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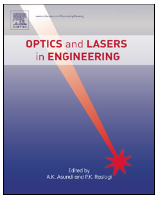

Laser cutting silicon-glass double layer wafer with laser induced thermal-crack propagation

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ABSTRACT

This study was aimed at introducing the laser induced thermal-crack propagation (LITP) technology to solve the silicon-glass double layer wafer dicing problems in the packaging procedure of silicon-glass device packaged by WLCSP technology, investigating the feasibility of this idea, and studying the crack propagation process of LITP cutting double layer wafer. In this paper, the physical process of the 1064 nm laser beam interact with the double layer wafer during the cutting process was studied theoretically. A mathematical model consists the volumetric heating source and the surface heating source has been established. The temperature and stress distribution was simulated by using finite element method (FEM) analysis software ABAQUS. The extended finite element method (XFEM) was added to the simulation as the supplementary features to simulate the crack propagation process and the crack propagation profile. The silicon-glass double layer wafer cutting verification experiment under typical parameters was conducted by using the 1064 nm semiconductor laser. The crack propagation profile on the fracture surface was examined by optical microscope and explained from the stress distribution and XFEM status. It was concluded that the quality of the finished fracture surface has been greatly improved, and the experiment results were well supported by the numerical simulation results.

1. Introduction

The application of silicon-glass device has gained widespread adoption in the IC industry, MEMS and solar energy system, due to the advantages in terms of its reliability and simplicity of the manufacturing process. Currently, the silicon-glass device was reported to account for the majority of many MEMS devices such as pressure sensor, accelerometer, microfluidic device, micropump, microturbine, and micro-actuator [1].

Typical joining technology for silicon and glass was anodic bonding, which was a well-established, reliable, simple and cost-saving bonding method used in the semiconductor industry. Over the last 50 years the Pyrex and Pyrex-like glasses have been proved as the most suitable type of glass for anodic bonding material of the silicon-glass device because of the coefficient of thermal expansion (CTE) of this kind of glass is much lower than ordinary soda lime glass and closes to CTE of silicon range from room temperature 25 °C to the bonding temperature 300 °C [1]. The first level packaging of silicon-glass device used the wafer level chip scale package (WLCSP) technology, which allowed the patterned glass and silicon wafer to be bonded in a single process step after the circuits depositing procedure and then proceed to the dicing process [2]. With the trend towards the WLCSP technology, suitable dicing method of silicon-glass bonded structure wafer has become necessary.

The conventional dicing process was performed on the dicing machine where the wafer was mechanically separated by the spinning diamond cutting wheel with coolant water jet involved. The separating process produced debris mixed with coolant which caused the possible contamination and left micro-fissures in the finished edge, which would lower the edge strength and might trigger impending device failure, and caused tool wear of the cutting wheel [3]. Furthermore, unlike the flat panel display manufacturing process, the additional procedures of grinding and cleaning were applied after cutting, the bonded wafer dicing was a finishing operation [4]. These disadvantages had significant influence in the finished product ratio.

Consequently, the industry sought for other non-mechanical dicing methods to address these limitations. Specialized laser systems which were applicable to wafer dicing and sheet cutting offered alternative solutions tailored to the manufacturing of the silicon-glass device and flat at panel display (FPD) etc. These laser systems included the traditional laser dicing machine [5], the femtosecond/picosecond laser system [6,7], the water-jet-guided laser [8] etc. The contact-free characteristic of laser dicing prevented tool wear and

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eliminates pollution by coolant and debris. However, heat affected zones (HAZ) were formed during the melting and evaporation of the material which only occurred at high temperature during the laser ablation process. The alternate heating and cooling process generated micro-cracks and thermal damages at the dicing cross profile which created a poor edge surface finish. None of the stealth dicing, ablation or full body cutting method could avoid the defect issue [9]. Therefore, the laser dicing technologies currently used was also not the optimum solutions.

The laser induced thermal-crack propagation (LITP) technology or refer to as laser thermal cleavage (LTC) appeared to be one of the promising solutions for silicon-glass bonded wafer cutting. LITP is a non-contact energy beam machining technique with zero-width cutting path (under full body cutting methods, not include scribing and cutting methods), lower operating temperature (under 500 °C) which means less or none heat affected zone, higher cutting speed, no chipping or micro-cracks on the cutting edge which brings about higher mechanical strength, suitable for various kinds of brittle nonmetallic materials include both silicon and glass. It was pioneered by Lumley [10] in 1968, and over the past few decades numerous publications have been devoted to making this technology applicable to industrial production—most of these studies focusing on various types of glass sheet (e.g., soda lime, aluminosilicate, borosilicate) [11–17], some focusing on silicon wafer [18,19], some focusing on other brittle materials such as ZrO_2 ceramics [20]. Most of these cases used the infrared laser with the wavelength of 10.6 μm carbon dioxide laser or 1064 nm solid-state laser as the main heat source, and accompanied by various types of auxiliary equipment for multiple purposes. The LITP technology has been proved perfect suitable for separating thin-film transistor liquid crystal display (TFT-LCD) glass substrate, plasma panel display (PDP), FPD and touch panel by many international companies (e.g., Samsung, LG, Foxconn Technology Group, Corning).

In almost all of these cases, the researchers focused on the single layer sheet cutting problems. And with regard to the cutting of packets of glass sheets or laminated sheets [21], insufficient efforts have been made in publications. There has been no study concerning extend the applied areas of LITP technology to solve the cutting conundrum of the silicon-glass bonded double layer wafer. So the purposes of this paper were to investigate the feasibility of this idea and study the crack propagation process of LITP cutting double layer wafer by theoretical analysis, numerical simulation, and verification experiment.

Since the 1064 nm laser could penetrate the glass layer and absorbed by glass layer and silicon layer [22], this paper chooses 1064 nm wavelength semiconductor laser. Section 2 describes the experimental setups, inspection methods and the specimen specifications. In Section 3, a finite element analysis (FEA) model with XFEM is established, the simulation parameters are given, which are further involved in analyzing the laser-material interaction process. Section 4 describes the physical process of laser beam interact with the double layer wafer and set up a mathematical model consists of a volumetric heating source and a surface heating source. The temperature and stress distribution and the crack propagation profile are studied in Part 5. Concluding remarks are presented in the end.

2. Experimental procedure

The schematic of the setup for the experiment of cutting silicon-glass double layer wafer using LITP technology is illustrated in Fig. 1. A 300 W fiber-optic-coupled continuous semiconductor laser, emitting at 1064 nm with TEM00 beam mode, is used as the heat source. The laser head could adjust its position by moving along the *Z* axis. The laser beam irradiates vertically to the specimen which is supported horizontally by the under fixture on the *x*–*y* positioning table which is controlled by the CNC system installed on the computer. A thermal infrared imager (FLIR), tilted at an appropriate angle ($<20°$) that would prevent direct radiation from reflected light rays, is arranged to record the surface temperature distribution during laser scanning process. The recorded temperature data would be compared to the simulation result, for the verification and calibration of the theoretical model and relative parameters.

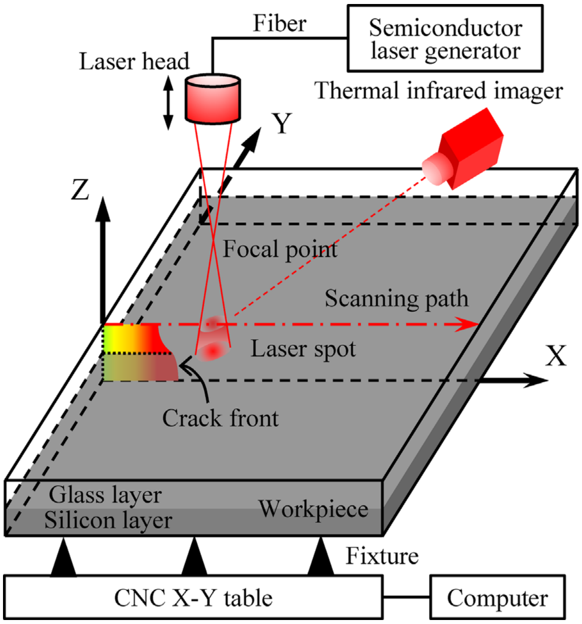

Fig. 1. Schematic of the experimental setup and the coordinate system of the specimen for the FE model.

The specimen is prepared by anodic bonding the Borofloat 33 borosilicate glass wafer (produced by Schott) and the silicon wafer (n-type with (100) crystal plane) together. Both wafers are 0.5 mm in thickness and 101.6 mm (4 in.) in diameter. An initial through thickness notch is incised on the leading edge with a diamond wire saw. The specimen is placed on the fixture with its glass layer side faces upwards to the laser head, and under laser beam focal point. This arrangement ensures both the glass layer and the silicon layer could be heated by the laser beam. The laser scanning path is perpendicular to the primary flat of the silicon wafer, i.e., parallel to the $\langle 011 \rangle$ direction.

The finished cutting surface is inspected by the optical microscope (Zeiss) and scanning electron microscope (FEI Quanta). The cutting surface profile is measured using the surface profiler (Taylor Hobson).

3. Numerical analysis

The commercial finite element analysis program ABAQUS is introduced to calculate the thermal-stress field and simulate the crack propagation process. Basic assumptions and simplifications for the numerical analysis are summarized as follows.

1. Both layers are homogeneous and flawless; the glass layer is isotropic; the silicon layer is isotropic in thermal analysis and anisotropic in stress analysis.
2. The residual stress after the anodic bonding process, gravity, friction between fixture and specimen, and other external mechanical forces are ignored. The heat transmitted to the fixture is ignored.
3. The two layers are completely bonded together without any defect. All geometrical and physical features of the anodic