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Research Status of Laser Cutting Technology

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Abstract

With the highly advanced development, high performanceof integrated circuit manufacturing, and rapid advancement of optoel-ectronic technology, hard and brittle transparent materials such as s-ilicon wafers and quartz glass have been widely used in fields incl-uding integrated circuits, micro-electromechanical systems, and aero-space, thanks to their excellent physicochemical properties. The dici-ng quality of silicon wafers plays a decisive role in the final produ-ct quality and economic benefits; similarly, quartz glass also requir-es high-quality dicing to prevent stress from propagating along the defective parts of the glass edges and thus causing cracking.This st-udy investigated the current status of dicing from three aspects:tradi-tional dicing, assisted dicing, and dicing after spatial light modulati-on (SLM). Meanwhile, the factors influencing dicing were studiedfr-om the perspectives of laser types, laser polarization states, process-ing parameters, and processing technologies.

Keywords

Cutting Technology; Traditional Cutting; New-Type Laser-Cutting

1. Introduction

Since the 21st century, lasers have become one of the fastest-develo-ping green technologies and among humanity's most important inve-ntions. Since their discovery in 1960, lasers have developed rapidly,breathing new life into traditional optical science and spawning newindustries[1].The application fields of transparent materials are const-antly expanding,covering microelectronics, microfluidics, optoel-ectr-onic, and other domains.

Owing to its excellent electrical and mechanical properties, silicon h-as made silicon wafers the most commonly used semiconductor ma-terials today, which are widely applied in the integrated circuit chi-p industry[2]. Quartz glass possesses a series of outstanding physicoc-hemical properties, such as high-temperature resistance, corrosionres-istance, light transmittance, and electrical insulation. Consequently, i-t is extensively used in integrated electronics[3], micro-electromecha-nical systems (MEMS), high-end displays, microchannels, aerospace,and other fields[4]. In the aerospace sector, ring laser gyroscopes ma-de of quartz glass are critical components of aircraft navigati-on sy-stems, used to measure minor changes in direction[5]. In the semico-nductor and data communication fields, quartz glass is a promising-material that can replace traditional substrate materials to serve as the substrate for radio frequency (RF) energy harvesting systems ba-sed on MEMS technology[6]. The specific applications of silicon w-afers and quartz glass in the aforementioned fields are illustrated in Fig1.

Contact-based machining methods make workpieces more sensitive t-o externally applied mechanical stress. Furthermore, they often requ-ire specific liquids for assistance, and dicing defects—such as mate-rial contamination, chipping, and cracking—are common. These iss-ues pose significant challenges to traditional tool-based dicing proce-sses[7]. However, despite the growing application of these transpare-nt materials in the consumer electronics field, their brittle nature m-akes the dicing process extremely challenging. Particularly when pro-cessing thinner substrates, achieving a high-quality diced edge com-pletely free of microcracks or fragments remains a challenge.

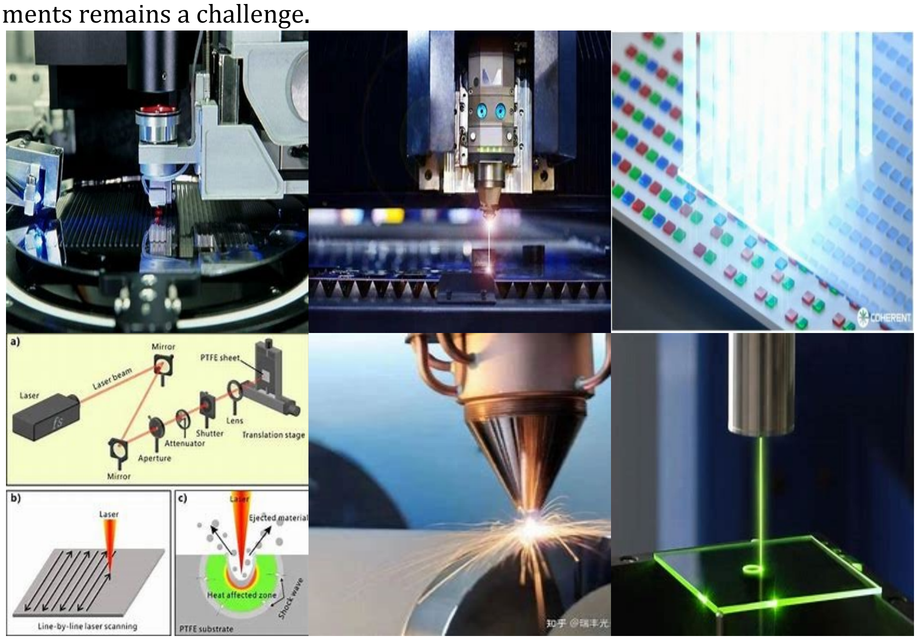

Fig 1. Applications of Laser Machining

Laser cutting technology is a cutting technique that uses lasers to p-rocess flat surfaces. Owing to its advantages such as high processi-ng precision and no pollution, it has attracted the attention of manyresearchers. With the continuous development and progress of scienc-e and technology, higher requirements have been put forward for t-he performance of parts; thus, the methods and equipment for proc-essing parts are constantly updated and improved.

Most traditional parts are manufactured using mechanical machiningmethods, which have shortcomings including low processing efficien-cy and poor environmental friendliness—problems that laser process-ing has exactly solved. Laser cutting technology utilizes a laser ge-nerator to output a laser beam with high energy density. This laser beam scans the processing surface, and the local area of the materi-al undergoes melting and vaporization, enabling rapid shaping[8]. In the field of cutting-edge processing, laser processing has been appl-ied in the design of micro-mechanical structures. It can maintain th-e dimensional accuracy of micro-structured parts and boasts advant-ages such as high cutting efficiency, fast speed, good quality, and e-nvironmental friendliness[9].

Domestic and international researchers have conducted certain studie-s on the interaction between lasers and materials, as well as the o-ptimization of laser cutting parameters, which have promoted the de-velopment of laser cutting. This paper will introduce the research a-nd development history of laser cutting technology, including the r-elevant theoretical research on traditional cutting, assisted cutting, an-d laser cutting after spatial light modulation (SLM). Meanwhile, it will also provide an overview of several factors that affect the cutti-ng process.

2. Traditional Cutting Technology

2.1. Tool-Based Cutting

In traditional cutting technology, mechanical blade cutting is a com-mon method that achieves material separation by applying mechanic-al force to the workpiece; over its development, dicing saw techno-logy has become highly stable and mature, making it the industry'sprevailing wafer cutting method. In semiconductor wafer manufactur-ing, after devices are fabricated on individual dies, the wafer is ty-pically divided using automated precision dicing saws or scribing m-achines—this technology has existed since the early days of the se-miconductor industry and represents a mature process with sophisti-cated blade designs, materials, and process recipes[10]. Blade cutting- operates via a grinding-like mechanism, where material is sheared from the wafer by fine abrasive particles embedded on the edge of a rotating blade[11]; the cutting blade functions as a thin grinding wheel that rotates at high speed to abrade the wafer, resulting in fu-ll or partial penetration through the wafer thickness. However, whe-n the wafer thickness decreases below 100 μm, blade cutting oftencauses severe wafer damage such as chipping, cracking, delaminatio-n, and residual stress in singulated dies, which significantly reducesprocess yield, and this has become a major challenge as the semico-nductor industry trends toward wafers thinner than 100 μm[12]. Theearliest wafer cutting technology was mechanical blade cu-tting, whi-ch uses a blade rotating stably at high speed to perform intensive grinding on the wafer while using a coolant to rinse the cutting poi-nt—this coolant serves to cool the blade and carry away dust gene-rated during cutting. Yet as wafer thickness continues to decrease, wafers become more brittle and unable to withstand the high-intensi-ty grinding of the blade, easily fracturing during cutting, damaging-chips, and lowering yield. Additionally, blade cutting itself has inherent shortcomings: it is a contact-based cutting method, which inevitably causes edge chipping and peeling on the wafer; the kerf widthis large (generally over 100 μm), reducing the effecti-ve usable areaof the wafer; the blade has a short service life and may break une-xpectedly, making maintenance difficult; and the cutti-ng process req-uires coolant, which increases economic costs, while improper disp-osal of residual coolant can easily cause environment-al pollution. F-urthermore, the incorporation of low-k dielectric mate-rials increase-s wafer brittleness and reduces mechanical performanc-e, making bl-ade cutting prone to peeling, edge chipping, and materi-al detachme-nt—these issues lead to decreased chip performance an-d low yield. To address the above problems, the industry has begunto develop l-aser cutting technology[13].

2.2. Traditional Laser Cutting Technology

Lasers used in traditional laser cutting technology include solid-statelasers (e.g., Nd:YAG lasers), gas lasers (e.g., CO_2 lasers), and fiber lasers ; the emitted laser can be continuous waves, pulsed waves, or mode-locked waves, with wavelengths ranging from ultraviolet to10.6μm (the wavelength of CO_2 lasers) and pulse widths spanning f-rom microseconds to femtoseconds[14]. Through rational selectionof these parameters, the cutting objective can be achieved. The dicing speed of wafers is related to the laser operating wavelength: lasers with longer wavelengths enable faster dicing, while those with shorter wavelengths result in slower dicing. Meanwhile, dicing quality isassociated with pulse width—during cutting with long-pulse lasers, t-he interaction time between the material and laser is prolonged, lea-ding to a large heat-affected zone (HAZ), whereas short-pulse lasers produce a smaller HAZ. Typical laser pulse widths includemicrose-cond, nanosecond, and picosecond levels,with corresponding thermaldiffusion lengths of 900 μm, 1 μm, and 0.1 μm, respectively; how-ever, lasers with shorter pulse widths are more expensive. C.Fornar-oli et al.conducted dicing experiments on doped silicon wa-fers wit-h a thickness of 500 μm using a laser with a wavelength of 532 n-mand a pulse width of less than 15 ps, achieving a mini-mum dic-ing width of 17 μm and a maximum effective dicing spee-d of 2mm/s—these are the best results obtained with short-pulse lasers to date. Lasers with a wavelength of 355 nm feature short wavelengt-hs and small pulse widths; they not only enable narrow dicing widt-hs and small HAZs but also achieve relatively high speeds,exhibiti-ng obvious advantages in terms of quality and efficiency.Comparedwith contact-based blade dicing technology, traditional lasercutting te-chnology offers advantages such as higher dicing speed, more flexi-ble dicing patterns, and higher wafer utilization[15]. However, the th-ermal effect between the laser and material introduces HAZs and microcracks: an excessively large HAZ reduces the effective usable area of the wafer, and if microcracks extend to the protection rangeof the chip, the chip's performance will be affected.

Therefore, to address issues such as HAZs and microcracks, two newtypes of lasercutting technology have been developed based o-n traditional laser c-utting technology—namely, micro water-jet guide-d laser cutting tec-hnology (designed to reduce the HAZ) and stealt-h dicing technolo-gy (developed to effectively control microcracks).

3. New Types of Laser Cutting Technology

3.1. Water-Jet Assisted Cutting Technology

Switzerland-based Synova SA applied the concept of micro water-jetguided laser to laser cutting and developed micro water-jet guided l-aser cutting equipment. This equipment mainly consists of four co-mponents: a laser system, an optical focusing system, a pressure wa-ter chamber, and the total internal reflection propagation module oflaser in the water jet[16].The basic principle of micro water-jet guid-ed laser technology is that an ultra-thin, low-pressure water jet gui-des the laser beam to the workpiece for processing. Meanwhile, thewater jet plays a cooling role during processing, eliminating thedefe-ct of excessively large heat-affected zone (HAZ) in traditional lasercutting.

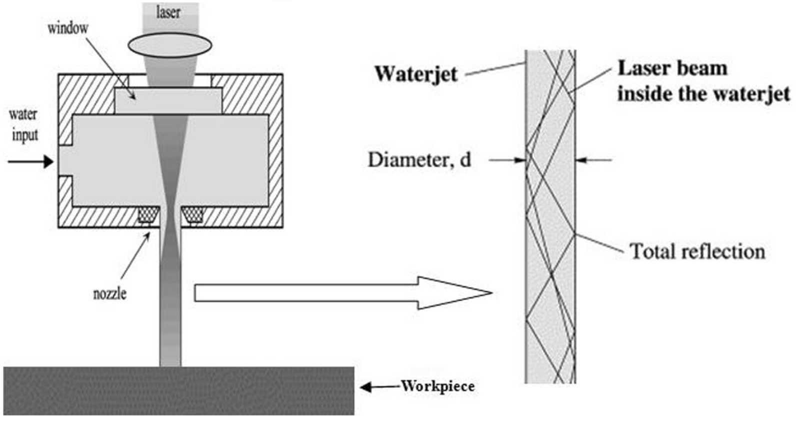

Fig 2. Working Principle of Micro Water-Jet Guided Laser

As shown in Fig.2[17], the laser beam passing through the focusing lens travels through the window above the pressure water chamber,i-s focused on the nozzle at the bottom of the pressure water cham-ber, and then enters the water jet at a certain divergence angle. Thr-ough total internal reflection at the water/air interface, the water je-t guides the laser beam to the workpiece surface.The nozzle,design-ed based on fluid mechanics, ensures that the emitted water jet mai-ntains its shape over a certain distance. Generally, the effective pro-cessing distance is 1000 times the nozzle diameter. Furthermore, ev-en if there are slight changes in the working distance, processing c-an continue without adjustment—a capability that traditional lasers cannot achieve.

3.2. Stealth Dicing Technology

Traditional laser cutting focuses laser energy on the wafer surface. However, the introduction of a heat-affected zone (HAZ) leads to i-ncreased dicing width and uncontrollable microcracks, which reducesthe dicing quality and efficiency of the wafer. One solution to this problem is to use laser irradiation to induce thermal shock inside th-e wafer, forming controllable cracking, and then apply external for-ce to achieve the cutting effect. This process is the Stealth Dicing Technology (SDT), which was invented and patented by HamamatsuCorporation.

The basic principle of stealth dicing is shown in Fig.3[18]: a laser e-mits a laser beam with a specific wavelength, which is focused ins-ide the wafer through a high numerical aperture (NA) lens to forma selective modification layer—known as the stealth dicing (SD) lay-er. This layer serves as the initiation point for subsequent wafer di-cing cracks. By optimizing the laser and optical path system, theseinitiation points can be confined inside the wafer without causing th-ermal damage to the front and back surfaces of the semiconductorwafer. External force is then applied to propagate these c-racks to t-he front and back surfaces, thereby separating the wafer into smallchips.

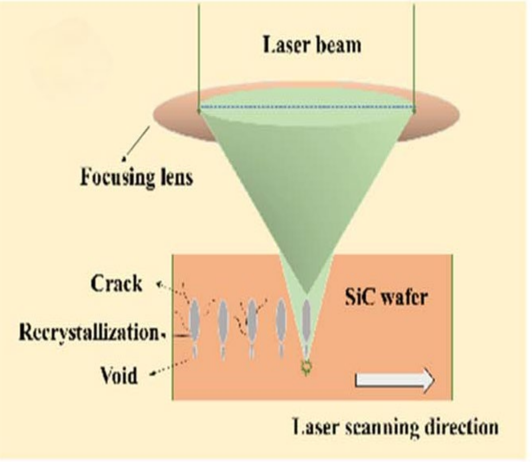

Fig 3. Schematic Diagram of Stealth Dicing

The general process of stealth dicing consists of four steps: front si-de wafer taping, laser scanning, wafer expanding, and ultraviolet (U-V) irradiation. To summarize: laser scanning is performed from t-hebackside of the wafer, avoiding the front-side pattern damage tha-t may occur due to front-side focusing in traditional laser technolo-gy.The number of laser scans varies depending on the wafer thickn-es,and each scan acts on a different depth of the wafer's backside. The ablation depth of a single laser scan is approximately 25 μm; thus, a wafer with a thickness of 150 μm requires 3–4 scans. After each scan, an SD layer remains inside the wafer, and microcracks a-re also generated along the positive and negative directions of the SD layer—these microcracks are key factors promoting wafer separa-tion. In the wafer expanding step, the chips are separated by stretc-hing the expansion tape attached to the wafer surface. Finally, UV irradiation is used to remove the tape from the chip surface, comp-leting the chip dicing process.

4. Conclusions

This study focused on the high-precision dicing requirements of har-d and brittle transparent materials (e.g., silicon wafers, quartz glass)and systematically reviewed the research status of laser cutting tech-nology from three aspects: traditional dicing, assisted dicing, and di-cing after spatial light modulation (SLM), while analyzing key influ-encing factors (laser type, polarization state, processing parameters).

Traditional cutting technologies show both maturity and limitations. Tool-based cutting, a mature process in the semiconductor industry, struggles with ultra-thin wafers (<100 μm) (e.g., chipping, residual s-tress) and faces coolant-related cost and environmental issues. Tradi-tional laser cutting (e.g., CO_2, Nd:YAG lasers) improves speed and wafer utilization but cannot eliminate thermal effects, leading to he-at af-fected zone (HAZ) and microcracks.

New laser cutting technologies achieve critical breakthroughs. Micro-water-jet guided laser cutting controls HAZ to the micron level vialaser-water jet coupling, suitable for ultra-thin wafers. Stealth DicingTechnology (SDT) forms internal modi-fied layers for stress-controlle-d separation, enhancing wafer utilization by 15%-20% without cool-ant pollution. These technologies effectively address the bottlenecksof traditional methods for hard and brittle material dicing.

References

[1] Liu Q, Duan X, Peng C. Novel Optical Technologies for Nanofabrication[M]. Springer Berlin Heidelberg, 2014.

[2] Rafailov, Edik, U, et al. Stealth dicing of sapphire wafers with near infra-red femtosecond pulses[J]. Applied physics, A. Materials science & processing, 2017, 123(5).

[3] Trotta G, Volpe A, Ancona A, et al. Flexible micromanufacturing platform for the fabrication of PMMA microfluidic devices[J]. Journal of manufacturing processes, 2018(Oct.): 35.

[4] Volpe A, Gaudiuso C, Ancona A. Sorting of Particles Using Inertial Focusing and Laminar Vortex Technology: A Review[J]. Micromachines, 2019, 10(9). DOI: 10.3390/mi10090594.

[5] Koji Matsumaru, Atsushi, et al. Advanced thin dicing blade for sapphire substrate[J]. Science & Technology of Advanced Materials, 2005. DOI: 10.1016/j.stam.2004.11.002.

[6] Cai Y, Wang M, Zhang H, et al. Laser cutting sandwich structure glass–silicon–glass wafer with laser induced thermal–crack propagation[J]. Optics & Laser Technology, 2017, 93: 49-59. DOI: 10.1016/j.optlastec.2017.01.028.

[7] Bae J Y, Gwak E J, Hwang G S, et al. Biodegradable Metallic Glass for Stretchable Transient Electronics[J]. Advanced Science, 2021, 8. DOI: 10.1002/advs.202004029.

[8] Zhou L, Kato F, Nakamura N, et al. MEMS hydrogen gas sensor with wireless quartz crystal resonator[J]. Sensors and Actuators B Chemical, 2021, 334: 129651. DOI: 10.1016/j.snb.2021.129651.

[9] Seo D, Jeong J, Kim T, et al. A MEMS glass membrane igniter for improved ignition delay and reproducibility[J]. Sensors and Actuators A Physical, 2017, 258: 22-31. DOI: 10.1016/j.sna.2017.02.011.

[10] Brusberg L, Whalley S, Herbst C, et al. Display glass for low-loss and high-density optical

interconnects in electro-optical circuit boards with eight optical layers[J]. Optics Express, 2015, 23(25): 32528-32540. DOI: 10.1364/OE.23.032528.

[11] Liao K, Wang W, Mei X, et al. Fabrication of millimeter-scale deep microchannels in fused silica by femtosecond laser filamentation effect[J]. Optics & Laser Technology, 2021, 142(1): 107201. DOI: 10.1016/j.optlastec.2021.107201.

[12] Senkal D, Ahamed M J, Askari S, et al. MEMS Micro-glassblowing Paradigm for Wafer-level Fabrication of Fused Silica Wineglass Gyroscopes[J]. Procedia Engineering, 2014, 87: 1489-1492. DOI: 10.1016/j.proeng.2014.11.580.

[13] Götze J. Chemistry, textures and physical properties of quartz–geological interpretation and technical application[J]. Mineralogical Magazine, 2009, 73(4): 645-671. DOI: 10.1180/minmag.2009.073.4.645.

[14] Blinov, L, N. Glass chemistry: Problems, perspectives, and application (A review)[J]. Glass Physics & Chemistry A Journal on the Structural Physical & Chemical Properties & Nature of Inorganic Glasses & Glass Forming Melts, 2016.

[15] Elbatal F H, Azooz M A, Hamdy Y M. Preparation and characterization of some multicomponent silicate glasses and their glass–ceramics derivatives for dental applications[J]. Ceramics International, 2009, 35(3): 1211-1218. DOI: 10.1016/j.ceramint.2008.06.009.

[16] Hidayah N, Yunus M, Yunas J, et al. Investigation of micromachined antenna substrates operating at 5 GHz for RF energy harvesting applications[J]. 2019. DOI: 10.3390/mi10020146.

[17] Guangyi Zhang, Zheng, et al. Gas shrinking laminar flow for robust high-power waterjet laser processing technology[J]. Optics express, 2019, 27(26): 38635-38644. DOI: 10.1364/OE.378328.

[18] Stroj S, Plank W, Muendlein M. Ultrashort-pulsed laser separation of glass-silicone-glass substrates: influence of material properties and laser parameters on dicing process and cutting edge geometry[J]. Applied Physics A, 2021, 127(1): 1-7. DOI: 10.1007/s00339-020-04192-z.