Development of Laser Process and System for Stencil Manufacturing

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ABSTRACT

Stencil is used normally as a mask for solder pasting on pad of a printed circuit board (PCB). The objective of this study is to develop a stencil cutting system and determine the optimal conditions to make good-quality stencil by using a Nd:YAG laser. The effects of process parameters such as laser power, type of mask, gas pressure, cutting speed and pulse duration on the cut edge quality were investigated. In order to analyze the cut surface characteristics (roughness, kerf width, dross) optical microscopy, SEM microscopy and roughness measurements were used. As a result, the optimal conditions of cutting process parameters were determined, and the practical feasibility of the proposed system was also examined by using a commercial Gerber file for PCB stencil manufacturing.

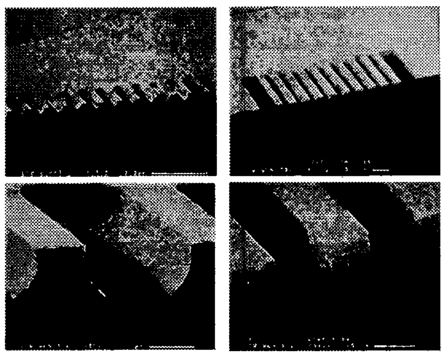
Keywords : Nd:YAG laser, Stencil, Cut edge, Surface roughness, Dross, Kerf width, Mask

1. Introduction

A mask for solder pasting on the pad of PCB is called stencil which can be produced by cutting (or patterning) a thin sheet of metal such as stainless steel. The mask pattern can be obtained from photolithography and etching processes[(1)]. Nowadays a new cleaning process is demanded to reduce the anti-environmental effects in the existing processes. One of the attractive processes is a laser cutting process which is simple, clean, precise and flexible.

In Fig. 1, (a) and (b) show the SEM photographs of stencil produced by etching and laser cutting, respectively (LPKF in germany). The edge and kerf width produced by laser cutting are straighter and narrower compared to the etching process. Especially, in the laser cutting process, the state of the cut edge is most important because it affects the durability of solder.

In this paper, laser cutting system for stencil processing is designed and constructed. The effects of cutting parameters are also investigated. Finally, the optimal parametrical conditions for laser processing are obtained.



(a) (b)

Fig. 1 SEM photographs of stencil produced by (a) etching and (b) laser cutting

2. Experimental procedure

2.1 Experimental setup

Fig. 2 shows the configuration of stencil cutting system composed of a Nd:YAG laser, driving part and a control system. The laser beam is expanded and delivered from the pulsed Nd:YAG laser to the cutting head in a parellel ray by using the telescope. The beam passed through the DCD(Distance Compensation Device) is focused on the material surface. Because the DCD can compensate the variation of spot size, the focused beam size is always the same at any position on the x-y table. The system is operated by a PC based main controller. The main controller is interfaced with the laser controller to determine the pulse width, flash lamp input voltage and the beam power. The CAD data (or Gerber file) must be converted to CAM data to control the system. A clamping device is used to fix the thin metal sheet horizontally and it is operated by air-pressure on-off signal.

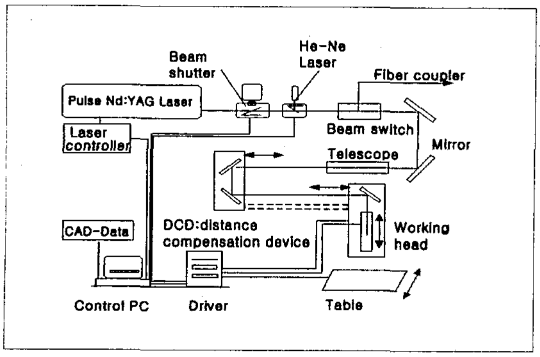


Fig. 2 Configuration of stencil cutting system with DCD and Nd:YAG laser

Fig. 3 shows the photograph of the developed laser cutting system for stencil processing. The pulsed Nd:YAG laser (λ=1064nm, TEMoo mode) and the cutting head with a focal length of 40mm are used in the system.

2.2 Experimental method

Stainless steel sheet (SS304, thickness: 0.15mm) is used as the stencil material. Table 1 shows the chemical composition of SS304.

Table 1 Chemical composition of stencil plate

	Fe	C	Si	Mn	P	S	Cr	Mo	V	Ni
SS304	69.73	0.04	0.88	1.57	0.054	0.025	17.49	0.11	0.11	9.27

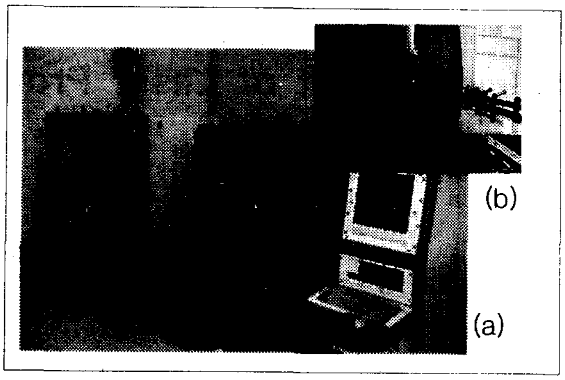


Fig. 3 (a) Stencil cutting system, (b) Cutting head

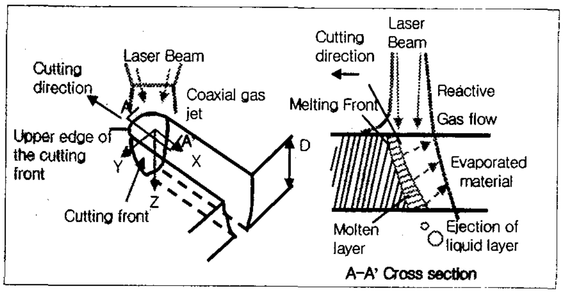


Fig. 4 Schematic diagram of laser cutting process

Fig. 4 shows a schematic diagram of the laser cutting process. The laser power has a direct influence on the energy input used to cut the material. When the laser beam is focused on the material, solid state is transformed into liquid state by melting. A molten material is generated throughout the depth of the workpiece and this is partially ejected from the cutting zone by pressurized gas jet acting coaxially with the laser beam. This cutting mechanism is complicated because many process parameters are correlated with respect to three state, solid, liquid and gas.

Thus, sequential experiments were executed for verifying the effects of cutting parameters on the cut surface, and the optimal conditions of process parameters were determined by investigation of the results.

The path of beam and the shape of workpiece used in this experiment are shown in Fig. 5. Geometry and dimensions of the workpiece are designed for convenient measurement of the cut surface characteristics.

Laser power, type of mask, gas pressure, cutting speed and pulse width are used as the major process parameters.

Table 2 shows the values of the major process parameters.

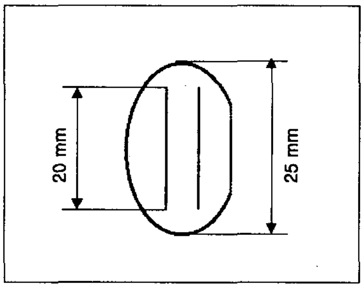


Fig. 5 Geometry and dimensions of workpiece

Table 2 Experimental conditions

Parameter	value
Beam mode	TEM_{00} (Pulse)
Gas Pressure (bar)	2~16
Frequency (Hz)	700
Nozzle gap (mm)	0.1
Mean Output Power (W)	4~32
Pulse duration (ms)	0.09~0.17
Cutting speed (m/min)	0.5~2
Mask type	No mask Circular mask Quadrangular mask

The nozzle gap in Table 2 is the distance between the nozzle and the workpiece. The nozzle used is known to have a region, which is 1 or 2mm near the outlet, where severe changes in gas flow conditions and MSD (Mach Shock Disk)[(2),(3)] exist. This area should be avoided by making the nozzle gap larger or shorter than the depth of the fluctuating pressure zone. In this experiment, the nozzle gap was 0.1mm and nearly contact with the workpiece for the purpose of generating a fluctuating pressure zone and MSD under the workpiece.

The cutting gas used was nitrogen which is most commonly employed although it is not completely inert. The reasons for the choice of nitrogen are its low chemical activity and its low cost compared with pure inert gases such as argon[(3)].

2.3 Measurement

The characteristics of the cut surface were defined as roughness, kerf width and dross[(4)]. The surface roughness was measured by an optical surface roughness tester which uses interference colors. Kerf width was measure by a microscope. Qualitative analysis for dross was graded and divided into five parts. Also, the state of the cut-surface was observed by SEM.

3. Results and discussion

3.1 Effect of laser power on the cut surface characteristics

Fig. 6 shows the SEM photos and surface roughness of cut edge processed under laser powers of 4~32W. At low laser power, incomplete cutting and ejection of melted material results in high value of surface roughness. Thus, high viscosity melting and oxidation reactions are observed in the cutting zone of Fig. 6(a). On the other hand, Fig. 6(d) shows that a substantial increment in laser power tends to increase the kerf width due to overheating and surplus melting. The surface roughness is also higher because the line of striation is obscure and the unremoved melt material remains in the cut surface.

The surface roughness in Fig. 6 means the average roughness(R_a) as shown in Eq. (1).

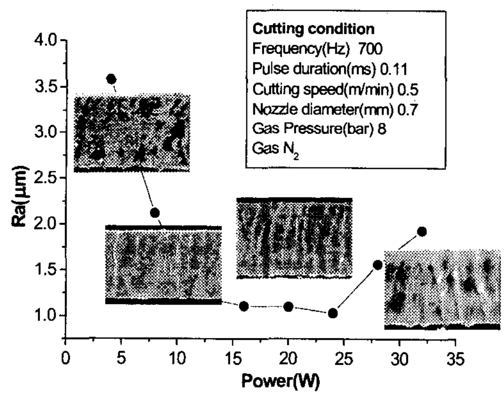


Fig. 6 Cut edge roughness vs. laser power : (a) 4W, (b) 12W, (c) 24W and (d) 32W

$$R_a = \frac{1}{L}\int_0^L |f(x)|dx \doteqdot \frac{1}{n}\sum_{i=1}^{n}|f(x_i)| \quad (1)$$

At the laser power of 24W, a surface roughness (R_a) of 1.03㎛ is obtained which is the optimum value in this experiment.

Fig. 7 shows the relation between kerf width and laser power. The kerf width proportionally increases with the average power of the laser. The minimum kerf width is 98㎛ and it is obtained at the laser power of 24W.

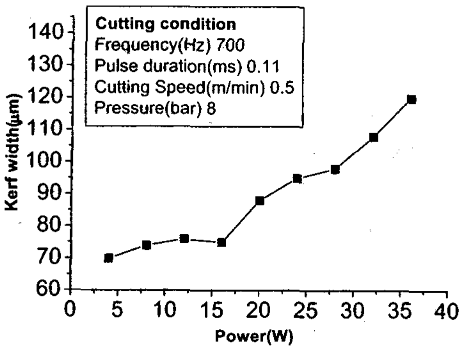


Fig. 7 Kerf width vs. laser power

3.2 Effect of the mask type on the cut surface characteristics

The mask is an aperture, which is equipped on the cutting head, for eliminating the border of the laser beam as shown in Fig. 8. Then, the diameter of the incident laser beam is 22㎜, and the eliminated area by the mask is about 33% of the whole beam size. Fig. 9 shows the principle of laser beam refining by using the mask.

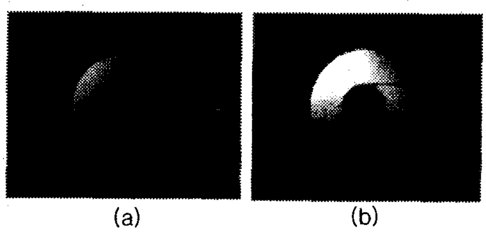


Fig. 8 Mask shapes : (a) quadrangular and (b) circular type

Fig. 10 shows the SEM photos and surface roughness of the cut edge processing using various mask types at a laser power of 24W. The cut edge under no mask condition shows irregular lace pattern and the cutting quality is worse than that processed with a mask. In case of using the quadrangular mask, the resulting minimum value of surface roughness was 0.86㎛ in the straight section. However, the surface roughness was 1.36㎛ in the curved section. This phenomenon results from the fact that the overlap ratio of the pulse becomes less due to the mask shape.

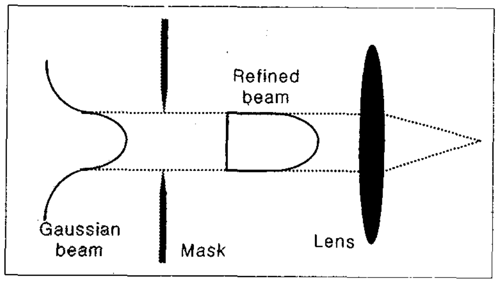


Fig. 9 Principle of laser beam refining by mask

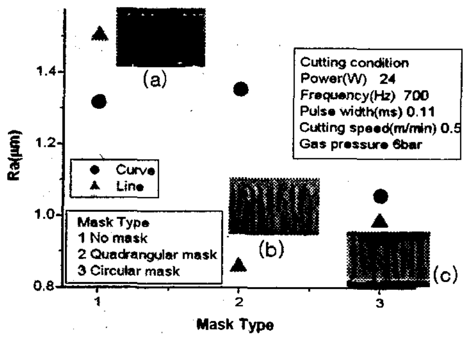


Fig. 10 Cut edge roughness for different mask types : (a) Maskless, (b) Quadrangular mask and (c) Circular mask

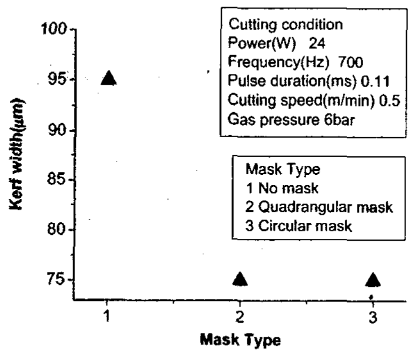


Fig. 11 Kerf width for different mask types

Fig. 11 shows the kerf widths obtained as a result of using different mask shapes. The kerf width is decreased at the straight section when the mask is used because a gradient of the beam power is made sharper by intercepting the border of the laser beam. From Figs. 10 and 11, cutting with a circular mask shows good cut edge condition at straight and curved sections.

3.3 Effect of cutting gas pressure on cut surface characteristics

The mechanical force of the nitrogen jet drives the melt out of the cutting zone. Fig. 12 shows the SEM photos and surface roughness of the cut edge obtained as a result of using various gas pressures at a laser power of 24W. Insufficient gas jet pressure brings out irregular dross as shown in Fig. 12(a). As the gas pressure increases, the melt is removed conspicuously due to the rising of the mechanical force of the nitrogen gas jet[4]. From the results, the lowest value of surface roughness obtained was 0.64μm at a gas pressure of 12 bar.

Fig. 13 shows the relationship between kerf width and gas pressure. As the gas pressure increases, the kerf width becomes narrower. High gas pressure results in the easy ejection of melting pool and high cooling rate.

Fig. 14 shows the relationship between dross level and gas pressure. The dross declines as the gas pressure increases. Above 8 bar the dross level is constant, and above 14 bar, the dross increases again because of the turbulence at the bottom of the cut edge[5].

3.4 Effect of cutting speed on the cut surface characteristics

At low cutting speed, the molten zone of the workpiece can be broaden. The low viscosity melt is easily eliminated by the dynamical momentum of the cutting gas. If the maximum cutting speed is exceeded then the cutting reaction cannot penetrate to the bottom of the sheet. Thus, very poor, incomplete cutting is obtained. The compensation[6] effect of surface-tension is diminished due to the high viscosity melt and the temperature gradient. Fig. 15 shows the SEM photos and surface roughness of the cut edge under the cutting speeds of 0.5m/min~2.0m/min. As the cutting speed increases, the value of surface roughness becomes higher because of increasing pulse duration.

Fig. 16 shows the relationship between kerf width and overlap ratio under the same condition as that of Fig. 15. As the cutting speed increases, the overlap ratio of pulse beam decreases. Thus, the kerf width becomes narrower.

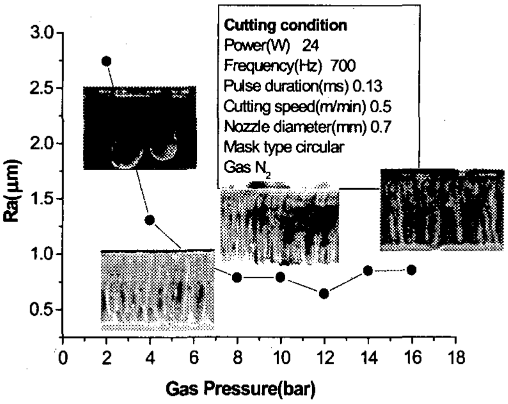


Fig. 12 Cut edge quality vs. gas pressure : (a) 2bar, (b) 6bar, (c) 8bar and (d) 16bar

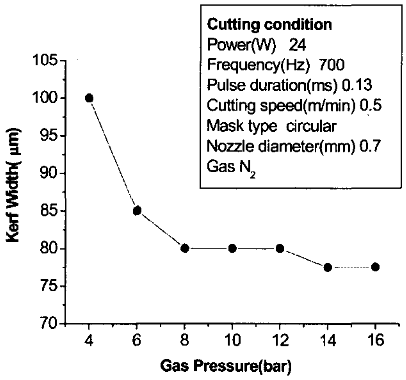


Fig. 13 Kerf width vs. gas pressure

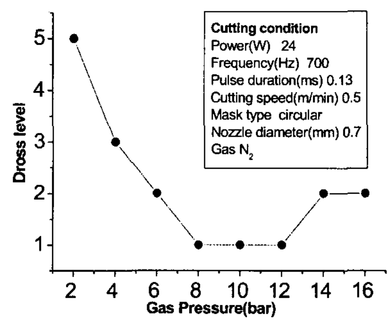


Fig. 14 Dross level vs. gas pressure

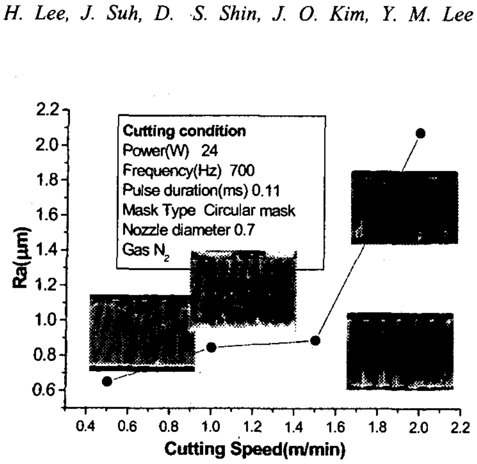


Fig. 15 Cut edge quality with different cutting speed : (a) 0.5m/min, (b) 1.0m/min, (c) 1.5m/min and (d) 2.0m/min

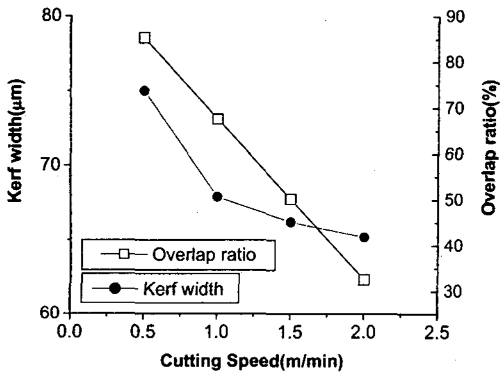


Fig. 16 Kerf width and overlap ratio vs. cutting speed

3.5 The relation of cut surface characteristics and pulse duration

To estimate the relationship between cut surface characteristics and peak power of laser, the effect of pulse duration condition (0.09ms~0.17ms) on the surface roughness is investigated. The relationship of pulse duration and peak power is represented by Eq. (2). The calculated peak power[4] using Eq. (2) and the pulse duration employed in this paper are shown in Table 3.

$$P_p = P_{ave} \times \frac{1}{FWHM} \times \frac{1}{Frequency} \qquad (2)$$

Fig. 17 shows the SEM photos and surface roughness of the cut edge under the pulse duration of 0.09ms~0.17ms. The short pulse duration (or high peak power) results in deep groove as shown in Fig. 17(a). As the pulse duration increases, the striation of molten zone becomes conspicuously vague after invariable pattern at 0.14ms. The lowest surface roughness of 0.6㎛ is obtained at the pulse duration of 0.14ms. Then, the kerf width is 78㎛.

Fig. 18(a) shows the stencil manufacturing process with optimal laser cutting parameters. Fig. 18(b) shows the finished stencil with CAD/CAM software (Conversion file of GERBER).

Table 3 Peak power with pulse duration (average power: 24W, Frequency: 700Hz)

Pulse width	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17
Peak power	442	398	362	332	306	284	265	249	234

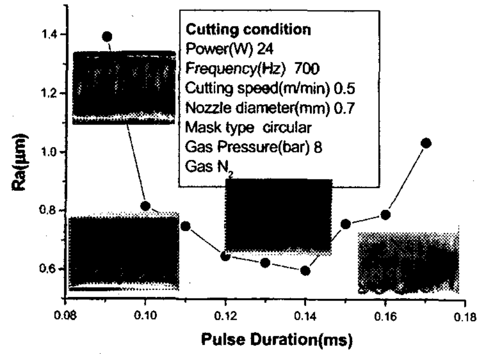


Fig. 17 Cut edge quality with different pulse duration : (a) 0.09ms, (b) 0.1ms, (c) 0.14ms and (d) 0.15ms

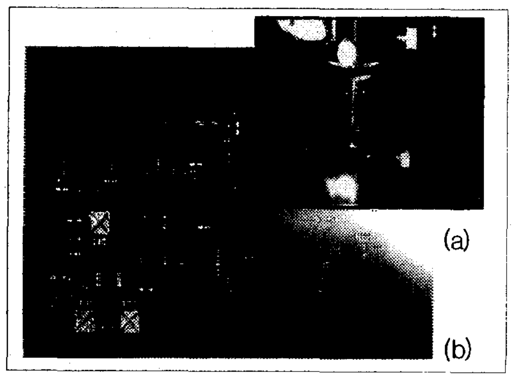


Fig. 18 A view of cutting process and completed stencil for solder mask

4. Conclusions

The conventional photolithography process for stencil manufacturing can be replaced with laser cutting process after analysing the cut surface characteristics under various cutting parameters. The capability for practical use of this process can be demonstrated by completed cutting of the actual stencil using commercial Gerber file.

(1) The surface roughness of the cut surface is inversely proportional to the gas pressure. The relation of surface roughness and laser power and pulse duration is parabolic. Increase in the cutting speed results in high surface roughness. By using the mask, the surface roughness may be decreased.

(2) The kerf width increases proportionally with the beam power. It is inversely proportional to increasing gas pressure and cutting speed. The mask can diminish the kerf width.

(3) The distribution curve of the dross, which is dominated by the gas pressure, can be described by a parabolic relationship with respect to the gas pressure.

(4) The CAD data for manufacturing stencil can be transformed into CAM data by GERBER conversion S/W, and the capability for practical use is demonstrated.

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