1. Introduction

Laser micromachining and microstructuring has attracted a great deal of interest in recent years. Because of necessity of machining accuracy, there is now a growing interest in laser micromachining using short pulsed laser with pico or femtosecond pulse width. It was shown experimentally that these pulses produced sharp and well defined holes and cuts. Also, many works were devoted to the laser cutting of ceramic materials with such pulses—they demonstrated the formation of high quality cuts and holes. For the high quality cuts and holes, the heat affected zone (HAZ) around machined area should be minimized. The thermal response of during laser drilling then needs to be investigated. In this present study, thermal response between the nano second and pico second lasers will be compared.

2. Mathematical Model

The two-dimensional square shape silicon wafer with a 200 µm length is modeled. The focused laser beam diameter is 20 µm and pulse width is selected as 110 ns or 15 ps. For the 110 ns pulsed laser, the repetition rate is 50 kHz, the energy fluence is 54 J/cm². For the 15 ps pulsed laser, the repetition rate is 200 kHz, the energy fluence is 1.57 J/cm².

The governing equation is modeled by the conduction equation with a laser source term as shown Eq.(1),

\[ \rho \frac{\partial T(x,y,t)}{\partial t} = \nabla \cdot (k \nabla T(x,y,t)) + \frac{S(x,y,t)}{\rho \cdot c_p} \]

where, \( S(x,y,t) \) can be represented as Eq. (2)

\[ S(x,y,t) = I_0 (1 - R) \omega \left(\frac{x}{d_T^2} \right) \left(\frac{y}{d_T^2} \right) \exp \left(\frac{-(t - t_a)^2}{2 \tau_T^2}\right) \]

where, \( I_0 \) is the peak power as an unit W/cm², \( \alpha \) is absorption coefficient, \( R \) is the reflectivity, \( t \) is the time, and \( t_a \) is the pulse duration. For the multiple pulse train, the consecutive pulse with certain pulse interval which can be \( t_0, t_1, ... \) is considered.

The boundary condition at the laser deposition side is

\[ \frac{\partial T(x,y,t)}{\partial y} = \sigma(T^4 - T_a^4) + h(T - T_a) \]

in which, \( \sigma \) is the Stepan-boltzman coefficient, \( h \) is the heat convective coefficient, and \( T_a \) is the ambient temperature. Other three sides are considered as the consistent temperature condition with ambient temperature. The thermal and optical properties of the silicon wafer are referred from the previous literature.

3. Numerical Scheme

The commercial software, COMSOL is utilized to solve above equation. The grid system for FEM is shown in Figure 1. The 1690 triangular meshes exist and finer grid system is employed around beam path area. The time step is selected as a \( \Delta t/100 \).

4. Results and discussion

In Figure 2, the temperature temporal plot is depicted at center of the Si wafer surface. The five pulse train with 110 ns pulse width is deposited. The temperature rises and drops periodically.

The temperature contour plots are shown in Figure 3(a) and (b) at certain time constant. At \( t = 80 \mu s \), just before depositing 5th pulse, the maximum temperature increment is around 800K as shown in Figure 3(a). In Figure 3(b), high temperature field concentration is predicted around deposition region after 5th pulse deposition, \( t = 80 \mu s + 200 \) ns. The maximum temperature increment is around 1600K. For the ablation of Si wafer, the temperature needs to rise up to melting point around 1600K. The applied energy fluence is close to threshold temperature for the drilling.

The single 15 ps laser is switched and the temperature field is predicted with low energy fluence, 1.57 J/cm². The temperature contour is shown in Figure 4 at \( t = 30 \) ps just. The peak temperature increment is over 1600K and sharp temperature distribution along the x-axis is predicted compared with 110 ns second laser result. The ablation may be started in this case. Also, deep temperature penetration along the y-axis is shown, which can provide deeper drilling depth.

In Figure 5, the temperature profiles along the wafer surface are compared between ns laser and ps laser. The confinement of temperature field around laser deposition region is obvious with ps laser. It may minimize melting artifact at unwanted drilling region.

5. Conclusion

The temperature response for the via hole drilling was predicted and compared between 110 ns laser and 15 ps laser. With the 15 ps laser, the threshold fluence to start to thermal irreversible damage was much smaller than 110 ns laser. The temperature distribution was also well confined around beam deposition region and it showed deeper penetration, which may cause deeper ablation depth.
Fig. 2 The temporal profile at the center of Si wafer surface with 110 ns laser for 5 pulses deposition

Fig. 3 The temperature contour plot with 110 ns laser at selected time instant ((a) $t = 80 \, \mu s$, (b) $t = 80 \, \mu s + 200 \, ns$)

Fig. 4 The temperature contour plot with single 15 ps laser at $t = 30 ps$

Fig. 5 The comparison of temperature along the Si wafer surface between 110 ns laser and 15 ps laser at $t = 80 \, \mu s + 200 \, ns$ for 110 ns laser and $t = 30 \, ps$ for 15 ps laser

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**Reference**