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Laser cutting sandwich structure glass–silicon–glass wafer with laser induced thermal–crack propagation

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A B S T R A C T

Silicon-glass devices are widely used in IC industry, MEMS and solar energy system because of their reliability and simplicity of the manufacturing process. With the trend toward the wafer level chip scale package (WLCSP) technology, the suitable dicing method of silicon-glass bonded structure wafer has become necessary. In this paper, a combined experimental and computational approach is undertaken to investigate the feasibility of cutting the sandwich structure glass-silicon-glass (SGS) wafer with laser induced thermal-crack propagation (LITP) method. A 1064 nm semiconductor laser cutting system with double laser beams which could simultaneously irradiate on the top and bottom of the sandwich structure wafer has been designed. A mathematical model for describing the physical process of the interaction between laser and SGS wafer, which consists of two surface heating sources and two volumetric heating sources, has been established. The temperature stress distribution are simulated by using finite element method (FEM) analysis software ABAQUS. The crack propagation process is analyzed by using the J-integral method. In the FEM model, a stationary planar crack is embedded in the wafer and the J-integral values around the crack front edge are determined using the FEM. A verification experiment under typical parameters is conducted and the crack propagation profile on the fracture surface is examined by the optical microscope and explained from the stress distribution and J-integral value.

1. Introduction

Recent experiences from MEMS, IC and solar power industries have clearly demonstrated the critical importance of silicon-glass devices. In the device package procedure, the glass wafer and the silicon wafer are joining together using anodic bonding technology which could provide high reliability, stability and hermetic sealing. And borosilicate glass, such as Pyrex or Borofloat, which has a lower coefficient of thermal expansion, is used [1]. Most of these devices have been using silicon-glass double layer structure [2,3]. However, in some peculiar application occasions, glass-silicon-glass (SGS) sandwich structure has also been adopted [4,5]. Typically, the wafer level chip scale package (WLCSP) technology has been used in the fabrication of the silicon-glass devices [6]. And the dicing process is carried out after the wafer bonding process. So the significance of developing a suitable dicing method for SGS wafer has become obvious.

There are a number of dicing methods available for glass and silicon respectively. Most of them could fall into the category of mechanical dicing or laser dicing. At present, three major basic dicing methods are being used in semiconductor industry: the diamond blade cutting method [7]; the laser melting and evaporation cutting method [8–11]; the laser induced thermal-crack propagation (LITP) method [12].

LITP has proven effective in separating FPD glass substrate [13–19] as well as many other kinds of brittle materials (e.g. silicon [20–22], ceramic [23], etc.). This method uses laser to heat up the sheet locally and cause non-uniform thermal expansion, which would generate a specific tensile-compressive thermal stress field that controls the crack propagation process. Compare to other methods, this method, especially the full body separation with LITP method, could separate the sheet without material removal and generate a perfect fracture surface without microcracks and defects.

Up until now, due to the complexity of the thermal crack propagation mechanism, most studies concerning LITP method were focused on the cutting problems of single material sheet of single

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layer or multilayer (not bonded together). However in practical applications, the device is usually characterized as multilayers structure of various kinds of materials which are bonded together and affected each other, for instance, the anodically bonded silicon-glass multilayer sheet. In previous studies, several solutions have been proposed for cutting anodically bonded silicon-glass multilayer sheet, such as fabricating a recess beneath the dicing line [24], using a combination of the ultrafast laser stealth dicing method and the LITP method [25,26], and full body LITP method [27]. The first solution requires extra processing step of grooving for the recesses. And the second solution requires dedicated multi-laser system which consists three types of lasers with different wavelengths and pulse-durations for each dicing steps. By comparison, the full body LITP method is a very promising solution, which only requires one types of laser with one clean and efficient processing step of cutting. In paper [27], the mechanism of cutting silicon-glass double layer wafer using full body LITP method was studied using an integrated experimental/analytical approach. During the cutting process, 79.6% of the 1064 nm laser energy were absorbed at the inner bonding surface of the silicon layer, and the crack front edge is a curve which starts at the bottom surface of the silicon layer, then crosses the interface, and finally ends at the top surface of the glass layer. Both layers were separated at once scanning process.

Inferring from the silicon-glass double layer wafer LITP method cutting mechanism, we reasoned that the SGS wafer would also be separated at once scanning process. Therefore in this paper, the authors attempted to set up a double laser beam cutting system to achieve full-body separation of the anodic bonded SGS wafer using LITP method. A FEM model with stationary crack was built and the fracture parameter J-integral wass chosen to analyze the crack propagation process. A feasibility experiment was conducted using moderate cutting parameters.

2. Experimental methods

A 1064 nm semiconductor laser cutting system with double laser beams which could simultaneously irradiate on the top and bottom of the sandwich structure wafer has been designed.

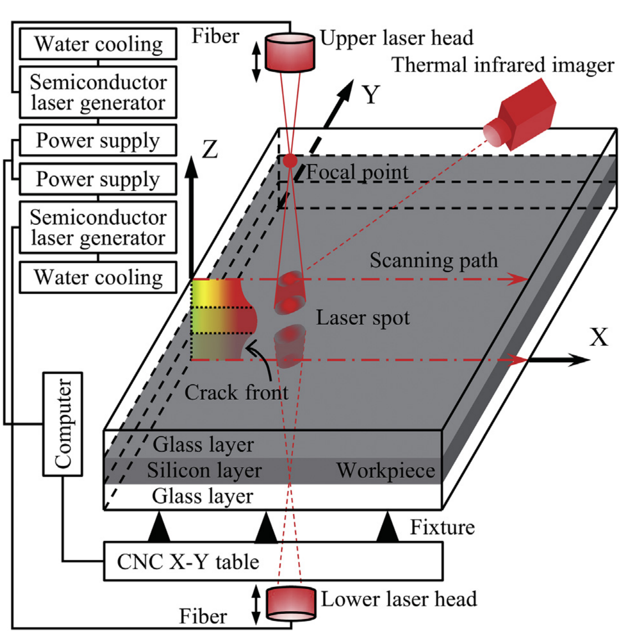

Fig. 1. Schematic diagram of the experimental setup.

As Figs. 1 and 2 illustrate, the system consists of two independent control laser sources, a horizontal x-y table, and a computer to control the CNC system. Two laser beams irradiate vertically on the top and bottom of the specimen. Both lasers are 300 W fiber-optic-coupled continuous semiconductor laser, and emitting at 1064 nm with TEM 00 beam mode. Each laser has an independent generator, together with the water cooling unit and the power supply unit. A horizontal fine adjustment device is installed to adjust the x and y position of the upper laser head and keep the two laser beams coaxial and symmetrical about the specimen. Both laser heads could move along the Z-axis driven by two independent motors. The computer controls the movement of X-axis and Y-axis of the x-y table, the movement of Z-axis of both laser heads, and the laser parameters through customized software. Further detailed specifications concerning the experimental setup are given in Table 1. A thermal infrared imager (FLIR) is arranged for measuring temperature.

The sandwich structure wafer, which is manufactured by anodic bonded a silicon wafer (n-type with (100) crystal plane with both surfaces polished) to two Borofloat 33 (BF33) borosilicate glass wafers (produced by Schott) on both sides of the silicon wafer. The specimen has a total thickness of 1.5 mm (0.5 + 0.5 + 0.5 mm) and a diameter of 101.6 mm (4 in.). An initial through thickness notch serving as the source fracture is incised on the leading edge with a diamond wire saw.

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

3. Numerical analysis

The temperature stress distribution of the specimen and the J-integral along the crack front in cutting process are calculated by using the FEM software ABAQUS. The non-steady sequentially coupled heat transfer and thermal stress analysis is adopted. Fig. 3 shows the flow chart of the simulation process.

General mesh geometry of the specimen is shown in Fig. 4. A stationary seam-type crack is placed at y = 0 on the scanning path with crack front edge set at x = 5 mm. In order to achieve high accuracy in the calculation of J-integral of the crack, mesh adjacent to the crack front region is reconstructed in X, Y, and Z directions and refined, as shown in Fig. 5. The minimum element width in the X-direction is 50 nm, and the minimum element depth in the z-direction is 15.6 μm. The total number of nodes is 327,159 and the total number of elements is 251,418.

Based on the theoretical model established in the previous study [27], the 1064 nm laser beam transmitted through the whole glass layer and then is absorbed on the surface of the silicon layer. Fig. 6 shows the thermal loads symmetrically applies on the specimen. There are two volumetric heating sources loaded in both glass layers and two surface heating sources loaded on the top and bottom surface of the silicon layer. The optical properties of the specimen under 1064 nm laser radiation are given in Table 2 [27].

Both lasers use the identical cutting paramters. The laser is modeled by applying the planar circular Gaussian heat flux. And the attenuation and divergence of laser in the glass layer is also considered. The heat flux in the upper glass layer could be described as Eq. (1). And for the lower glass layer, the formulation is similar to Eq. (1), except all of the ($3H$-z) terms in the expression should be replaced with z. The heat flux on the top and bottom surface of the silicon layer could be expressed as Eq. (2). In these equations, q_G is volume heat intensity, q_S is surface heat intensity, I is the laser power, $R_{\Delta G}$ is the air-glass interface reflectivity, α is the