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Technical Communication

Interconnection for Power Electronics Using Laser Ablation

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Due to the increase in working temperature of power electronic components, the conventional component design is slowly facing out and is being replaced with new design which introduces new challenges to the manufacturing process. Flat silver films with customised geometry are required to realise the new component design but such films are hard to produce with conventional manufacturing methods. This paper details the feasibility study of using laser ablation technique in producing customised patterns on thin silver film for lamination during power electronic manufacturing process. The laser used in the study is a 30 W nanosecond laser from IPG with a wavelength of 1064 nm. The ablation profiles with different laser parameters are presented and the influence of the beam energy distribution and pulse duration on the ablation quality is discussed. It was found that shorter pulse duration produces better surface finish with minimal re-melting and smaller cut width. The optimum laser parameter was determined to be 30 W with a pulse duration of 4 ns, frequency of 750 kHz and a scanning speed of 1000 mm/s to ablate a silver film of ~70 µm thick on a PET substrate. The optimised laser ablation parameters were employed to demonstrate the production of a customised silver film.

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1. Introduction

The use of die transfer film for power electronics and high temperature electronic packaging has been accepted by the electronics manufacturing industry due to the limitations of conventional joining materials such as solders and epoxies. Part of the manufacturing process for electronic power modules involves die attachment where the standard manufacturing process involves two processes involving lamination (Fig. 1) and sintering using heat and pressure.

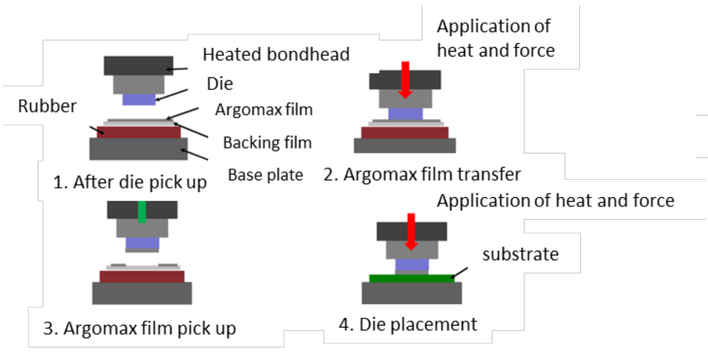


Fig. 1 Die Transfer Film (DTF) process and die placement using a Die Bonder equipment [1].

The standard lamination process requires the transfer of the silver to the bottom of the die which is fully metallised in conventional designs. Due to the increase in junction temperatures, working environment in excess of 230°C and electrical requirements for power modules, double sided cooling designs have been adopted which use a partially metallised die as shown in Fig. 2.

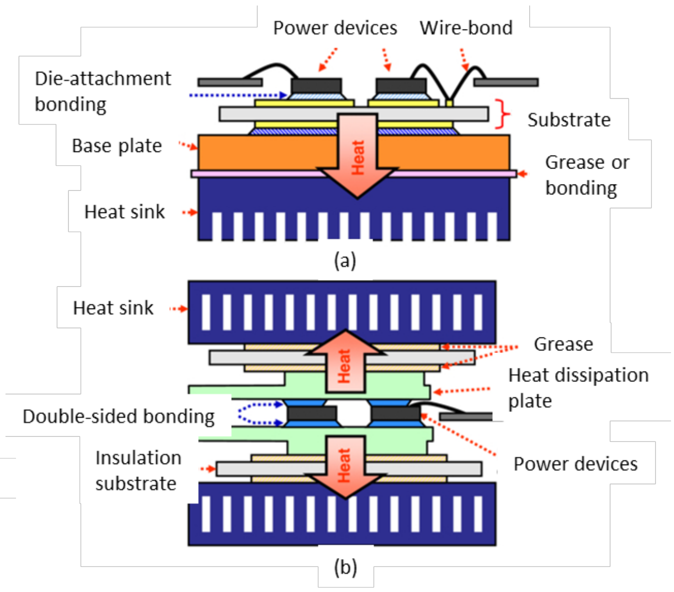


Fig. 2 Power module schematic of single and double-sided cooling [2].

The partially metallised die design cannot use the standard lamination process which involves bulk lamination of the entire bottom of the die. In order to achieve selective lamination of the partial metallised die with silver, the die transfer film has to have the same geometry as the partial metallised die area. This can be achieved through either accurately printing the silver onto a film for lamination or selectively removing silver from the film to create the geometry required. Due to the geometry size and flatness requirement of the film, printing the silver with the exact size for the partial metallised die area is not achievable.

Laser technology has been known to be able to produce geometries to high level of accuracy achieving material removal rate of sub-micron thickness. Therefore, a novel process of producing customised silver film for lamination through laser ablation is being explored in this work.

2. Materials and methods

A silver film of size 70 x 70 mm with a dry film thickness of 65 ± 5 μm was supplied by Alpha Assembly Solutions. The silver film consist of nano silver powder in an organic binder and is printed on a transparent PET material. The laser system used in this experimental work is the AgieCharmilles P 400 U laser by Georg Fischer Machining Solution as shown in Fig. 3. The laser system consists of a nanosecond 30 W Ytterbium fiber laser by IPG photonics. The specifications of the laser source is summarized in Table 1.

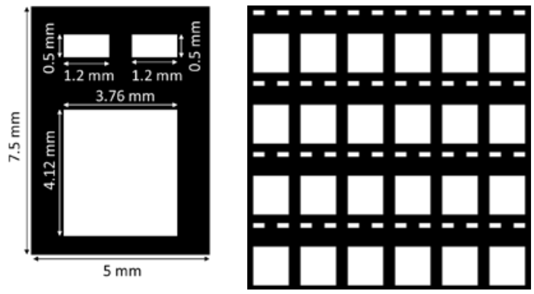
Fig. 3 AgieCharmilles P 400 U laser by Georg Fischer Machining Solution.

Table 1 Laser source specifications.

Laser P 400 U	
Laser source	Ytterbium fiber laser
Average output power	30 W ± 5%
Wavelength	1064 nm ± 1%
Pulse duration	4 – 200 ns
Frequency	2000 kHz
Pulse energy	1 mJ
Beam quality, M^2	1.5

The laser system uses a galvo scanner from SCANLAB with an f-theta lens of F160. The focal distance of the lens is 171 mm with a focal depth of 0.3 mm resulting in a focal beam spot size of 50 μm. In this work, the nanosecond laser was used. The laser power used in the study ranged from 3 W – 30 W for pulse duration ranged from 4 ns – 200 ns and frequency ranged from 30 kHz – 750 kHz where the nominal frequency for each pulse duration was used to obtain the maximum pulse energy. The scanning speed used in the experiment was 1000 mm/s.

The unit cell of the power module consist of two small rectangular shape areas of size 0.5 mm x 1.2 mm and a large rectangular shape area of size 4.12 mm x 3.76 mm as shown in Fig. 4(a). In order for the silver film to be transferred onto the power module precisely, the black area of the unit cell needs to be ablated leaving the three white areas covered with the silver film. Hence, a two-step process is proposed where the outline of the shape is cut down to the silver film leaving the PET substrate intact using a single laser pass followed by the ablation of the black area to remove any silver on the PET substrate. For mass production purposes, such a process can be replicate into an array by duplicating the unit cell as shown in Fig. 4(b). In order to identify the optimum laser parameter for the ablation of the silver film without affecting the PET substrate, a design of experiment (DOE) was conducted to investigate the effect of pulse duration, laser fluence and number of pulses (NOP) on the ablated silver film.



(a) (b)

Fig. 4 (a) Dimension of the unit cell for the power module. (b) Array of unit cells for mass production.

The dimension of the ablated grooves were measured using a Zeiss Axio Imager 2 model optical microscope and a Cyber Technology CT300 confocal microscope. The surface morphology of the ablated grooves were observed using a Hitachi TM3000 Table-top SEM.

3. Results and Discussion

A series of lines were ablated on the silver film with different laser powers and pulse durations and the grooves were imaged with a SEM as shown in Fig. 5. From the SEM images, it is observed that the ablated grooves increase in width with increasing laser power and pulse duration. This observation will be validated with the geometrical analysis using optical microscope and confocal microscope. In addition to the geometrical changes, it is also observed that re-melting and re-deposition of the silver film on the edge of the grooves became more prominent with increasing laser power and pulse duration. Splashes of re-melt can be observed at higher pulse durations and laser powers.

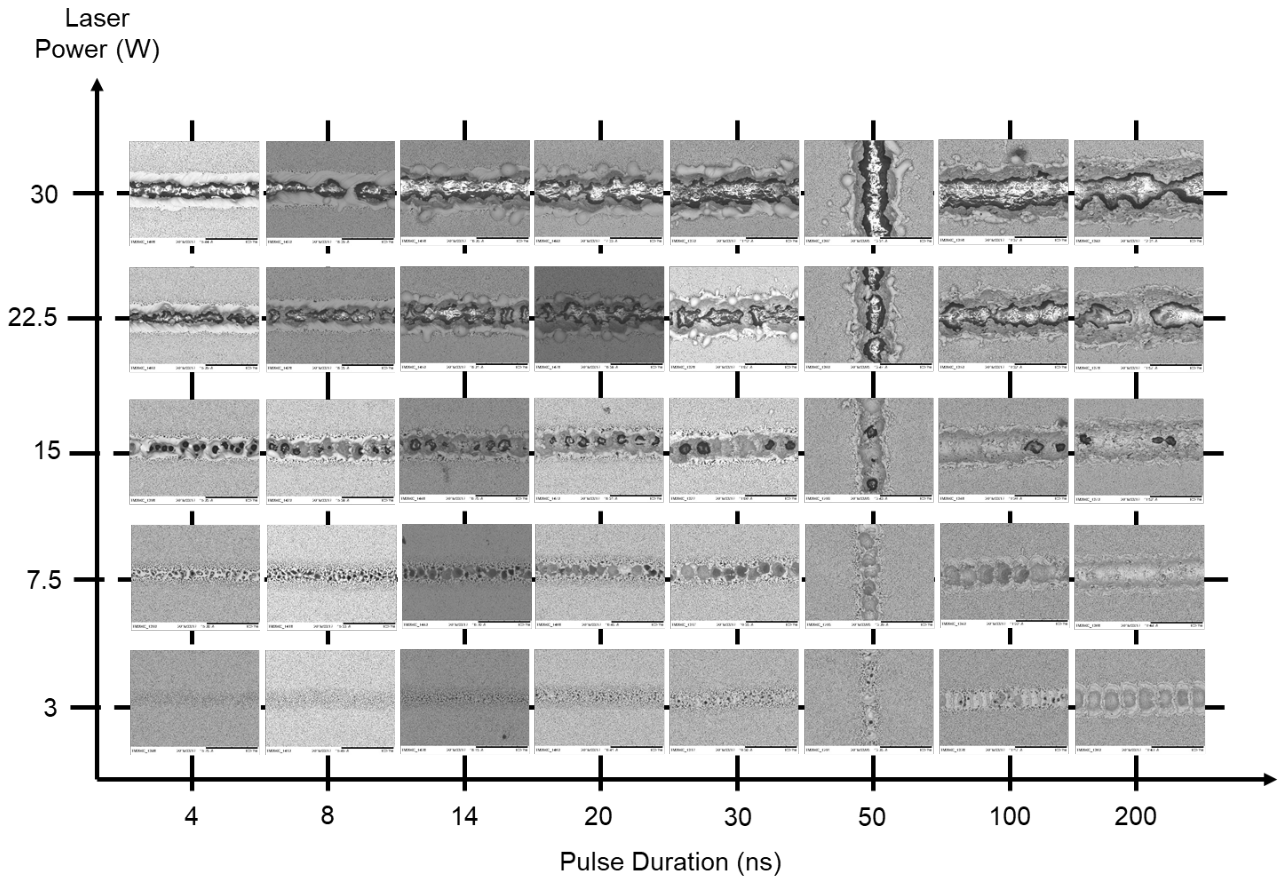


Fig. 5 SEM images of laser ablated grooves with different laser power and pulse duration with a single pass.

The widths of the ablated grooves were measured using an optical microscope. Fig. 6 shows changes in groove width ablated with different laser fluence and pulse duration. It is observed that the groove width increases with increasing laser fluence as well as increasing pulse duration. The increase in groove width in relation to laser fluence is steeper for shorter pulse duration as compared to longer pulse duration.

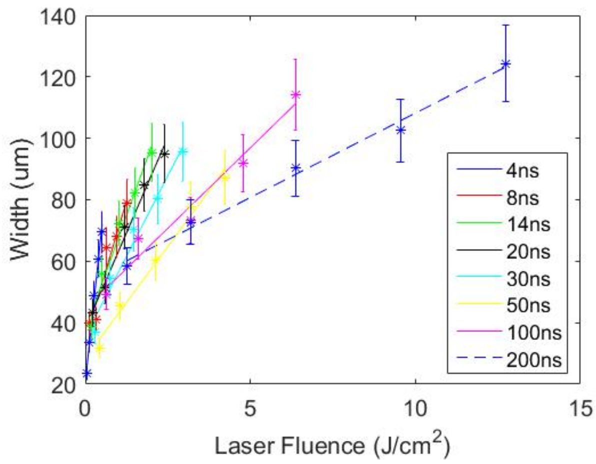


Fig. 6 Groove width variation with different laser fluence and pulse duration with a single pass.

The observed phenomena is mainly due to the Gaussian nature of the laser beam. Laser fluence higher than the ablation threshold value is required to initiate material removal [3-4]. As the laser fluence increases, the diameter of the spatial distribution of the laser fluence above the threshold value increases. The change in diameter with laser fluence is governed by the equation [5-6]:

$$\boldsymbol{D^2 = 2\omega_0^2 \, ln\left(\frac{F_0^{pk}}{F_{th}}\right) = 2\omega_0^2 \, ln\left(\frac{E_p}{E_{th}}\right)} \qquad (1)$$

where E_{th} is the threshold energy and E_p is the pulse energy and this equation is deduced from the equation governed by the fluence distribution of a Gaussian spatial beam profile $F(r)$ with laser beam spatial radius, ω_0 .

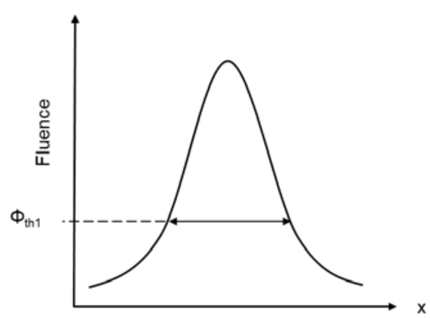


Fig. 7 Schematic diagram illustrating the correlation between the Gaussian spatial distribution of the laser fluence with the ablation width.

The depth profile of the ablated grooves were measured using a confocal microscope. The 3D and 2D profile for grooves ablated using a 50 ns pulse duration is shown in Fig. 8 and Fig. 9. From the plot, it is observed that the grooves increases in depth with increasing laser fluence. In addition, the re-deposition of the silver at the edge of the groove is more prominent with higher laser fluence.

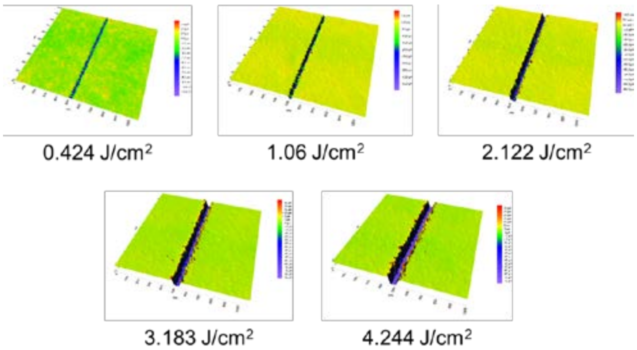


Fig. 8 3D contour profile of grooves ablated with 50 ns pulse duration at different laser fluence.

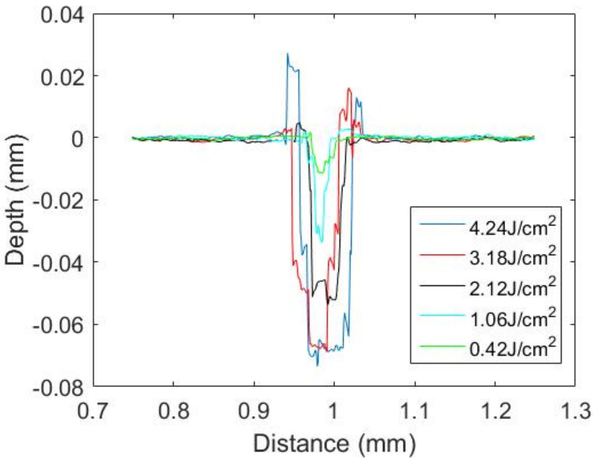


Fig. 9 Cross section profiles of grooves ablated with 50 ns pulse duration at different laser fluence.

Fig. 10 summarises the ablated depth of grooves with different laser fluence and pulse duration. The thickness of the silver film was measured to be around 65 ± 3 μm. It is observed from Fig. 10 that all grooves produced with the highest power through a single pass creates a groove deeper than the thickness of the silver film. This indicate that a clean cut has been produced on the silver film.

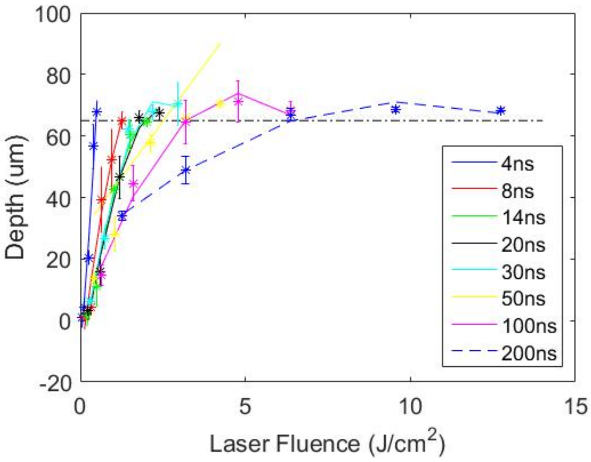


Fig. 10 Groove depth variation with different laser fluence and pulse duration with a single pass.

Although the shorter pulse duration achieves a clean cut with a lower fluence, it required more NOP to achieve the cut. This is due to differences in nominal frequency associated with different pulse durations. A higher frequency setting is required for shorter pulse durations in order to achieve the maximum pulse energy. The difference in laser fluence and NOP results in a different ablation mechanism. At short pulse duration, the ablation per pulse is smaller due to the shorter pulses which result in less re-melting and sputtering as seen on the SEM images in Fig. 5. As for the longer pulse duration, severe re-melting was observed with sputtering of melted silver along the edge of the grooves.

4. Process demonstration

Based on the experimental work, the optimum laser parameter is deemed to be 30 W with a pulse duration of 4 ns, frequency of 750 kHz and a scanning speed of 1000 mm/s. Fig. 11 shows an example of a customised silver film produced using a laser ablation technique from which a power module is successfully produced.

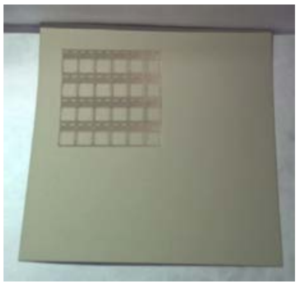


Fig. 11 Example of customised silver film produced using laser ablation technique.

5. Conclusion

The feasibility of laser processing in producing customised silver film for lamination has been demonstrated in this study. Through careful selection of laser parameters and processing strategy, ablation of thin silver film on PET substrate using an IR wavelength laser is possible without damaging the polymeric substrate. The optimal laser parameters used to ablate a silver film of ~70 μm thickness is at 30 W power level with a pulse duration of 4 ns, frequency of 750 kHz and a scanning speed of 1000 mm/s.

Acknowledgments

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