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Direct Patterning of Ceramic Circuit Board with Q-Switched Nd:YAG Laser

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SYNOPSIS

Direct patterning of copper coated ceramic circuit board is experimentally investigated with Q-switched Nd:YAG laser in order to shorten the time of the trial manufacture of electronic circuit board and to adapt the flexible design change. It is pointed out that the fast direct patterning the speed of which reaches about 100 mm/s is possible if the repetition frequency and the average power are selected properly. Furthermore cutting off and/or drilling of ceramic board are also possible under the condition that the repetition frequency is less than 3kHz.

This technique makes it possible the maskless patterning of ceramic circuit board which has been widely used recently in place of conventional glass-epoxy or phenolic resin circuit board, and it leads to the shorter time limit of delivery as compared with the conventional end-milling method.

. INTRODUCTION

Electronic circuit pattern is generally manufactured by ›hotolithography technique for mass production. However it is used

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milling machine with fine end mill and drill for a trial manufacture. In this case, the management of tool wear or tool change is troublesome and the time limit for delivery is considerably long. Furthermore this method is impossible to use for ceramic circuit board which has been widely used in place of glass epoxy or phenolic resin circuit board.

In this paper, from the above point of view, the possibility of utilization of Q-switched Nd:YAG laser for direct patterning of copper coated alumina ceramic circuit board is experimentally investigated. First the insulation characteristic of removed groove is analyzed for various repetition frequency and average power of Q-switched YAG laser. Furthermore the cutting and drilling characteristics of ceramic circuit board are investigated.

2. EXPERIMENTAL PROCEDURE

Fig.1 shows the schematic diagram of experimental apparatus used in this study. The rated average output is 15W maximum and the peak output is 30kW maximum with Q-switched device. Minimum pulse duration is more than 100ns and pulse repetition frequency is 1-50 kHz. The focus length of lens is 100 mm. The groove width generated with this device is about 50μ m. The workpiece is copper coated alumina ceramic board whose size is 100x100x0.635 mm, and the thickness of coated copperis 20 μ m. The laser irradiation experiment was performed onto the ceramic board mounted on the X-Y table moving at the setting speed. The quality of patterning is investigated by measuring the electric resistance between A and B in Fig.2(b) with an insulation tester. In this experiment, the case

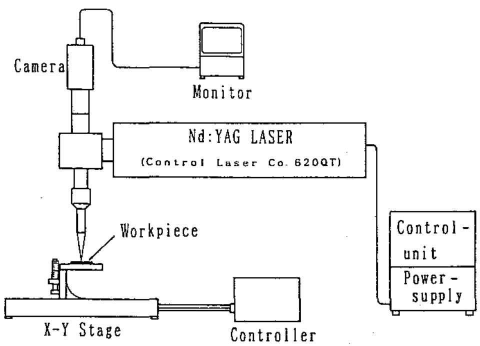
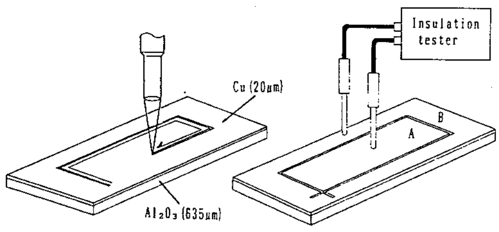


Fig.1 Schematic diagram of experimental apparatus



(a) machining method (b) insulation test

Fig.2 Measuring method of insulation of machined circuit that the electric resistance is more than 2000 MΩ is judged to be sufficient insulation.

Fig.3 shows the output characteristic of YAG laser used in the experiment. As shown in the figure, the average output P increases with the exiting current I and the pulse repetition frequency f.

The variation of pulse shape with the repetition frequency f of Q-switch is shown in Fig.4. The peak intensity decreases with the repetition frequency under the same exciting current I=22A. On the other hand, the rising time to the maximum value becomes longer with the repetition frequecy. Considering together with Fig.3, the average power becomes higher by the number effect of the pulse repetition in case of higher frequency. Therefore it should be noted that total heat given to workpiece becomes more while peak power becomes less in this case as compared with the case of lower repetition frequency.

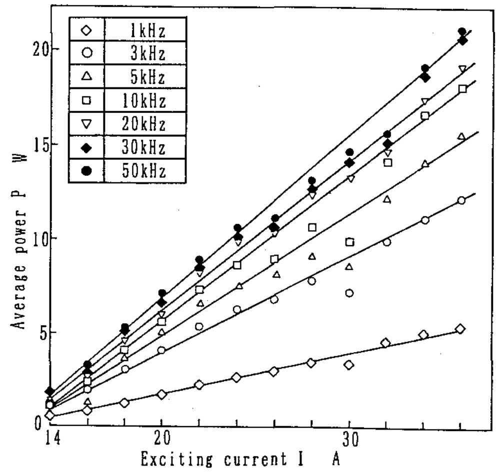


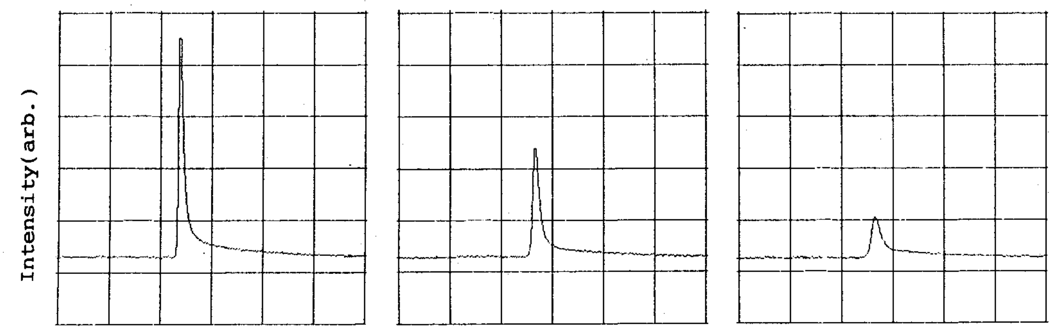
Fig.3 Output characteristic of Q-switched YAG laser

The machined surface and the section of groove are observed by microscope, SEM, EPMA and so on.

3. DIRECT PATTERNING OF CERAMIC CIRCUIT BOARD

Figs.5(a)-(d) show the possible condition of sufficient insulation (R>2000MΩ). As can be seen from these figures, the higher the repetition frequency is, the faster the maximum feed rate becomes at which insulation is sufficient. At the repetition frequency 10 kHz, the maximum feed rate reaches 100 mm/s. As mentioned before, however, the lower limit power becomes higher with the repetition frequency because of the characteristic of the device that peak power decreases with the repetition frequency.

Figs.6(a)-(c) show SEM photographs of the machined surface of groove when the feed rate is varied 10-80 mm/s, while the repetition frequency (f=5kHz) and the average power (P=10W) are



(a) f=1kHz (b) f=5kHz (c) f=10kHz

Fig.4 Variation of pulse shape with frequency (I=22A const., 2μ s/div)

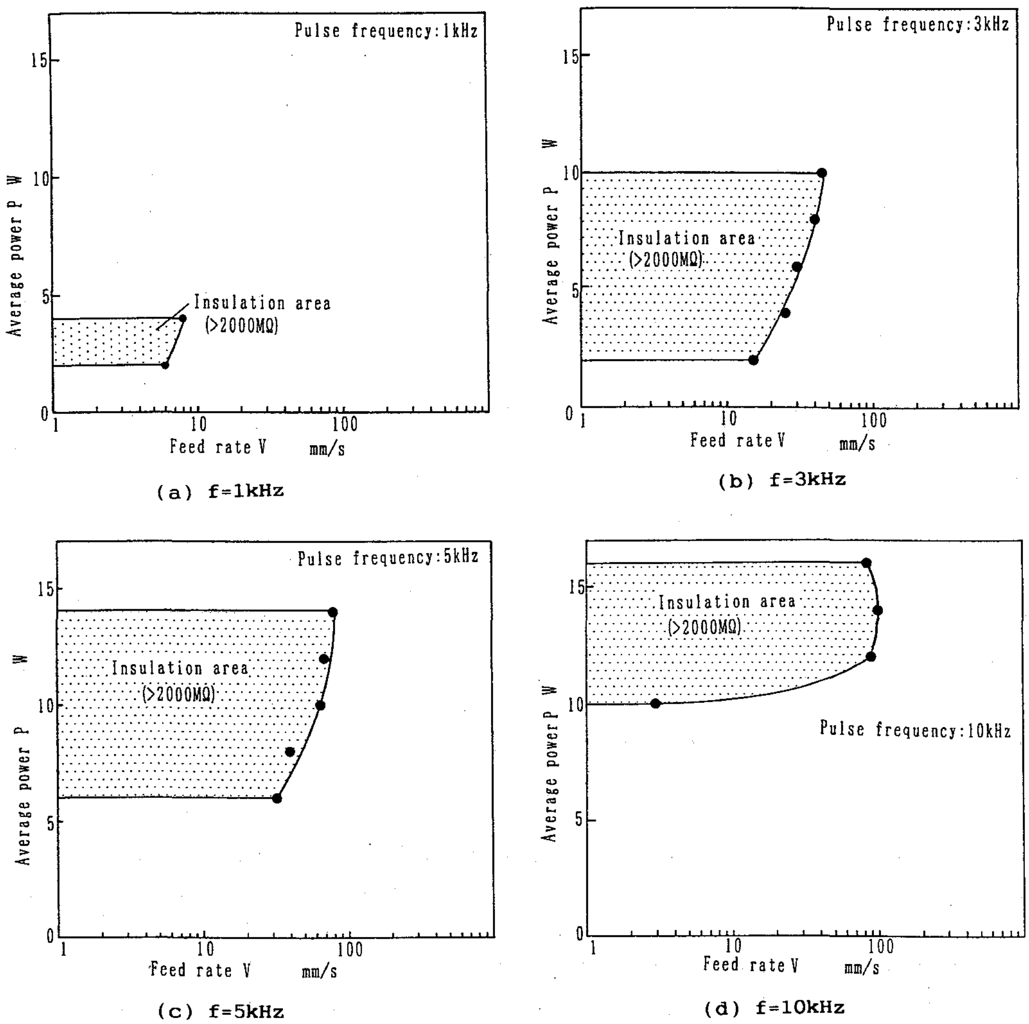
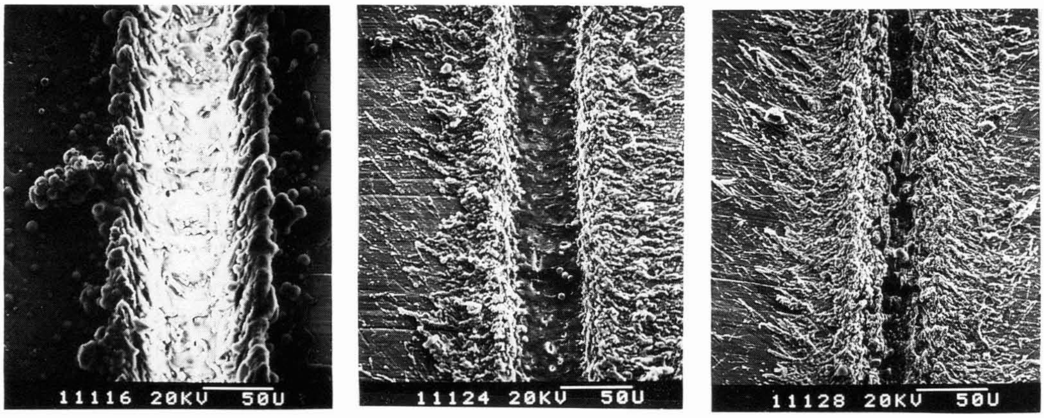


Fig.5 Possible condition for sufficient insulation

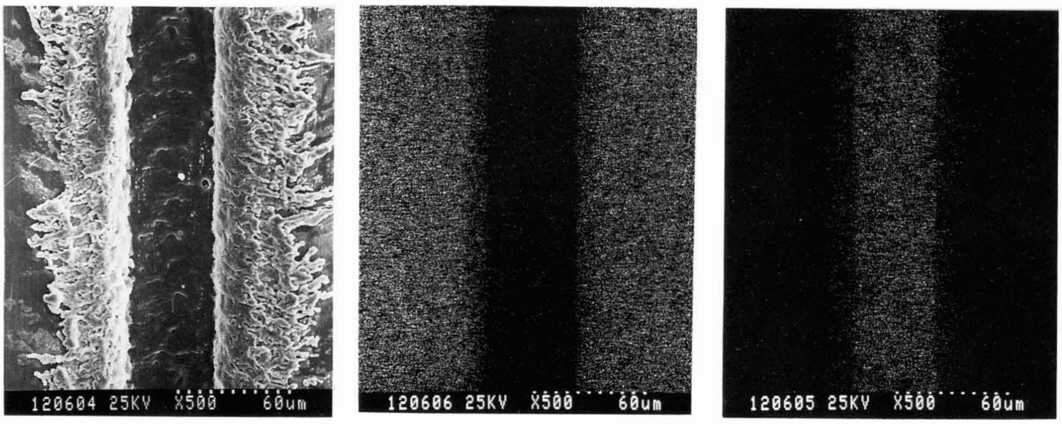


(a) V=10mm/s (b) V=60mm/s (c) V=80mm/s

Fig.6 SEM photographs of machined surface for various feed rate (f=5kHz,P=10W)

kept constant. When the feed rate is slow (V=10mm/s), alumina substrate under the copper coating is also machined because of excessive heat input. On the other hand, when the feed rate is fast (V=80 mm/s), some parts of copper coating are left unremoved in the groove which leads to low electric resistance. When the feed rate is 60 mm/s, only copper coating is removed and the insulation is sufficient. After all the feed rate should be selected properly according to the irradiation condition.

Figs.7(a)-(c) show SEM and EPMA mapping photographs of the machined part under sufficient insulation condition. As can be seen from the figures,copper element cannot been recognized while aluminium element of alumina is detected in the groove, which proves the completion of this machining.



(a)SEM (b)CuKα (c)AlKα

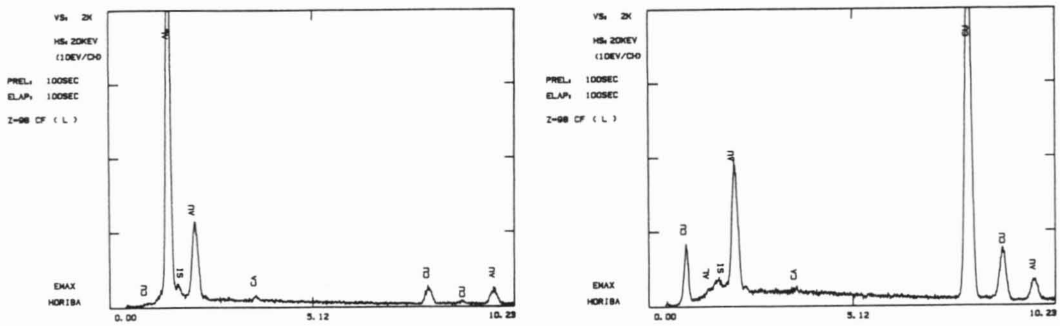
Fig.7 Mapping photographs of CuKα and AlKα under sufficient insulation condition (f=3kHz,P=6W,V=30mm/s)

Figs.8(a),(b) show the elementary analyses of the central area of groove and the dross area respectively, and these records correspond well to those in Fig.7.

Figs.9(a)-(c) show SEM and EPMA mapping photographs of the machined part under incomplete insulation condition. As shown in these figures, aluminium element is not recognized in the groove because of incomplete removal of copper coating.

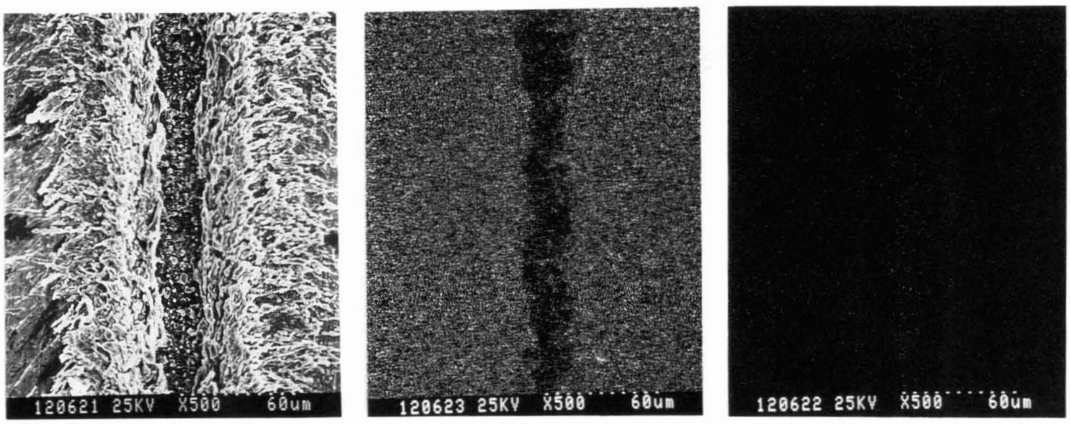
Figs.10(a)-(c) show SEM and EPMA mapping photographs of the machined part under the condition that alumina substrate is also machined. In this case, aluminium element is detected on the pile up part as well as the groove part because of resolidification of fused alumina.

Figs.11(a)-(c) show SEM and EPMA photographs of a crater generated by a single pulse laser. As shown in these figures, copper on alumina substrate is melt and blown off by a single pulse



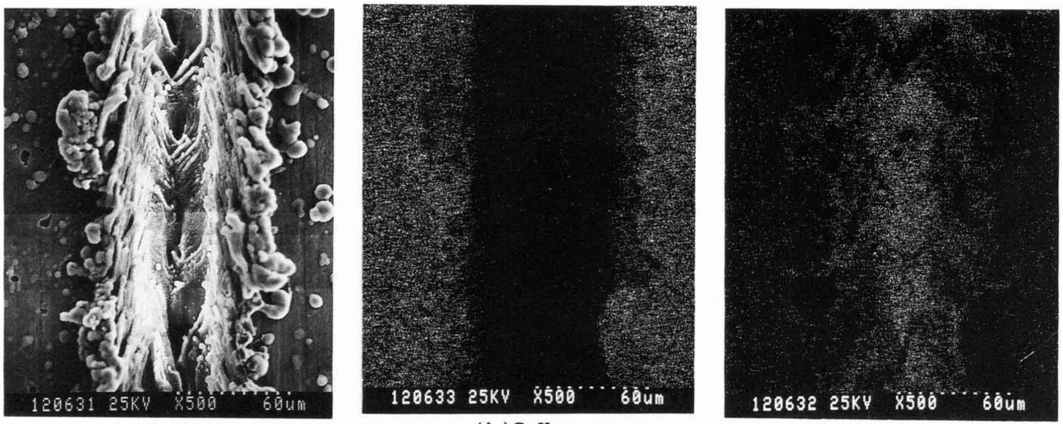
(a) central area of groove (b) dross area

Fig.8 Elementary analysis of machined surface



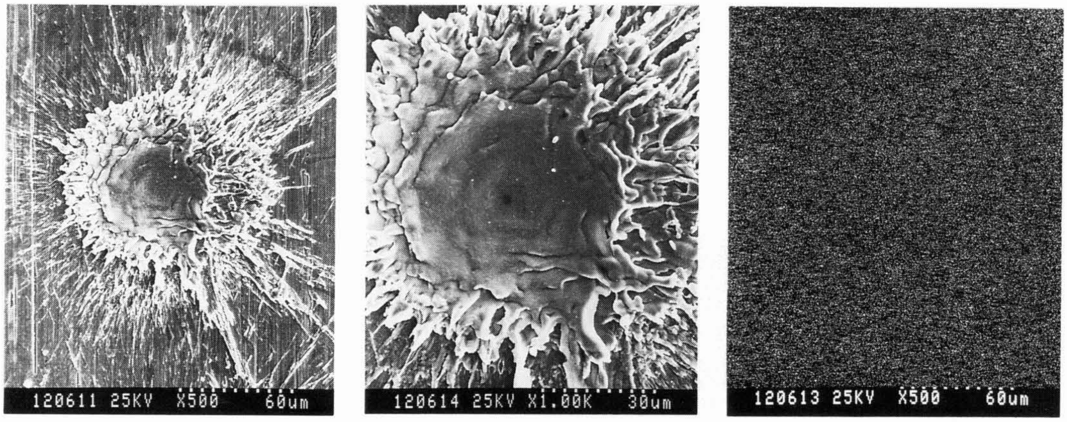
(a)SEM (b)CuKα (c)AlKα

Fig.9 Mapping photographs of CuKα and AlKα under incomplete insulation condition (f=5kHz, P=10W, V=90mm/s)



(a)SEM (b)CuKα (c)AlKα

Fig.10 Mapping photographs of CuKα and AlKα under condition that alumina substrate is machined (f=5kHz,P=10W,V=10mm/s)

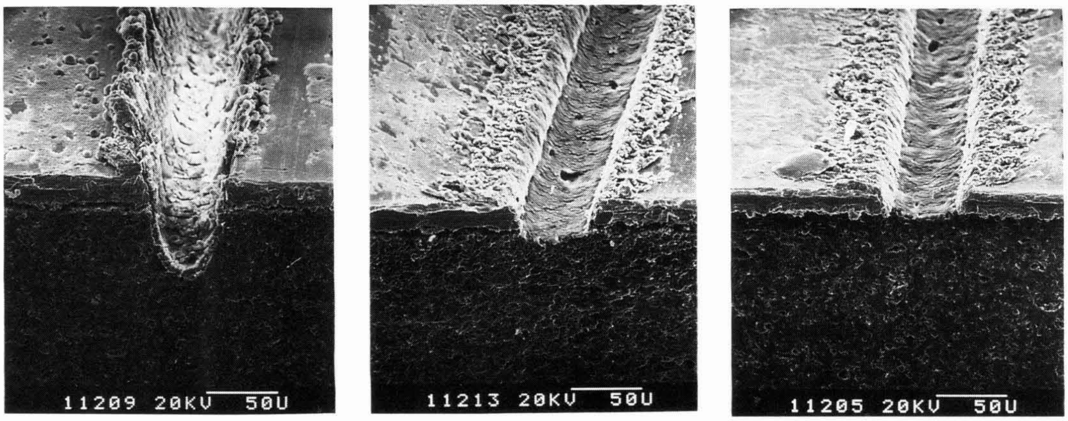


(a)SEM (b)SEM (c)CuKα

Fig.11 A crater generated by a single pulse laser (f=1kHz,P=4W,V=200mm/s)

laser. However it is shown from Fig.(c) that copper is left on alumina. Therefore it is pointed out that copper coating is removed by an assemblage of some pulses. The degree of overlapping of successive crater is controlled by the feed rate.

Figs.12(a)-(c) show the sectional surfaces for various machining condition. As can be seen from the figures, the depth of the groove becomes shallower with the feed rate. The distance from one pulse to another on the board for (a),(b),(c) is 2,8,15 μm respectively. In case of Fig.(c), the removal of copper coating is incomplete. On the other hand, alumina layer is also removed in case of Fig.(a). In case of Fig.(b),copper coating is removed completely. It should be noted that there is no side etching like as shown in chemical etching[2]. This is due to the differences of



(a) d=2μm (b) d=8μm (c) d=15 μm

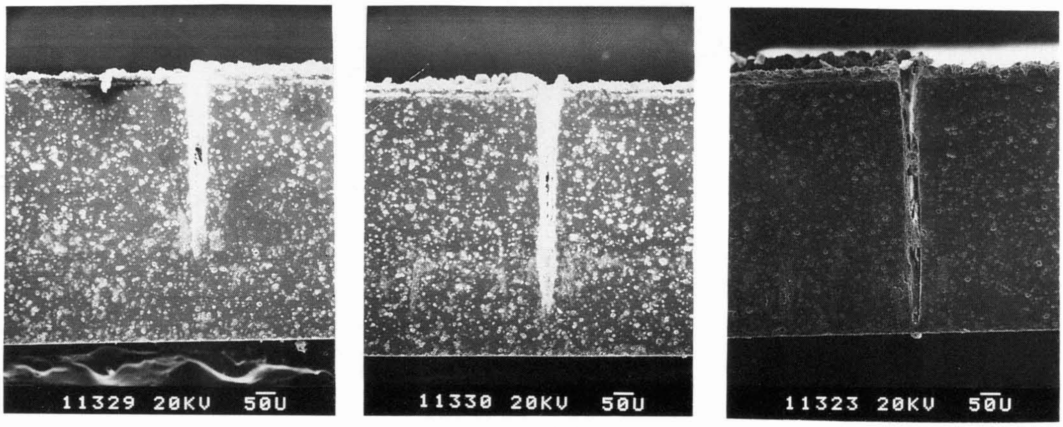
Fig.12 Sectional surfaces for various machining condition (f=5kHz,P=10W)

melting point and thermal conductivity between copper and alumina.

4. CUTTING CHARACTERISTIC OF CERAMIC CIRCUIT BOARD

This experiment is executed by the method of cutting a square piece (1x1mm) from alumina ceramic board with the repetition of laser scanning.

Figs.13(a)-(c) show the variation of the groove depth with the number of laser scanning. As can be seen from these figures, the width of groove is less than 50 μm and high aspect ratio cutting is possible without macro crack around the groove.



(a) N=10 (b) N=30 (c) N=60

Fig.13 Variation of groove depth with the number of scanning (f=1kHz,P=3W,V=2mm/s)

Fig.14 shows the relation between the depth of groove and the number of laser scanning. As shown in the figure, the depth of groove increases rapidly for the first 10 scannings, then the machining rate decreases suddenly. The mean rate of machining is about 42 μ m/scanning for the first 10 scannings, but it decreases to 3.9μ m/scanning, about one-tenth on and after 10 scannings. It is considered that the decrease in machining rate is due to the decrease of energy density resulted from the focus divergence and the difficulty of chip removal.

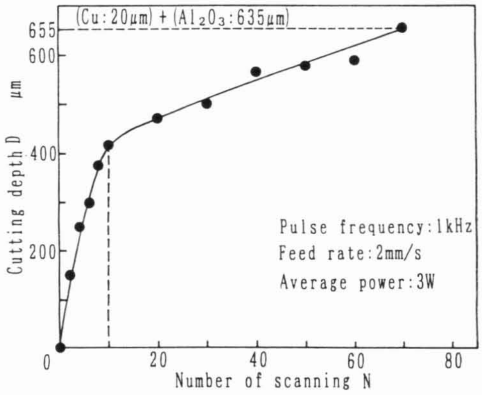
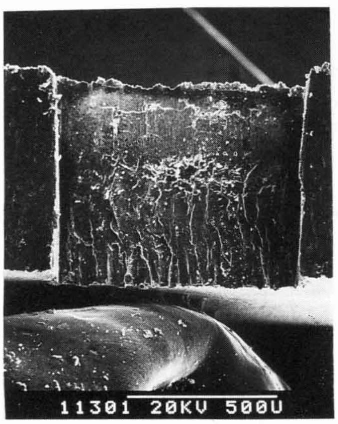
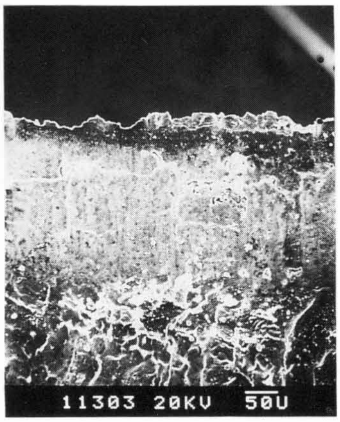


Fig.14 Relation between groove depth and the number of passing (f=1kHz, P=3W, V=2mm/s)

Figs.15(a)-(c) show the general view of cutting surface. As can be seen in the figures, the upper part cut in early period is relatively smooth surface, while the lower part cut in later period is rough surface. The taper angle is very small shown in Fig.(a), therefore drilling or trepanning is considered to be practical. Moreover the rapid machining rate in early period should be used for efficient scribing of ceramic circuit board.



(a) general view



(b) upper part

(c) lower part

Fig.15 SEM photographs of sectional surface with the number of scanning in cutting off operation (f=1kHz, P=4W, V=2mm/s)

Fig.16 shows the possible conditions for patterning or cutting off of ceramic board obtained in this experiment. As shown in the figure, the condition for cuttig off is narrower than that of patterning. In patterning process, the feed rate increases with the repetition frequency and/or the average power. However the pulse repetition frequency is limited because of the decrease of energy per pulse. In cutting process, the pulse frequency should be selected to be less than 3kHZ in order to avoid the damages such as colour change or macro crack resulted from overheating.

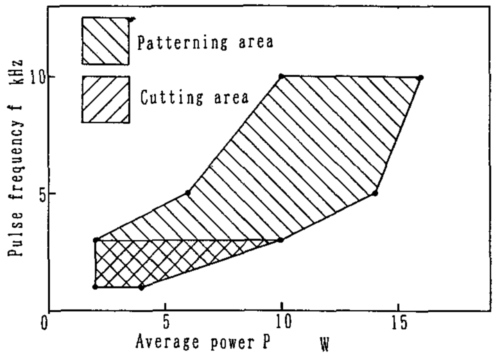


Fig.16 Possible conditions for patterning or cutting off of ceramic circuit board

5.CONCLUSIONS

Direct maskless patterning of copper coated ceramic circuit board with Q-switched Nd:YAG laser is experimentally investigated. The analysis makes it clear that the fast patterning whose feed rate reaches about 100 mm/s is possible laser if the machining condition is properly selected. Furthermore cutting off or drilling is also possible under the condition that the repetition frequency is less than 3 kHz.

This technique leads to the shorter time limit for delivery as compared with the conventional end-milling method.

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