Methodology to Improve the Die Singulation Quality for Low-k and High TEG Saw Street Wafer

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***Abstract*— This paper describes the development of a robust process to improve chipping and peeling defect on low-k/heavy metalised saw street wafer during die singulation process using laser grooving technique. After laser groove process, the sidewall tends to have voiding and become brittle, due to recast material formed with the complex material such as IMD, TEG, silicon nitrate and etc. The sidewall area will be easily fractured and lead to top surface peeling, chipping and sidewall crack. For low-k material, even a minor chipping will lead to low-k interlayer delamination and subsequently cause the unit fail at application.**

Hardware such as optical lens with 0 degree, 90 degree and circular polarization were used for optimization, design of experiment (DOE) were performing on the laser groove and sawing process/parameter to improve the singulation quality.

***Keywords*— Laser groove, low-k material, peeling & chipping, sidewall crack, delamination, circular polarization lens, etc.**

I. Introduction

The mechanical sawing process commonly used to singulate the wafer will cause peeling and chipping defects as shown in Fig.1 on a low-K TEG and silicon nitrate material on devices that used advance node wafer fabrication process.

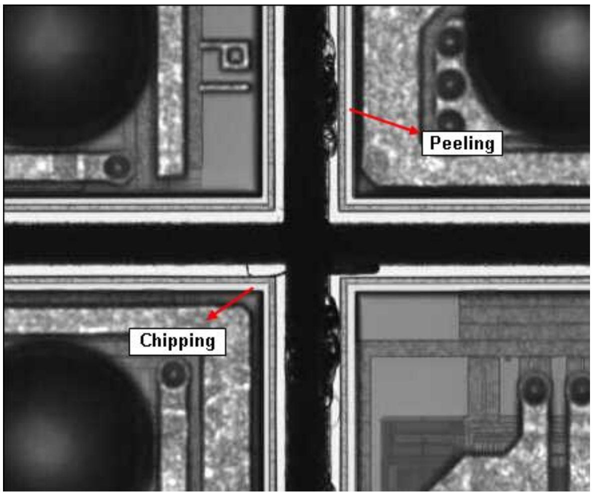

Fig. 1 Top side peeling and chipping after sawing process

To overcome these defects, laser groove is used to cut a groove on the saw street leaving the rest of the bulk silicon material. The groove process tends to create delamination defect as shown in Fig.2

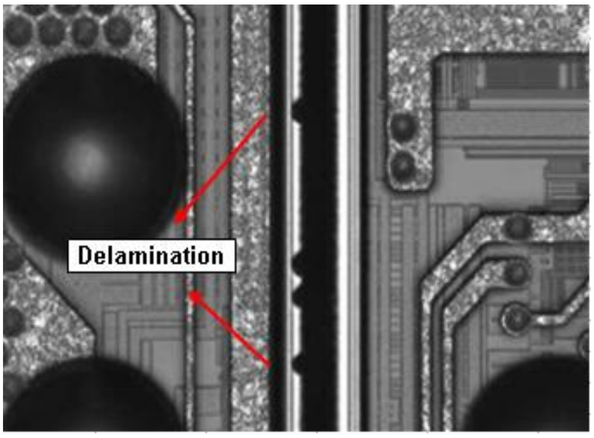

Fig. 2 Delamination defect after laser groove process

Previous studies on optical lens found that the linear polarization is the main cause of delamination defect due to both laser beam are not propagating in the same polarization direction thus the energy distribution is not equal to each other; in which, there is continuously shot out single beam into designated area. Beam to beam overlapping will cause the beam edge energy density become higher; this lead to delamination effect on the vertical polarization direction. To solve delamination defect, circular polarization lens can be used for laser beam equalization and control the dual laser beam propagation in the same polarization direction.

Subsequent studies shows that by optimised the narrow and wide beam combination will improve the quality of the grooving in reducing the debris generated during laser grooving recasting on the sidewall. This recast material is porous and will cause sidewall damage during the second stage of singulated by mechanical saw process. A DOE on key factors in mechanical sawing was done to further optimise the sawing process to improve the chipping and peeling defect.

II. Theoretical Basic

A. Polarization Lens

Light is an electromagnetic wave which is oscillating in random direction along the electric field vector **E** and magnetic field **H** are in directions perpendicular to (or "transverse" to) the direction of wave propagation **Z**; as shown in Fig.3. A light wave that is vibrating more than one plane is defined as unpolarized light. The purpose of polarization lens is used to filter the unpolarized light to polarized light.

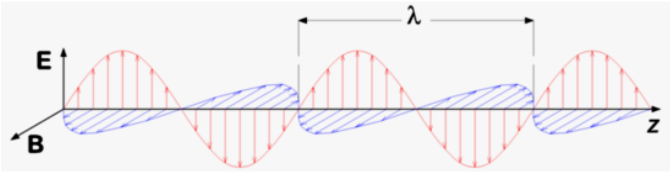

Fig. 3 Electromagnetic wave oscillation in random direction along the vector E and H perpendicular to Z direction

From the machine optical system, UV laser from laser head will pass through the linear polarization lens thus splits the laser beam to two polarization directions. Two refracted beams are polarized with perpendicular orientations which are the horizontal and vertical direction to generate dual balance indexing laser beam.

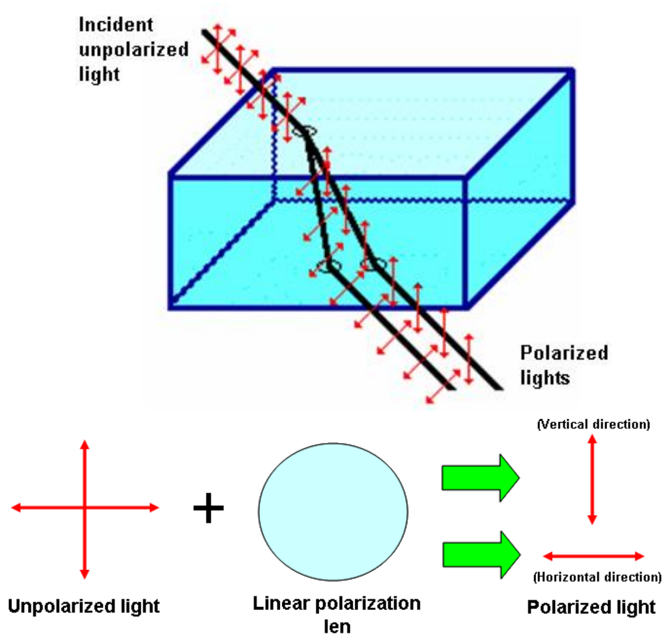

Fig. 4 Light refracted into 2 different polarization directions when the incident unpolarized light pass through the linear polarization lens

Different polarization direction can generate different energy distribution on the laser beam. When the incident light propagate to the boundary of two different media, some of the light will be reflected back to the first medium and the other will be refracted to second media[1]. For the vertical polarization direction; most of energy is refracted and concentrated to the beam vertical centre, small amount of the light will be reflected to left and right side; For the horizontal polarization direction; most of the energy is refracted and concentrated to beam horizontal centre, small amount of the light will be reflected to up and down side. The differences between both linear polarization directions are the energy distribution; for the vertical direction, the energy distribution will fully cover the groove line; alas for the horizontal direction, the energy distribution will only cover the centre area, as shown in Fig.5.

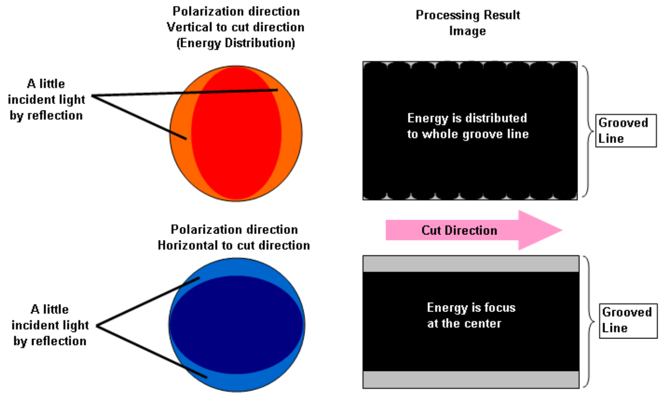

Fig. 5 The energy distribution for vertical and horizontal polarization direction

The total energy of laser groove is continuous shots of beam, as shown in Fig.6. Beam to beam overlapping will cause the energy on the beam edge area become higher. It is the reason why the delamination always occurred at one side only which is vertical polarization direction.

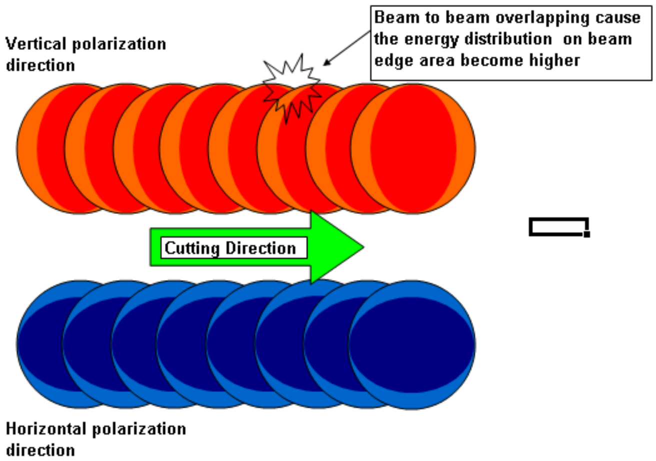

Fig. 6 Analysis of continuous shots of laser beam

B. Narrow & Wide Beam methodology and Saw Blade vibration/clogging

The laser groove machine optics system can generate four types of laser beam, such as single narrow, dual narrow, single wide and dual wide. Different types of laser beam can be applied to several of application depends to the industry requirement. For normal low-k material wafer, the multiple pass of narrow beam is able to remove all the metal along the saw street. But there has one disadvantage for the multiple pass of narrow beam, which is the debris/recast of the metal will be generated onto the sidewall thus will cause peeling and chipping during sawing process.

Using combination of narrow and wide beam methodology were able to reduce the debris generated onto the sidewall, as shown in Fig.7.

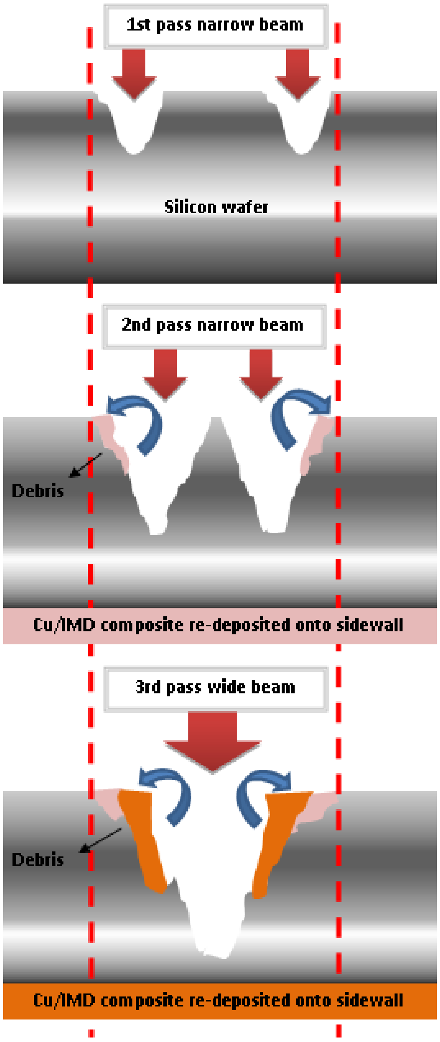

Fig. 7 Laser groove narrow and wide beam combination process

Below are the functions for the different pass of laser groove process:

- 1st pass narrow beam laser eliminates the metal /silicon layer
- 2nd pass narrow beam laser eliminates more metal/silicon layer and form a complex material (debris) onto the sidewall
- 3rd pass wide beam laser eliminate more and more metal/silicon and also form more complex material onto the sidewall.

Sawing process was meant to perform separation between dice. For low k wafer with heavy metal street; sawing process will need to ensure the blade shift within grooved area and deal with clogging during sawing the composite metal remain after groove, as shown in Fig.8.

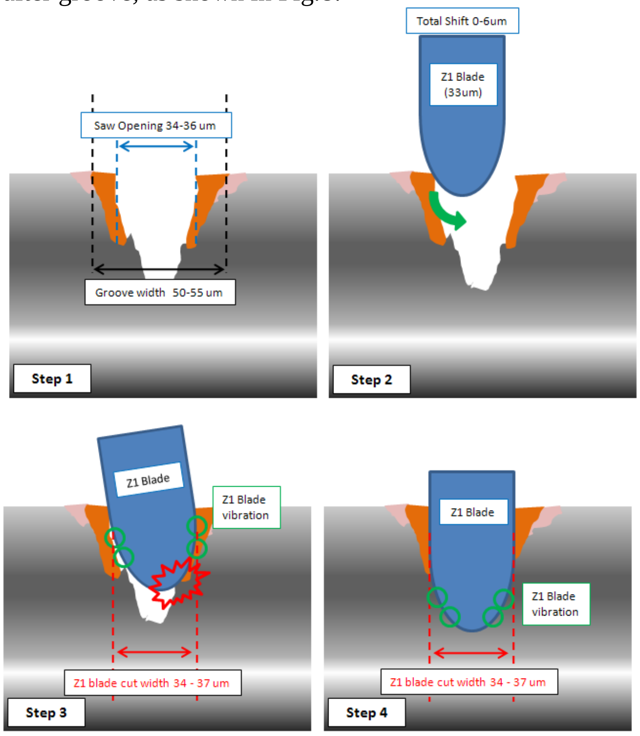

Fig. 8 Sawing mechanism; blade shift and cut process.

The saw blade self sharpening need to be controlled to ensure metal remain during sawing will not clogged the diamond portion and lead to peeling/chipping during saw process. Lower diamond concentration blade will have high blade wear and lead to quick renewal of dulled/clogged diamond grit as shown on Fig. 9.

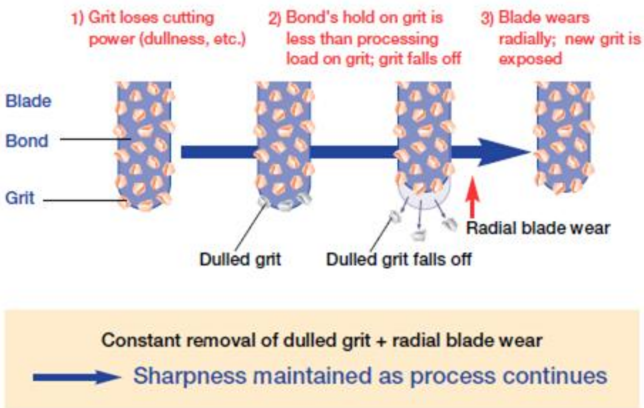

Fig. 9 Blade self sharpening mechanism [3]

III. Experimental Work

A. Delamination Defect

Before installation of the circular polarization lens, both of the linear polarization lenses were swapped to further check and ensure the delamination defect is caused only by the vertical direction polarization. The hypothesis is valid as the location of delamination defect is appeared at the other beam side after swapping the linear polarization lens, as shown in Fig.10.

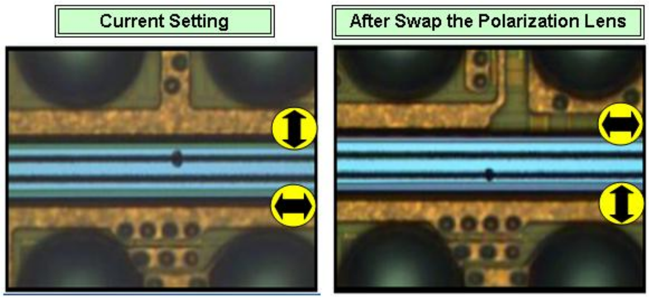

Fig. 10 The location of delamination defect before and after swapping the linear polarization lens

The circular polarization lens installation is the first study to reduce the delamination defect PPM (parts of million) level. The circular polarization lens is being used to shift the phase of linear polarization direction to a specific orientation. It can rotate the light to left and right elliptically polarized depending on clockwise or counter-clockwise rotation of the E-vector [2]. The wave comparison between linear and circular polarization direction is shown as Fig.11.

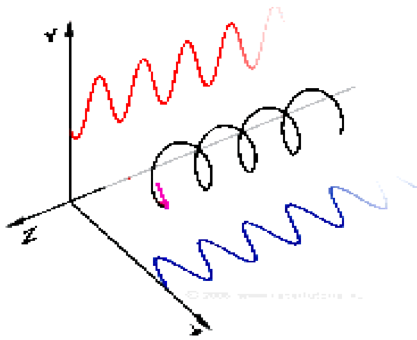

Fig. 11 The comparison of propagating wave between vertical polarization (y-axis), horizontal polarization (x-axis) and the circular polarization direction

From previous theory explanation; the energy distribution of horizontal polarization direction were known to have more focus on the centre. Two circular polarization lenses have been installed to rotate the light direction from current setting (vertical and horizontal direction of linear polarization) to the new setting of circular polarization (to shift the vertical polarization direction to become horizontal polarization direction), as shown in Fig. 12.

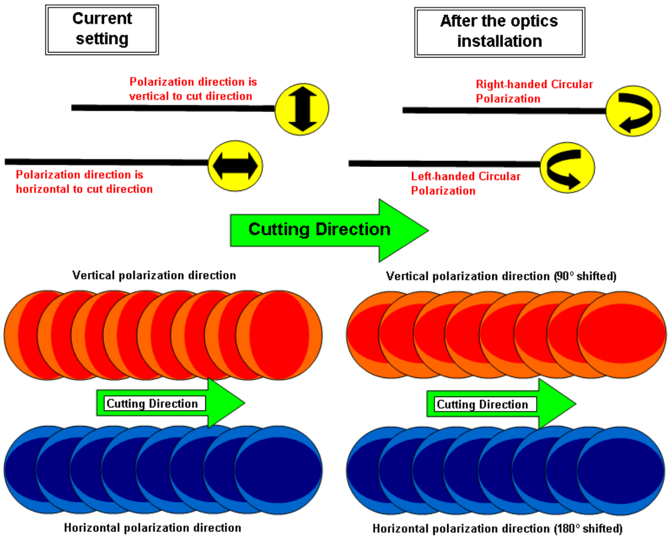

Fig. 12 The polarization direction before and after the installation

The parameter of laser groove must be the same to compare the result before and after the improved lenses installation. Checking were performed by performing groove of condition before and after the lens installation on 1 wafer, followed by 100% high power scope inspection using magnification 100X for groove quality comparison.

B. Peeling & Chipping Defect

There are three main factors of laser groove parameter, which are frequency, power and feed speed of the laser beam. These factors will influence the energy density during laser groove process and also the grooving quality; thus will be the base for DOE study. JMP software had been used to evaluate the 3 main factors of parameter for the initial optimization. The DOE study is shown in Table I:

TABLE I
LG DOE Study In Different Factor

Leg	Laser Groove – Main Factor			Peeling PPM
	Frequency (KHz)	Speed (mm/s)	Power (W)	
1	160	200	3	900
2	160	200	3.2	700
3	160	250	3	1200
4	160	250	3.2	1000
5	180	200	3	1000
6	180	200	3.2	900
7	180	250	3	1300
8	180	250	3.2	1200

After generating the DOE result, the significant and optimized factors as per Fig.13 will be used as parameter baseline for further improvement.

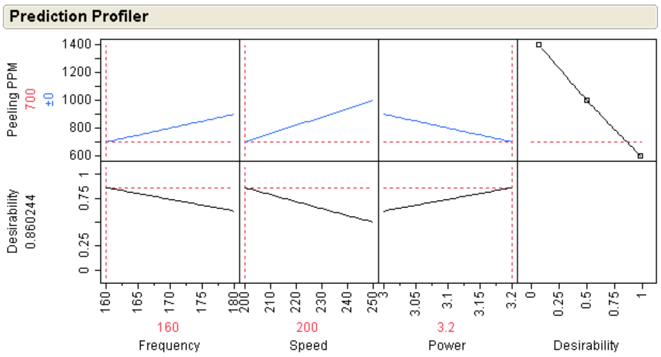

Fig. 13 The optimum LG parameter based on DOE

Blade evaluation further performed on the optimized groove result to check the impact of diamond concentration upon blade wear Table II.

TABLE III
BLADE WEAR CHECK COMPARISON ON GROOVED WAFER.

Wafers Processed	Blade Wear (um/Kft)	
	Conc. 70	Conc. 50
5	1.06	3.2
10	0.94	3.64
15	0.76	3.3
20	0.64	3.22

Based upon monitoring on the blade wear on Fig.14; using lower concentration will have significant higher wear rate. This would likely reduce the potential of clogging during sawing process.

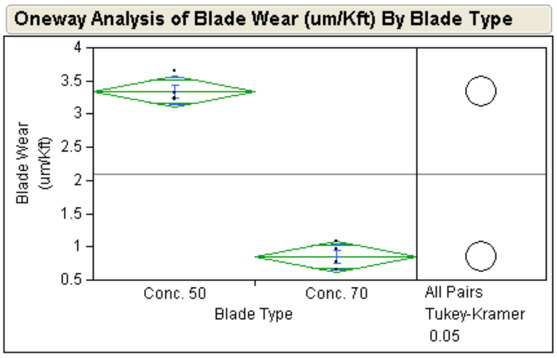

Fig. 14 The DOE test analysis of blade wear

IV. RESULT AND DISCUSSION

The following of experimental evidences can be further support the theoretical model based on the evaluation results obtained.

A. Delamination Defect

The experimental result indicates the location of the delamination is on the vertical polarization direction. After the circular polarization lens installation, the vertical polarization direction shifted to 90º become horizontal polarization direction. Compare the result of before and after the lens installation by using the same parameter, observed the groove quality of dual index beam become the same, as shown in Fig. 15.

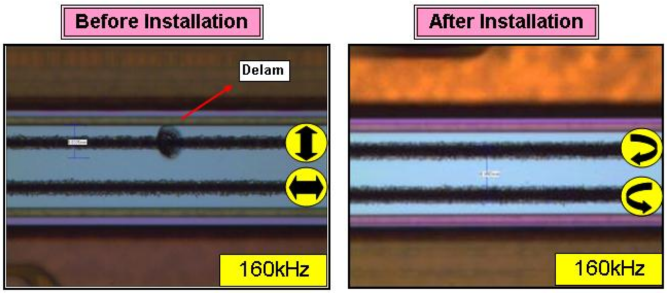

Fig. 15 The comparison results before and after the lens installation

After the circular lens installation, the PPM level of the delamination defect is improved from 1050PPM to 249PPM. Due to the additional optics installation, the energy density of laser power and the grooving depth will be affected. By further optimizing the laser groove parameter, the PPM level is improving from 249PPM to the goal target which is less than 100PPM, as shown at Fig.16.

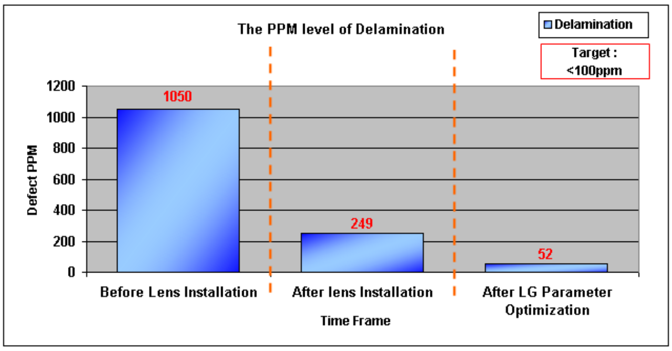

Fig. 16 The delamination defect PPM level monitoring

B. Peeling & Chipping Defect

Based on the DOE study, the initial 1st pass of the laser groove parameter had been used for the optimization on 4th month of monitoring. The PPM level of peeling defect is improved from 3500PPM to less than 1000PPM, as shown in Fig.17.

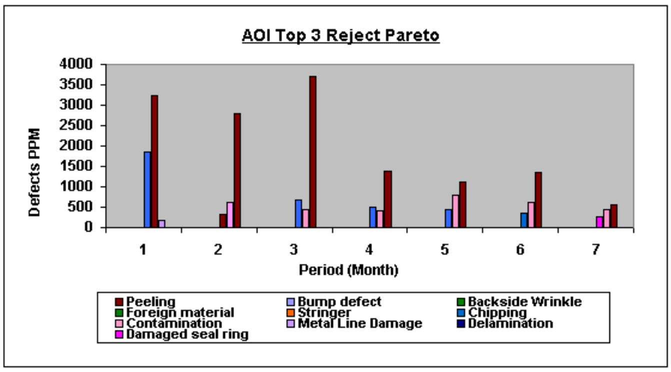

Fig. 17 The PPM level of AOI Top 3 Reject for 7 months monitoring

During SEM cross section check on the laser groove area, the laser groove process window improved from previous "V' shape to "U" shape and the debris/recast on sidewall for narrow wide combination beam is reduced compare with using narrow beam, as shown in Fig.18.

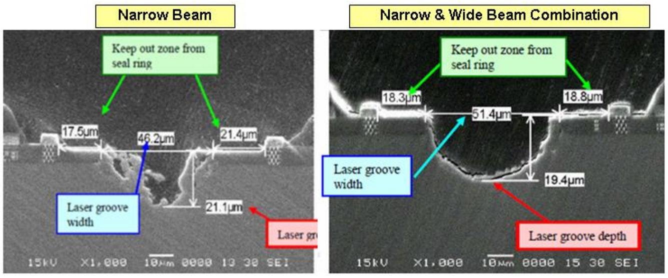

Fig. 18 SEM cross section on the laser groove area

The narrow and wide beam combination methodology was able to reduce the porosity void issue. Based on initial study, the porosity area with many void and connected together (double void) on the sidewall, the particular area will become weak/brittle and easy to cause chipping. From Fig.19 can be observe, the porosity different between narrow beam and narrow/wide combination. Almost all the porosity void is not accruing on the narrow and wide beam combination.

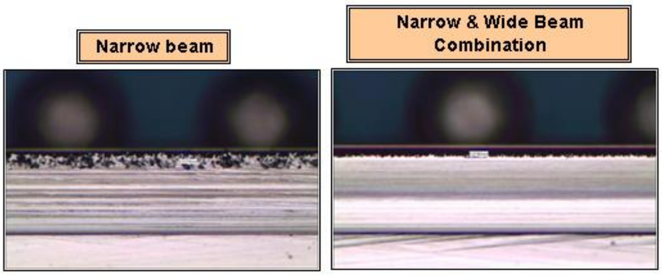

Fig. 19 Sidewall porosity quality using 2 different methodology

The porosity depth is one of the contributing factors to cause the peeling and chipping defect. Higher porosity depth, the risk of sawn street chipped out will become higher. The porosity depth is greatly improved by using "narrow and wide beam" combination. The porosity depth can be reduced from average 32um to current average 21um, as shown in Fig. 20.

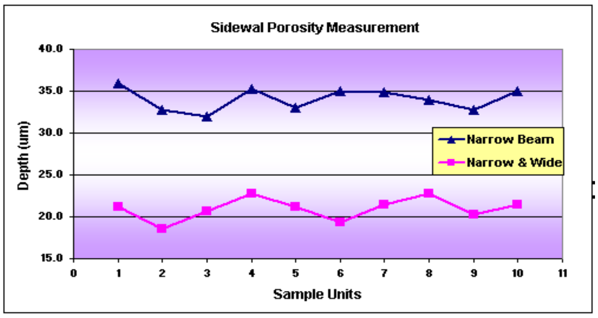

Fig. 20 The porosity depth measurement for both different parameters

Sawing blade evaluation with lower diamond concentration (Conc. 50), shown higher and consistent blade wear throughout many wafers processed without any additional conditioning (interval dressing). Previous higher concentration blade (Conc. 70) required additional blade dressing to maintain its yield performances. The consistent wear on lower diamond blade would ensure yield performance maintain within saw processing as shown on Fig. 21.

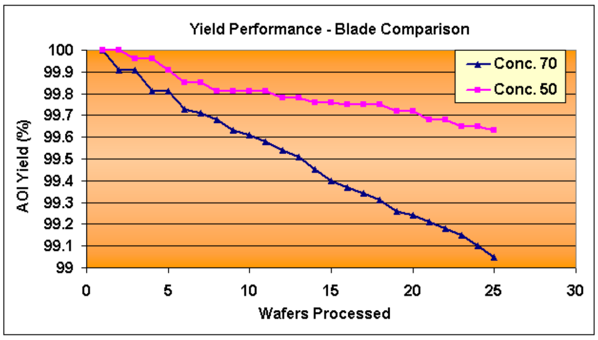

Fig. 21 The lower concentration blade yield consistency check after sawing

V. Conclusions

This paper is proposing the theoretical analysis to explain delamination, surface peeling and chipping defect caused by laser groove and dicing process. All the evaluation results can be proved by the experimental evidences or data. The concept of circular polarization lens shift the vertical direction to horizontal direction reduces the PPM level of delamination to below 100PPM. After determine the three main factors on the DOE and continue optimize the narrow and wide beam combination parameter, the PPM level for peeling and chipping defect had been reduce from 3500PPM to below 1000PPM. The results also shown the narrow and wide beam combination can solved porosity void issue and improved porosity depth from 32um to 21um. In combination; sawing blade evaluation with lower diamond concentrations (Conc. 50) shown higher and consistent blade wear throughout many wafers processed.

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