Laser Singulation of Thin Wafers & Difficult Processed Substrates: A Niche Area over Saw Dicing

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Laser beam has found its more extensive applications in microelectronics industry based on the advantages of low cost, non-contact and fast speed microfabrication. In this paper, laser singulation to separate wafer and multi-layer device structures is studied. It shows that laser can achieve superior cutting quality challenged to mechanical dicing saw with the proper tuning of laser processing parameters. Heat induced crack during the laser irradiation is discussed. Critical issues which are limiting laser application to singulation, such as surface contamination, laser power and balance between cutting speed & edge quality are investigated. It is found that laser singulation can find its niche area over saw dicing to separate thin wafers & difficult processed substrates with special designed approaches. Techniques on pocket scanning and dual laser beam irradiation are developed for multi-layer devices.

Keywords: Laser singulation, heat affected region, thin wafer, glass substrate, multi-layer structure.

1. Introduction

The trend of technology development is toward high precision engineering in micro & nano scales, which has raised strong research interests in the world. Laser as an advanced manufacturing tool has advantages to achieve precise engineering integration control and solve the industrial problems.[1-2] In semiconductor industry, thousands of tiny dies are fabricated in a single wafer. Before the IC packaging, they need to be separated into individual dies. It is called wafer singulation or dicing in the production lines. Wafer singulation is a big business with the worldwide market at hundreds of million dollars. Currently, mechanical saw cutting is the conventional approach. The saw embedded with tiny diamond particles is running through the streets between the dies and cutting away the wafer materials with an aid of cooling water. Dicing speed for a Si wafer at a thickness of 600 μm can be higher than 100 mm/s with a good quality cutting edge. [3-4] Laser singulation is a novel wafer dicing method to separate the dies by the high power short pulse laser ablation of the wafer substrate materials. It has the advantages of dry & non-contact processing and much smaller cutting width due to the capability of focusing the laser spot less than 10 μm. [5-6] However, the laser singulation has the difficulty on how to increase the cutting speed to separate a thick (600 μm) Si wafer to compete the saw dicing. Its cutting speed is a few times lower limited by current available laser power (for example, 50 W for DPSS 532 nm Nd:YAG laser). The other challenge is the high initial investment of laser systems.

Driven by the demand for smart cards, implantable medical devices, security/keyless entry systems, portable computing and military/aerospace applications, wafer industries is moving toward the mass fabrication of large memory for mobile phones, cell base station, PDAs, internet routers and switches on ever-thinner substrate surface (thickness < 200 μm). [7] It brings in the extreme technical challenges for the current mechanical saw dicing technique. It can be easy to imagine that an improper handling of an 8 inch thin wafer would cause the whole wafer cracks into many smaller pieces due to the extreme brittle nature of this big and thin (as thin as a human hair) wafer. Even much slower mechanical singulation can make thin wafer chipping, cracking and device failure eventually. However, it provides the excellent opportunity for the laser singulation to replace the current saw dicing as the next generation wafer separation technique. Laser irradiation can achieve a much higher cutting speed for the thinner substrates due to much less wafer materials needed to be removed and a smaller laser spot size to be focused. The other niche area for the laser singulation over the mechanical saw dicing is on the separation of difficult processed substrates, such as glass substrates and multi-layer structure devices. Mechanical saw dicing has to slow down the processing speed greatly for a good quality cutting edge or even could not process the samples due to the cracks generated from the mechanical stress acting on these brittle substrate materials. Materials property difference on a multi-layer device also causes the delaminating between the interface layers due to the variation of the mechanical forces applying on the different layers.

In this paper, pulsed laser singulation of 1) thin wafer of Si, GaAs, Al_2O_3 and glass wafers and 2) multi-layer structure devices of glass/Si/glass and Cu/IC molding material packages is investigated. Influence of laser processing parameters on the dicing quality and cutting speed is discussed. Effect of the heat generated during the laser singulation is studied to have a better understanding of mechanisms behind the crack formation. New approaches on dual laser beam irradiation and pocket scanning singulartion for a high quality cutting edge are briefed. It shows that the pulsed laser singulation has a very high potential to replace the mechanical saw dicing in the processing of thin

wafer and difficult processed multi-layer structure as the next generation device separation technique.

2. Experimental

Figure 1 shows a schematic drawing of Nd:YAG laser singulation setup for microdevice separation. Laser light goes through a beam expander in order to get a smaller focused laser spot on the substrate surface. Three mirrors are for the automatic Z-stage adjustment of the objective lens (10x to 100x magnification) height to control the focusing depth into the samples during the laser ablation. It is to keep the focused laser spot on the fresh materials surface. Samples are placed on an X-Y stage. Its motion is controlled by a PC. To meet the special singulation geometry requirement, CNC programming is applied to design different cutting contours, for example squares for Si wafer and rings for glass substrate. A CCD camera and video monitor are coupled into the system in order to observe the laser processed sample surface in real time. To avoid the damage of the CCD by the reflected laser light, a light filter is installed in front of the CCD. A small bulb is used to provide lighting for the camera. To lessen the laser ablation debris deposition on the sample surfaces, a gas stream blows on the samples by applying compressed air through a metal nozzle. Different wavelength pulsed Nd:YAG lasers (Coherent AVIA: 355 nm & 200 ns; Lightwave: 532 nm & 100 ns; Spectra Hippo: 1064 nm & 10 ns) were used for the laser singulation experiment. After the laser singulation, separated samples were observed under an optical microscope (Olympus Metallurgical BH2). The fabrication quality was also evaluated by a Zygo optical profile analyzer.

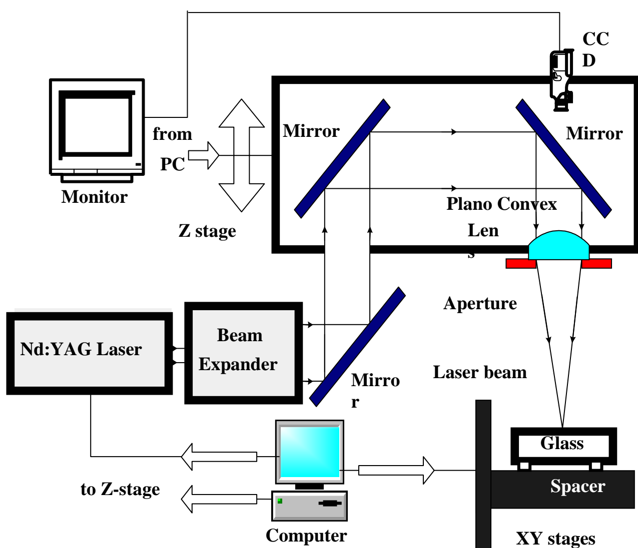


Fig. 1 Experiment setup of Nd:YAG laser singulation.

3. Results and discussion

3.1 Laser singulation of thin wafers

Figure 2 shows an optical microscope image of a magnetic slider surface cut by a pulsed 355 nm Nd:YAG laser at a laser fluence of 23 J/cm^2 and a cutting speed of 5 mm/s. The laser spot was focused down to 20 µm. As the stage moves, the high repetition rate of the laser pulses (5 kHz) makes a cutting line on the substrate surface. One scan of laser beam can only achieve an ablation depth of a few µm.

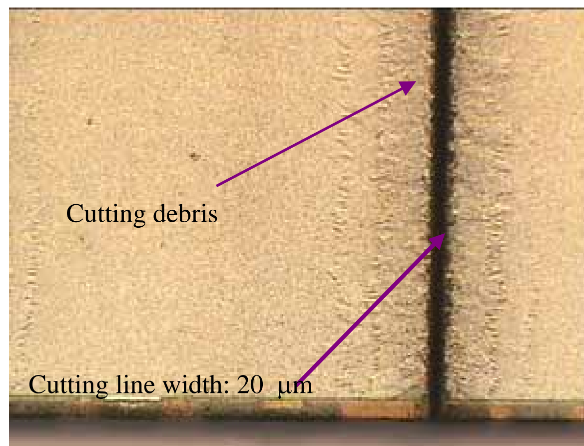


Fig. 2 Image of magnetic slider cut by a 355 nm Nd:YAG laser at a laser fluence of 23 J/cm^2 and a speed of 5 mm/s.

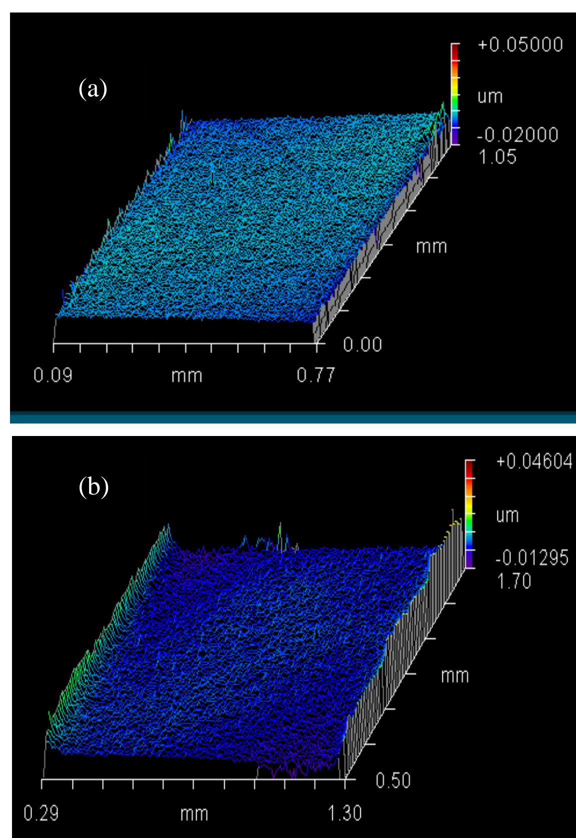


Fig. 3 Zygo surface analyses of magnetic slider edges cut by (a) laser singulation and (b) saw dicing.

Dozens of laser scanning is required to separate the sliders at a thickness of 200 µm. It can be observed that the line roughness or variation along the cutting line is less than 1 µm. Figure 3 is the Zygo surface analysis results for the magnetic slider edges cut by laser singulation and saw dicing, respectively. From the cross section of the edges, it also proves that laser singulation can provide a much smoother cutting edge. Meanwhile, laser singulation can achieve the smaller height variation than mechanical saw dicing. Therefore, it can be concluded that laser irradiation is one of the potential approaches for high quality magnetic slider singulation.

However, it can also be seen from Fig. 2 that there are cutting debris deposited along the cutting line in a region of 100 µm. It is because the cutting debris were ejected out of substrate surface during the explosive laser ablation of ceramic materials and then re-deposited on the nearby area due to the loss of their kinetic energy from the gravity force acting on them. It is necessary to remove the debris before the assembly of magnetic sliders into hard disk drives since a slider flying height is only around 10 nm above magnetic media surface. These debris contaminants would scratch the media surface and induce recording device failure. Surface cleaning is one way to solve the debris problem. In the singulation process, a gas stream or sucker can be introduced to remove the debris and lessen their re-deposition onto slider surfaces. To place the slider facing down and shoot laser pulses bottom up is another option to eliminate the debris deposition though it brings in the complexity of sample handling and system modification to avoid the debris deposition on optic lens and mirror surfaces.

Thin wafer (thickness < 200 µm) separation is a high technical challenge for the saw dicing due to the brittle nature of substrate surfaces. During a fast rotating mechanical saw touches thin wafer surfaces, it causes whole wafer cracks. It is very difficult for this conventional wafer dicing technique to obtain a good quality cutting edge on thin die surfaces. Figure 4 is the optical microscope images of die surfaces separated by Nd:YAG laser singulation from 50 µm thick Si wafer and 100 µm thick GaAs wafer. It demonstrates that laser singulation of these thin wafers can produce high quality cutting edges (with the device circuit structures as the reference). For thin wafers, laser singulartion can provide a much higher processing speed since much fewer substrate materials are required to be removed. It is one of the niche areas for the laser microprocessing to replace the saw dicing to be next generation wafer singulartion method. How to proper handling of these thin and tiny wafer dies after the laser singulation is one of the technical challenges needed to be solved before the successful applications of this novel approach in the production lines.

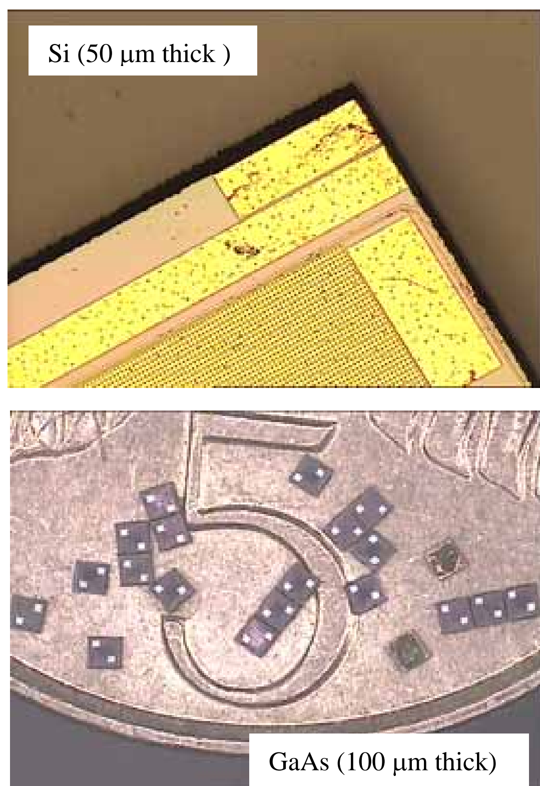


Fig. 4 Images of microdevices separated from Si thin wafer (50 µm thick) and GaAs wafer (100 µm thick) by laser singulation.

3.2 Laser singulation of glass substrates

Glass is a transparent substrate material to most of the laser sources. It only absorbs laser light at a wavelength shorter than 300 nm for glass precision engineering. Femtosecond laser, short wavelength excimer laser and the 4th harmonic Nd:YAG laser can get high quality glass ablation. But the cost of these laser systems are much higher with much lower laser power available. It limits these lasers' singulation of glass substrate for industrial applications.

Due to the light absorption coefficient less than 5%, 355 nm, 532 nm and 1064 nm laser irradiation of glass causes many cracks (crack length can be longer than 50 µm) along the cutting line. It is not applicable for glass precision engineering at the basic requirement of cracks less than 10 µm. Figure 5 shows the optical images of glass substrate front view and cross section surfaces after a 355 nm pulsed laser direct scanning singulation. The weak absorption of laser light and much heat dose applied on cutting line induce strong thermal stress and evolve the stress into crack formation on glass surfaces. The depth of glass cutting tends to be saturated and it is difficult to separate a glass substrate at a thickness > 200 µm. It is because of the crack formation and glass debris deposition on the trench, which limits the laser light irradiation on fresh glass surfaces and reduces further ablation of the substrate. It can be

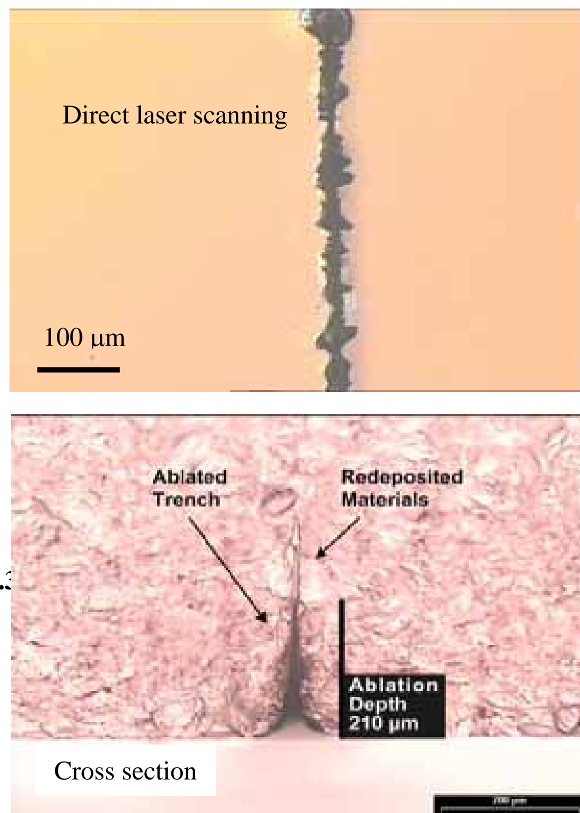
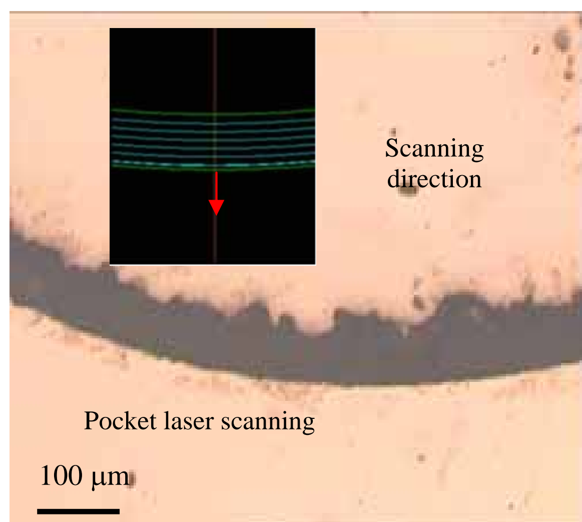


Fig. 5 Optical images of glass surface and cross section after laser direct scanning singulation.

observed in Fig. 5 that cracks formed on the surface is not consistent across the line. This makes unstable processing results. Crack difference also brings in another latent side effect as glass is going through heat or stress cycles, which causes the extension of crack size and make device failures.



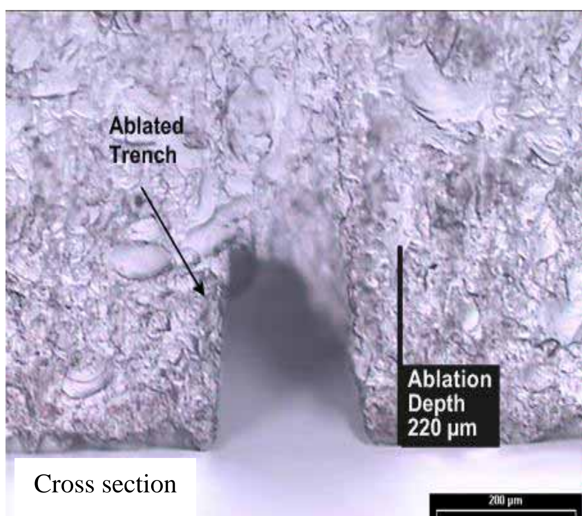


Fig. 6 Optical images of glass surface and cross section after laser pocket scanning singulation.

To achieve precision glass engineering at a reasonable cost by using Nd:YAG lasers, a laser pocket scanning singulation technique was developed. [8] The working mechanism is to apply the first path of laser direct scanning on the glass surface, followed by the second path of scanning with a displacement of one third or a half of laser spot size. The second path of laser energy is strongly absorbed by the glass cracks generated in the first path irradiation. It results in the precise laser ablation of glass materials. A few paths of laser scanning design are applied to achieve a high quality cutting edge with a wider trench. With this method, there is not laser ablation saturation problem for thick glass substrate. The overall laser cutting speed for 0.7 mm glass substrate is much higher than laser direct scanning. Figure 6 shows the optical microscope images of a small disk separated by the pocket scanning method. It can be seen that the outer circle does not have any cracks. The circle line variation due to the laser singulation is less than 2 µm. It meets the glass precision engineering of 10 µm. The inner circle has much bigger cracks around 40 µm. These cracks are generated from the first path of the laser direct scanning. Since the pocket scanning direction is moving outward, the inner circle edge quality is not changed. It can be improved greatly by modifying the scanning path to move laser beam inward to remove the crack materials for a high quality cutting edge as well.

3.4 Laser singulation of multi-layer structure devices

There is a large amount of microelectronics devices fabricated on a multi-layer structure. Different layers consist of different substrate materials. Mechanical saw dicing has a great technical challenge on how to avoid the package chipping or delaminating generated during a saw plate runs through different mechanical property materials, for example copper layer on the top of IC molding materials for CSBGA packages and glass/Si/glass structure devices. Laser singulation has the advantages in processing of these structure devices because laser ablation can remove most of substrate materials and one pulse of laser irradiation only removes a sub-micron depth of substrate materials and the laser spot can be focused down to dozens of microns. It achieves substrate materials removal in a tiny volume. With dozens of thousands pulse irradiation by a high repetition rate DPSS Nd:YAG laser, a precise laser cutting edge can be obtained, especially at the interface layer. Figure 7 shows the optical cross section views of an IC package and glass/Si/glass multi-layer structure after the laser singulation. It is clear that there are not chipping and delaminating

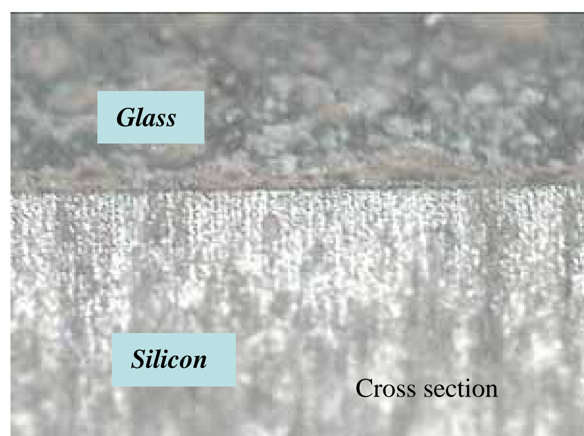


Fig. 7 Optical cross section views of IC package and Si/Glass multi-layer structure after laser singulation.

at the copper and IC molding materials though thermal and mechanical properties of these two materials are big different. It can also be observed that there are not crack and delaminating generated between Si and glass bonding area after the laser singulation.

3.5 How to increase singulation speed

Singulation of the IC units is facing new challenges as IC becomes more complex and smaller with increasing packaging density. The use of the traditional saw cutter is no longer suitable for the singulation of these fragile high density IC units because the vibration and heat generated could create micro-cracks and damage the fine interconnects leading to mal-functions. This method of singulation is also associated with high water consumption, risk of contamination and tool wearing. Industries are exploring and adopting pulsed lasers for the singulation of high density and thin IC packages, such as QFN packages.

Results shown in the previous discussion indicate that laser singulation can offer a fine cutting kerf and its non-contact nature minimizes the risk of cracks and contamination. Currently DPSS Nd:YAG lasers with the wavelengths of 532 nm and 355 nm are the optimal light sources for the laser singulation of micro-devices in terms of their stability, system cost and available laser power. Laser cutting speed depends on processing parameters, micro-device types and thickness. A cutting speed of 50 mm/s was achieved by a 50W 532nm pulsed Nd:YAG laser to separate an IC package with a thickness of 1.3mm. As 200 W 532 nm Nd:YAG laser available, laser singulation can meet the target of 100 mm/s to compete the conventional saw dicing. The other situation would be as the IC package thickness reduces further down to 0.7 mm, pulsed lasers would replace the dicing saw in the production lines. The singulation speed can be increased further with the use of a dual laser beam singulation setup, as shown in Fig. 8, for multi-layer structure singulation. Two different laser beams are applied to cut dual layer IC packages. The first laser beam could be a 355 nm Nd:YAG laser which can cut away the top layer (for example, Cu layer) at a high speed and the other laser beam could be a CO_2 laser or 1064 Nd:YAG laser to ablate IC molding materials at a high speed. Powers of these two lasers are tuned and matched together for a same cutting speeds of the individual layers. Laser beam 2 is following laser beam 1 as the beam 1 finishes the top layer singulation and the beam 2 starts the bottom layer singulation. To get the high quality cutting edge, laser interaction with top layer and bottom layer materials needs to be investigated to select the optimal laser wavelengths and laser fluence for the precise laser ablation at a minimum heat affected region.

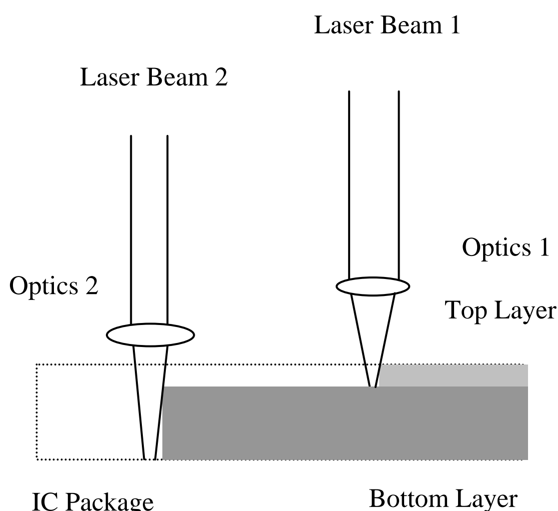


Fig. 8 Dual laser beam approach for high speed and good quality IC packages singulation.

4 Conclusions

Laser singulation as a highly potential next generation wafer separation technique is investigated. Limited by current available laser power (50 W for a 532 nm Nd:YAG laser), high system cost and low cutting speed (40 mm/s for 1.3 mm IC packages), it is difficult for the laser singulation at the current stage to compete the mechanical saw dicing to separate thick substrate wafer. However, as the technical trend of industrial development moves to smaller and thinner dies with the complexity of functions for the device miniaturization, laser precision engineering will play a key role in the wafer singulation. The niche area of the laser singulation over the mechanical saw dicing is in the processing of thin wafers (thickness < 200 micron) and difficult processed substrates, including brittle glass substrates, copper/IC molding packages and glass/Si/glass multi-layer structure devices since the mechanical saw dicing brings about severe cracks, chipping and delaminating problems. It forces the cutting speed to reduce greatly for the saw dicing to ensure a good cutting quality. As the new high power and stable DPSS Nd:YAG laser sources (> 200 W for a 532 nm Nd:YAG laser) available in the market and applications of novel laser processing approaches, such as laser pocket scanning and dual laser beam irradiation, laser singulation will replace the saw dicing in the production lines in the near future.

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