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A More than Moore Enabling Wafer Dicing Technology

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***Abstract*—As the materials that the wafer dicing process need to singulate become more complex, a diverging current Process of Record (PoR) dicing technologies are not able to meet the quality and/or cost requirements. Laser provides the solution to dice all these different materials but has the challenge to achieve the die strength level specified. In this paper, we will elaborate on the advances made to apply a laser full cut process while achieving the required die strength.**

***Index Terms*—Laser, plasma, dicing, die strength, thin wafer, heterogeneous integration**

I. INTRODUCTION

Wafer singulation in the semiconductor industry has transformed in recent years [1] from having to dice predominantly Si to a complex stack of various materials in which the Si substrate is a relatively small portion of the total stack thickness [2]. As Moore's law (1.0) is running out of steam, more focus is put on advanced packaging to keep the momentum going. Heterogeneous Integration, 2.5 and 3D packaging, are some of the technologies which have further accelerated this market trend in recent years.

For these types of wafers, a traditional blade dicing process is encountering serious yield issues. These issues can be addressed by applying hybrid dicing technologies such as DBG, SDBG or Plasma dicing. However, as the wafers are becoming thinner and have many other materials in the dicing street than just Si, these process flows are not providing the yield, cost, flexibility and productivity required.

For wafer thicknesses in the range of 100 µm up to 250 µm the laser ablation singulation process has become the process of record in many semiconductor applications areas. For the wafer thickness regime below 100 µm, it is considered to have limited capability due to a reduced die strength (related to the alternative separation technologies). More specifically, as the ratio between die size and wafer thickness is > 10:1, traditional laser ablation is not considered as a separation technology.

Advances in the laser sources used for dicing as well as applying post-processes created a full cut solution which meets all the different requirements for advanced (packaging) singulation.

As presented in ECTC 2018 [3] a study has been done to compare three different laser based dicing technologies for thin Si wafers. Each of the three processes had their own characteristics and benefits, however the multi beam laser full cut solution followed by a plasma etch process demonstrated the highest productivity, process window and die strength performance.

The previous study showed that in order to improve die strength, the laser-processed areas need to be separately treated in order to anneal or remove defects. Currently, high volume manufacturing solutions use post-treatment methods such as wet etching and laser irradiation. This latter method, such as that described in US9312178, is particularly attractive since it potentially increases productivity and reduces costs. However, for Si based wafers this wet etching process can not be applied and therefore alternative methods need to be developed.

In this paper, the parameter regime of the laser + plasma etch process is further investigated. The scope of the investigation is a comparison of different plasma sources, Radio Frequency (RF) vs. Micro Wave (MW) source. We will explore the influence of different etch gasses. In addition, we will investigate various parameter scans. The output parameters analyzed are die strength, productivity, undercut and overall quality.

Unfortunately, at the time of writing this paper not all experimental data was available. During the presentation at ECTC 2019 more data and results will be shared.

II. PROCESS FLOW

The process flow for the laser + plasma process is the following (as shown in Figure 1). A wafer is loaded into an integrated coat and cleaning system which performs a pre-clean process step. The pre-clean process step applies a demineralized water (DI) water jet over the wafer surface to remove dust and particles from the wafer surface. Once this step is completed and the wafer is dried through spin drying the second step is to apply a water-based polymer coating on the wafer surface.

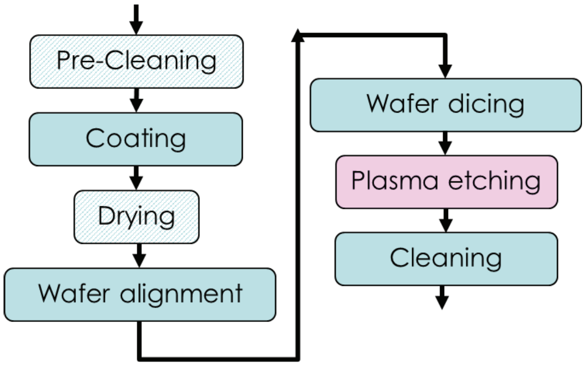

Figure 1. Laser + Plasma etch process flow

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The typical polymer used in the coat material is an ASMPT proprietary developed coat material. However, additional trials have been done with other commercially available protective coat materials and these have also shown to work. More details will be provided in chapter V, Protective Coating Materials. Once the wafer is dried, it is loaded onto the dicing chuck and wafer alignment is executed. Once this is completed, the multi beam laser dicing is executed. After the laser dicing is completed, the wafer is (currently) transferred back to the cassette and loaded onto a separated plasma etch system. Within the plasma etch system the wafer is automatically loaded into the plasma etch chamber. After the plasma etch cleaning, the wafer is loaded into the clean station which removes the water-based coating material and remaining residue that may be present on the wafer. Subsequently, the wafer is transferred back to the cassette. This process flow results in a fully singulated wafer with the Heat Affected Zone (HAZ) removed. Below (Figure 2) is a Transmission Electron Microscope (TEM) image, as presented during ECTC 2018 [3], of a laser diced Si wafer prior to plasma etching. In the TEM image, the HAZ is clearly visible and a strong contributor to a reduced die strength of the singulated device. The plasma etch post process needs to remove the HAZ and thus recover the die strength. At the same time, it will remove the burr and recast from the side wall.

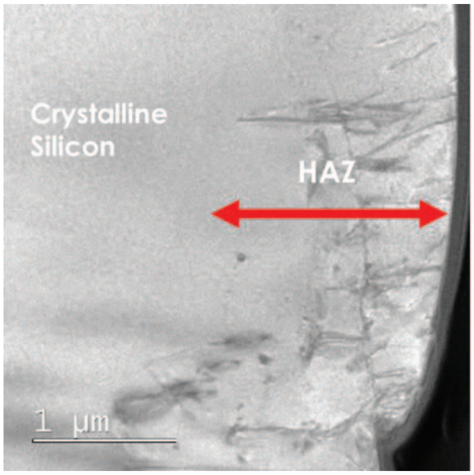


Figure 2. TEM image cross-section of the side wall after standard laser dicing demonstrating a 2um Heat Affected Zone (HAZ).

III. PLASMA SOURCE

Plasma is known as the forth state of matter after solid, liquid and gas. Plasma results from the ionization of gas. Using a plasma source to create radicals that will be able to etch Si is a well-known process in semiconductor industry.

An example of a chemical reaction is provided in the underneath Figure 3 [4].

$$CF_4 + O_2 \rightarrow 4F^* + CO + other \qquad (1)$$

$$Si_{(s)} + 4F^* \rightarrow SiF_{4(g)} \qquad (2)$$

Figure 3. Chemical reaction of plasma etching using CF_4 as the etch gas to etch Si.

The plasma etching process used is utilizing a high-density plasma (10^{14} to 10^{16}) in which a chemical reaction is used to etch the Si side wall. This in contrast to another typical etch process called Deep Reactive Ion Etching (DRIE) [5]. The DRIE process uses a relatively low plasma density flow. A bias between the source and the target (wafer) is applied to accelerate the ions towards the wafer surface at which they bombard the Si and therefore are capable to remove it. The benefit of this process flow is the capability to perform directional etching (anisotropic). The drawback of this process is the requirement of a hard mask (e.g. a photoresist) and the heat generated in the work piece (wafer) during the etching process.

Using ae chemical etch process with a high plasma density has the advantage that it is a “cold” process (40°C), and no bias is needed. It has the disadvantage that it is an isotropic etch (see Figure 4 below).

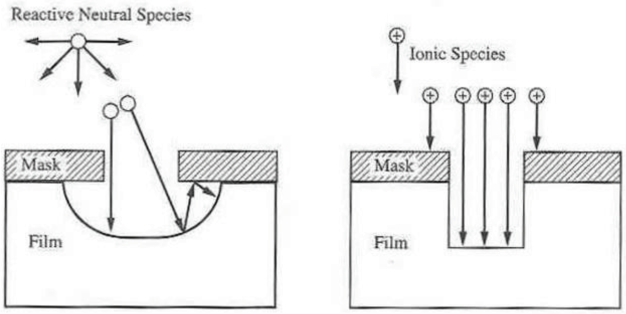


Figure 4. Comparison between isotropic etch (left) and an anisotropic etch on the right side (e.g. DRIE etching) [5].

However since the etch rate required is only 2-3um from the side wall of the die (thickness of the HAZ), there is limited impact on the etch shape.

When moving forward with this plasma etching technology there are basically two choices to make. To use a micro wave (MW) plasma source or a radio frequency (RF) plasma source. In this study we have investigated both.

When first comparing the hardware a MW source is approximately a factor 2 higher in cost compared to a RF source due to the complexity of the electronics.

From a process point of view the MW produces more heat which impacts the productivity and cooling requirements of the system.

The benefit of the MW is a higher Si etch removal rate vs. an RF source (2um/min vs. 1um/min respectively). The higher etch rate of an MW source is beneficial from a productivity point of view. However, a negative side effect is the associated undercut as shown in picture 5. The study has found that the MW source produces a stronger isotropic etch behavior resulting in a stronger undercut of the top section of the die side wall. With the RF source it is approximately 50% less (6.8um vs 4.5um). The undercut is seen as a significant quality issue and needs to be kept as narrow as possible to prevent delamination and chipping of the active top structures.

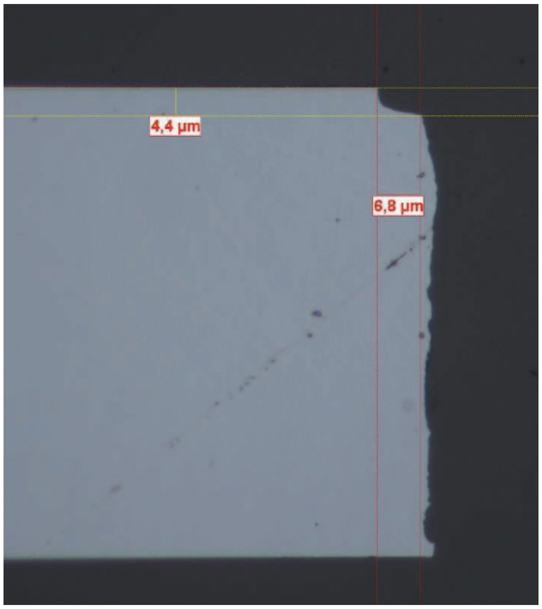


Figure 5. Side wall undercut of 6.8um when using an MW plasma source to etch die side wall

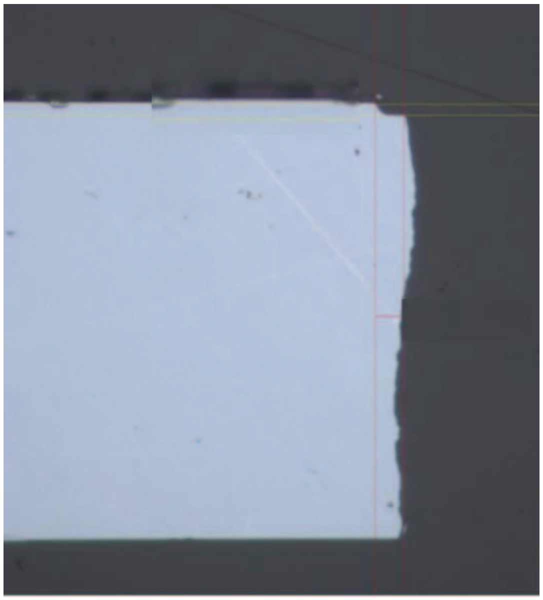


Figure 6. Side wall undercut of 4.5um when using an RF plasma source to etch die side wall

The above pictures are crosscuts of blank Si wafer sample. However, when assuming there are active layers present on top of the wafers (SiO, SiN, Low-K, Metal), it is not desired to have these "free standing" which leads to a potential chipping. ThusXXX

In table 1 the comparison result between the two plasma source types are evaluated and based on these results the conclusion is made to continue the developments with the RF source.

Source	CapEx	Etch rate	Undercut	Complexity
MW	$$	++	--	-
RF	$	+	-	+

Table 1. Comparison between a MW and a RF plasma source.

IV. ETCH GASES

There are several options to use for the plasma etching process as an etch gas.

Most common gases used are CF_4 [6] or SF_6, besides the alternatives NF_3 (toxic) and CHF_3. The main similarity between the gases is that plasma source breaks down the gas and creates the fluorine radicals which etchthe Si.

However, during side wall etching not only Si needs to be etched but also other materials such as SiO or SiN. When there is a strong selectivity it does not provide a homogenous etch process.

At the time of writing of this article we have only tested CF_4.

Etch rate CF4	
Si	0.5um/min
SiO	0.1um/min
SiN	1-1.5um/min

Table 2. Etch rates of CF_4 for various materials.

During the presentation at ECTC 2019, we will share more results for other etch gases. However, based on the results for CF_4 we can already conclude that when etching IC wafers which have a stack on top of the wafer of consisting of SiO_x, Si_yN_z among other materials, this results in an etch rate-dependent pattern resulting from the type of etch gas. It seems like this etch pattern induced structure results in a low die strength even though the HAZ in the Si is removed. Part of this study is to find etch gases which provide a similar etch rate for the various materials.

V. PROTECTIVE COATING MATERIALS

As described in the previous chapter the plasma etching process not only etches the HAZ in the Si side wall but also etches into the active top structures and or passivation. As this is not allowed the top surface and active structures of the devices need to be protected. Regardless of the post process of plasma etching, the standard Process of Record (PoR) for laser ablation dicing is using a water based protective coating. The initial purpose of this coating is to prevent (molten) particles which are ejected from the laser processing to adhere to the wafer surface. With the coat protection these particles can easily be removed after laser dicing with a water cleaning process. The typical thickness of this coating is 1-2um thick. This same coat material also has the characteristic that it will protect the wafer surface from the plasma etch process. As the etch rate in coat material is low compared to Si (>1:10) a 1-2 um coat thickness layer is enough to protect the top surface of the devices when 2-3um of Si is etched away from the side wall.

This is significant difference from a DRIE process. For a hard-baked Photo Resist (PR) the etch rate of PR vs Si is 1:10 [7]. When plasma dicing through a 100um thick Si wafer a 2um PR layer is not enough. For the plasma dicing application a photo resist is required to protect the surface from the ion bombardment.

During the complete process investigated in the paper the wafer is not cleaned after the laser dicing step is completed. The wafer can directly be loaded into the vacuum chamber and the plasma etching step can be applied. After the plasma etching step is completed the wafer is cleaned using a high-pressure water jet which is a standard way of cleaning wafers when using a laser grooving or dicing process flow.

In this study we have investigate several coating materials. One of them (BMK) is developed by ASMPT and made commercially available to its customers. Other commercially coating materials are also going to be investigated to determine compatibility to both the laser dicing process as well as the plasma etching process. For the laser dicing process, it is critical that the coating adheres properly to the wafer surface and does not delaminate from the surface and provide sufficient protection from the particles which are redeposited on the wafer surface. More results will be made available during the presentation at ECTC 2019.

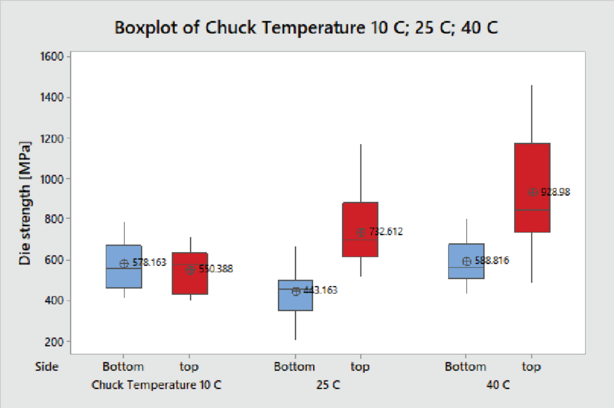
VI. PARAMETER SCAN

In order to optimize the plasma etching process performance (die strength, undercut, side wall smoothness) as well as optimize the productivity several parameters can be varied to achieve this.

Key parameters are temperature, gas flow, pressure, time and gas mix as already discussed in chapter IV.

Temperature is a critical parameter as a higher temperature will help to increase the etch rate and therefore efficiency and productivity. However, when the temperature becomes too high it may create heat damage to the die and or dicing tape or die attach foil (DAF) underneath the die. Therefore, finding the optimum window for the operating temperature is important. Heat and cooling of the chuck on which the wafer is placed is required as well as the heating of the vacuum chamber wall.

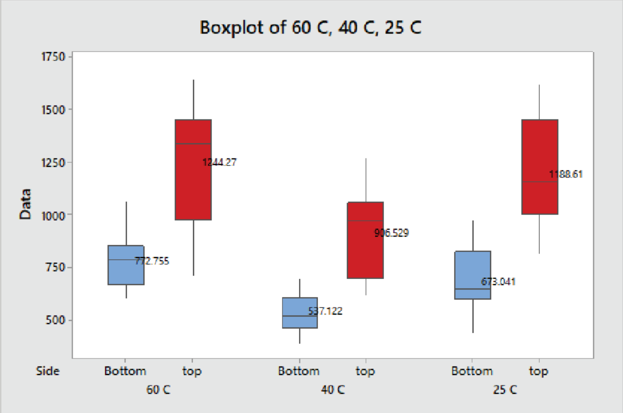
In the underneath graph 1 the temperature of the chuck is varied vs. the die strength measured on the sample.



Graph 1. Die strength vs. chuck temperature.

This data demonstrates that a higher chuck temperature (40°C) provides an improvement in the die strength compared to the room temperature condition of 25°C.

In another experiment we have varied the vacuum chamber wall temperature, see graph 2.



Graph 2. Die strength vs. vacuum chamber temperature.

This data shows no significant influence of the temperature on the die strength measured.

Further analysis of this data is required, and other parameter scans need to be executed. One of them is the influence of the gas flow. A higher flow will create more radicals. The increase in radicals may results in too strong etching on the top side vs. the back side of the device which may result in a non-uniform etch rate between top and bottom side wall and therefore a not optimum die strength recovery. In addition, it can lead to an undercut. More results and analysis will be presented during the ECTC 2019.

VII. CONCLUSIONS

Advanced packaging trends such as heterogeneous integration are increasing the complexity of the wafer stack while at the same time the total thickness and specifically the SI thickness needs to come down. This is trend requires wafer dicing technology which can enable this type of packaging. The main benefit of using laser ablation is the fact that it has the capability to dice through many different types of materials (Si, passivation, metals, polymers, etc). Yet equally important is the requirement of having a high die strength and is this area a typical laser ablation process is lacking (300MPa). Combining a laser singulation process with a plasma etching process addresses the issue of the die strength. In this study the plasma etch process conditions as well as hardware configuration has been investigated. Preliminary data shows that a combination of the plasma source and process parameters can lead to a die strength well over 1000MPa. Further investigation of the process parameter and how they impact both quality (undercut), die strength and productivity will be executed in the coming months and presented at the ECTC in 2019 in Las Vegas, USA.

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