Thermal effect of stealth laser dicing

Engineering R&D Division, Laser Engineering Department/ Sales Engineering Department

Abstract

Stealth dicing (SD) equipment has features such as dry processing, a narrow kerf width, and no chipping. Thus, SD processing is employed for cutting LED chips and MEMS. The SD processing method, which irradiates a high transparence laser beam on the workpiece, is not able to fully absorb the laser using a focus point. As a result, the thermal effect on the dice has been attracting interest. This review presents the absorption features near the focus point when performing SD processing on silicon and simulates the thermal effect on the device surface.

1. Introduction

Stealth dicing is an innovative dicing technology to cut a workpiece in two stages. In the first stage, a pulsed laser beam transmissive to wafers is focused at the inside of a workpiece, thereby causing noticeable nonlinear absorption only in the vicinity of the focal point. A localized high-temperature region is generated as a result and forms a high-transfer-density layer called a modified layer. At the same time, a vertical crack develops[1]. In the second stage, the crack extends upward and downward to the front and rear surfaces when an external force is applied.

SD has features such as no chipping, a narrow kerf width, and completely dry processing, compared with conventional blade dicing. Thus, SD has been attracting recent attention as a unique way of cutting various types of semiconductor device wafers.

The SD process, however, has a problem: the irradiated laser beam is not fully absorbed at the focus point, and part of the beam penetrates into the bottom surface because a highly permeable laser is employed. Fig. 1 is a schematic view showing the method of irradiating a laser beam from the backside, which is required for the process of stealth dicing before grinding (SDBG). Since the laser beam is irradiated from the opposite side of the surface on which devices are integrated, it is necessary to consider the thermal effect of a through beam on the device surface, in addition to the effect caused by the heat generation near the focal point.

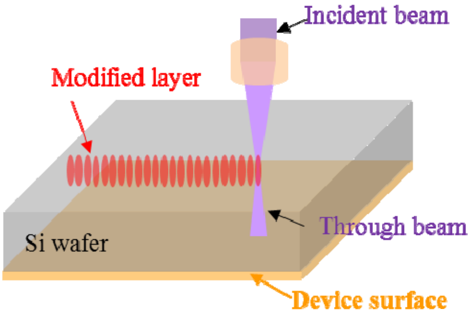

Fig.1 Schematic view of the SD laser irradiation from backside

Beam absorption and thermal diffusion in the SD process occur in a tiny area of several tens of micrometers in a short time of several microseconds. Thus, it is extremely difficult to measure transitional temperature distribution through an experiment. In recent years, however, numerous research studies were conducted on the dependency of the absorption coefficient of the laser wavelength on temperature based on nonlinear absorption theory. The mechanism of the SD process has been further clarified through simulations using thermal conductivity analysis models that take the absorption, heat generation, and the thermal diffusion of the laser beam into account[1][2].

At DISCO, with reference to the methods mentioned above, we examine physical models of the SD process for various materials such as silicon (Si), sapphire, and silicon carbide (SiC) to evaluate the thermal effect of a through beam on the device surface, in addition to the temperature increase at the focus point. This review presents simulation results using Si wafers.

2. Overview of a laser absorption and thermal analysis model

In a physical model of the SD process, a laser beam propagates as a Gaussian beam, and linear absorption occurs near the focal point. It is assumed that a through beam is absorbed by a mechanical layer (copper (Cu) film) provided on the bottom surface, and there is no energy loss other than lens aberration and beam absorption such as scattering.

Imagine a column-type coordinate system with the z-axis as an optical axis and the r-axis in the radial direction in the Si wafer. As shown in Fig. 2, the single-crystal Si wafer is divided into many microvolume elements. The beam absorption amount and the thermal diffusion amount from the peripheral for each volume element per unit of time are calculated using the finite difference method. Then, temperature variations in Si and the bottom Cu layer are calculated along the elapsed time of the pulsed beam irradiation.

The beam absorption amount and thermal diffusion amount are mainly calculated based on the following equations.

The pulse waveform (time distribution of energy) of the laser beam can be described with the following equation:

$$I(t)=I_0\left(\frac{t}{2\pi^3\sqrt{\ln 2}}\right)^{1/2}\exp\left(-\frac{(t-2t_p)^2\ln 2}{(\frac{t}{\theta})^2}\right)$$

(Equation 1)

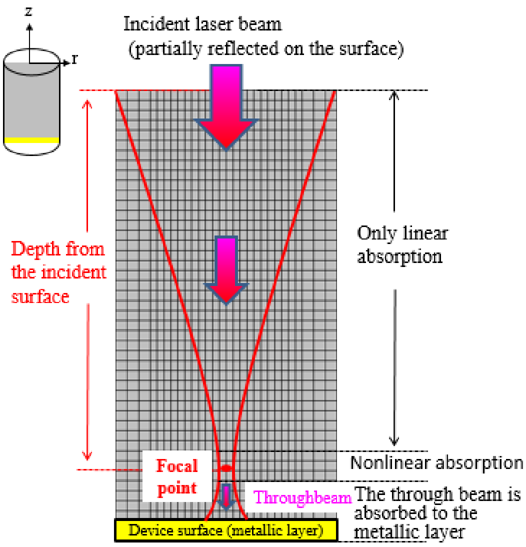

Fig.2 SD physical model

where *I(t)* is the intensity of the laser beam at time t, I_0 is the peak intensity, t_p is the pulse width, and θ is the waveform adjustment coefficient.

Further, the intensity distribution $D(r, z)$ of the laser beam at position (r, z) in the single-crystal Si is calculated as shown below, in accordance with the Gaussian beam-propagation equation:

$$D(r,z)=\frac{2}{\pi R(z)^2}\exp\left(-\frac{2r^2}{R(z)^2}\right)$$

(Equation 2)

$$R(z)=R_0\sqrt{1+(\frac{\lambda}{\pi R_0^2})^2(z-z_0)^2}$$

(Equation 3)

where Z_0 is the focal point position, and $R(z)$ and R_0 are the laser beam diameters at z and z_0, respectively.

The beam absorption amount at position (r, z) at time t is expressed as Equation 4, in accordance with Equation 1, Equation 2, and the Beer-Lambert law:

$$Q(r,z,t)=A(r,z)I(t)D(r,z)\left(1-\exp\left(-\alpha(r,z,t)\times dz\right)\right)$$

(Equation 4)

where $\alpha(r, z, t)$ is the beam absorption coefficient, and $A(r, z)$ is the coefficient to satisfy a law of energy conservation.

Temperature T of the volume element at time t is calculated by solving the following thermal conductivity equation:

$$\rho C\frac{\partial T}{\partial t}=\frac{1}{r}\frac{\partial}{\partial r}\left(rK\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right)+Q(r,z,t)$$

(Equation 5)

where ρ is the density, C is the specific heat, and K is the coefficient of thermal conductivity.

3. Analysis example

A thermal analysis is simulated of the inside of the Si workpiece having the thickness of 750 μm and the Cu layer on the bottom surface when the laser is irradiated from the Si surface under the processing parameters in Table 1.

Table 1 SD processing parameters

Engine	Pulse energy	Focal point position (depth from the surface)
SDE06	21.1 μJ	700 μm

Fig. 3 a) shows the waveform from the start to the end of one pulse irradiation. As shown in Fig. 3 b), in the initial stage of irradiation ((1) and (2)), a temperature increase in the vicinity of the focal point is not high enough, so noticeable nonlinear absorption does not occur, and most of the incident beam penetrates into the bottom surface. As a result, the Cu at the bottom layer absorbs the through beam, and its temperature rapidly rises. In accordance with the elapsed irradiation time, the through beam is suddenly weakened at the timing of (3). This is because the processing transfers to a phase of an abrupt increase in temperature (nonlinear absorption) where the absorption coefficient becomes sufficiently high and absorption and diffusion rapidly increase. Then most of the laser beam is absorbed. As a result, a modified layer (SD layer) is formed inside the Si. On the other hand, the temperature of the Cu layer gradually decreases owing to thermal diffusion because heat generation by the through beam becomes almost zero. Immediately after the end of irradiation (6), heat remains around the focal point and on the bottom surface. However, since the temperature returns almost to room temperature before the arrival of the next pulse, it is anticipated that the effect of heat accumulation is minimal.

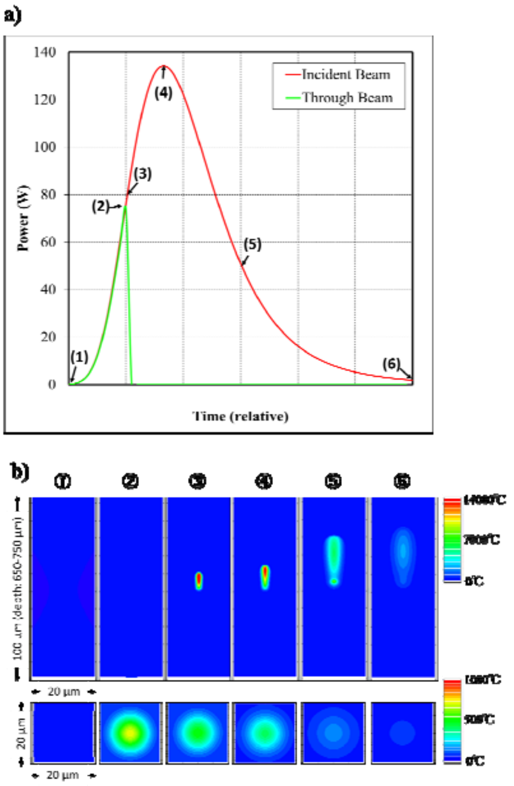

Fig.3 a) Waveforms of the through beam and incident beam. b) Changes of temperatures with time near the focal point and bottom center of the workpiece

Fig. 4 shows the distribution of the maximum temperature of the bottom Cu layer in the radial direction. The center of the through beam (positioned directly underneath the focal point) is the start point. The maximum temperature at the center position is approximately 700ºC, which is relatively high, but the temperature drastically drops at the area distant from the center. The temperature at a distance from the center of 10 μm (assumed to have a street width of 20 μm) is approximately 60ºC, and is only 40ºC when its distance from the center is 15 μm. Thus, it can be considered that there is almost no thermal effect of the through beam on the device surface unless the street is too narrow (20 μm or less).

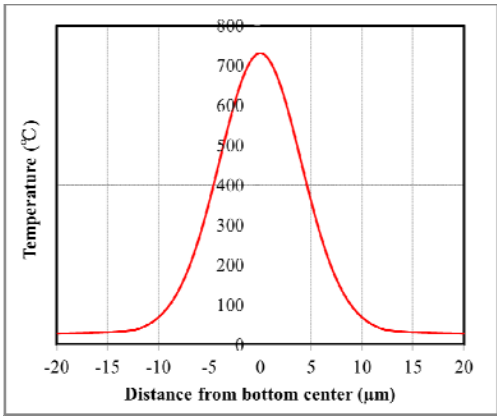

Fig.4 Radial distribution of the maximum temperature of the bottom Cu layer

As shown in Fig. 5, in accordance with the fact that the focal point position (depth from the incident surface, see Fig. 2) becomes shallower from 700 to 680, and to 570 μm, the temperature at the center on the bottom drops drastically. For example, by making the focal point position shallower by only 20 μm from 700 to 680 μm, the temperature at the center on the bottom becomes almost half its previous value. On the other hand, the distribution in the radius

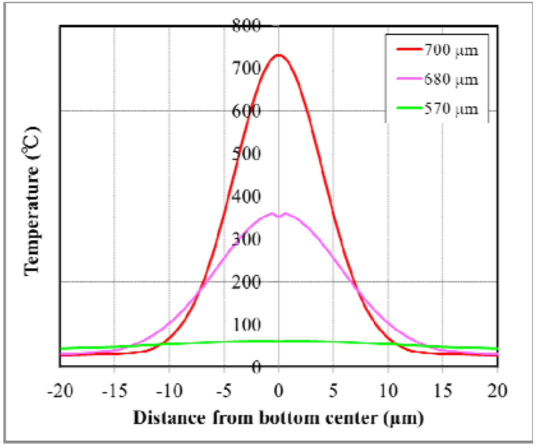

Fig.5 Radial distribution of the bottom surface temperature at the different focal point positions

direction of the energy density becomes broader as the focal point position becomes shallower. In the end, the optical energy entering the area apart from the center increases, which means the temperature becomes higher.

In order to suppress the temperature increase at the center of the bottom surface, the focal point position can be made shallower. However, this incurs a risk in which the temperature of an area apart from the center may slightly increase.

4. Conclusion

In the SD process using a laser beam highly transmissive to semiconductor wafers, a laser beam partially penetrates around the position directly underneath the focal point. Simulation results reveal that when the focal point is specified at a place 50 μm above the bottom surface, the maximum temperature at the point directly underneath the bottom surface (Cu layer) exceeds 700ºC. However, it is assumed that the temperatures can be suppressed at low levels: approximately 60ºC at a distance from the center of 10 μm, and 40ºC at a distance of 15 μm. Generally speaking, it is considered that a higher temperature does not affect the device surfaces as long as the street width is 20 μm or more.

The simulation also reveals that the effect of heat generated by the through beam is greatly mitigated when the focal point position is raised from the bottom surface.

At DISCO, we select processing parameters, such as laser power and focal point, which are optimal for customer products through test cuts while aiming at establishing a more reliable SD process.

Reference

[1] K. Fukumitsu, et al., Online Proc.4th Int. Cong. Laser Adv. Mat. Proc., 2006.

[2] E. Ohmura . “HeatTransfer - Engineering Applications”, Vyacheslav Vikhrenko (Ed.), InTech, 2