
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<tr>
<td>Reduce Handling</td>
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<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

1) sub-surface; aspect ratio 0.4
2) Ablation; achieved via post process or short pulse laser
3) sub-surface; requires retaping, breaking, expansion

**Graph 2. Low-K separation technology overview**

<table>
<thead>
<tr>
<th>Category</th>
<th>Ablation</th>
<th>Laser Scribe + Saw</th>
<th>Law</th>
<th>Dicing Time</th>
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<tbody>
<tr>
<td>Street Width</td>
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<tr>
<td>Visual Side Wall Quality</td>
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<tr>
<td>No Chip-Outs</td>
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<tr>
<td>DI Water Exposure</td>
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</tr>
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</table>

1) Ablation; achieved via post process or short pulse laser
**Post process**

When wafers become thinner, they also become fragile and more likely to break when put under stress, specifically when the die strength value is influenced by the separation method. Therefore a new separation technology has to meet and even exceed the die strength values of the current conventional technology. When using a laser dicing technology to separate wafers, die strength can be lower compared to saw dicing technology due to the HAZ. This HAZ is determined mostly by the laser power and pulse duration of the laser irradiated at a certain location on the wafer surface. To minimize HAZ, laser power or pulse duration has to be reduced but as a drawback, the material removal rate is also reduced which means more traverses (more time) are needed to cut through the wafer material. Using a multiple beam technology already solves this problem of speed. If however, there is still too much HAZ and the die strength after laser dicing is too low, a post process can be used. In the post process step the recast material against the side wall of the die is removed and micro cracks that have been generated are made blunt such that they will not propagate further when put under stress. As the post process is fully integrated into the laser dicing system, each wafer coming out of the system has a die strength higher than the reference technology (see graph 3 below, SU = Structure Up).

![Graph 3. Die strength dicing saw vs. laser dicing](image)

**Future developments**

To further improve laser material interaction and at the same time reduce the HAZ, it is beneficial to use even shorter laser pulses (pico second regime). When using laser pulses in this regime the laser material interaction is moving from a predominantly melt and vapor driven process (as for nano second pulses) to a vapor and bond breaking process (also called optical or ionization process). In a pico second laser pulse, all energy is supplied to the wafer surface within an even shorter period generating extremely high fluence. These high power densities have the capability to pull all the electrons from the atom structure and therefore breaking the bond structure between them. This is also referred to as “cold dicing” but is only valid when relative low pulse energies are used. This obviously also means that the amount of material removed per pulse is low. When the power (fluence) of pico second pulses is increased, the process is changing from a predominantly bond breaking process to a thermal process equal to nano second pulse lasers and basically the advantage is lost (see figure 7 below).
The transition to a thermal process occurs because the plasma generated by the ionization in the first stage of the pulse is becoming too hot and is starting to “dice” into the wafer material on its own, generating melt and more HAZ. Therefore, it is necessary in order to use the advantages of pico second pulse laser to keep the pulse energy per beam low. When this happens the HAZ is minimized and the recast layer against the sidewall is also of a different structure. The recast layer for nano second pulses consists of molten Si which did not get ejected out of the kerf. For a pico second laser the recast is merely a thin oxide layer, which also acts as a passivation layer on the side wall and aids in the die strength value. The first die strength tests demonstrate values close to the saw reference and there is ongoing development being done (more details will be presented during the oral presentation). As low powers need to be used to utilize the advantages of pico second pulses, the initial dicing speed will also be low. However, the multiple beam technology also brings a good solution in this application, for a pico second laser. In this case high power levels are available allowing splitting up the pico second laser pulse into a plurality of beams ensuring a high total removal rate and speeds, higher than currently possible with the conventional dicing saw.

**Conclusion**

Memory and IC manufacturers are facing difficult challenges to keep up with the strong demand for packaging. Substrate thicknesses of 50um and less on DAF tape force them to look to new separation technologies. Laser dicing is providing them a solution to meet the strict specifications on the diced die. However, no matter what laser dicing solution is chosen, it will always be a trade off between quality and speed. The multiple beam technology from ALSI provides a solution to go around this impasse and maintain both high quality and speed. Each of the technologies supplied by ALSI; ablation (nano or pico) or subsurface, is equipped with this multiple beam technology to ensure better dicing quality and higher yield, in combination with a quick return of investment, in laser dicing technology.