Blind Via Formation with Solid-State Ultraviolet Laser Using Imaging/Shaping Technique

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イメージング／シェーピング技術を用いた紫外線固体レーザによるブラインドビア形成

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概要 紫外線固体レーザを用いて樹脂にブラインドビアを形成するに当たって、イメージング転写技術とビーム整形技術を採用した技法を紹介する。これらの技術の採用により、加工ビア形状のみならず内層銅へのダメージの制御に大幅な向上を確認した。この論文では、ビア形成と照射されたフルエンスの関係についても論じる。特定のレーザにおいてビア形成時間を最小にするフルエンス範囲があることを示す。すなわち、それは1.5から2.5J/cm²の範囲であり、この範囲を超えるとフルエンスの増加に伴うレーザパルス当たりの樹脂除去量が減少し、この範囲を両側にはずれるとビアの形成時間が増大する。これらから、与えられたレーザにおいて最大のスループットを得るためにプロセスを最適化することが可能である。最後に、新しいより高出力のレーザを用いてのプロセススループットのスケールアップについても述べる。フルエンスはプロセスのスケールリングに特に重要な要素で、その結果についても述べる。

Key Words: Laser Drilling, Laser Material Process, Solid-State Ultraviolet Laser

1. Introduction

Laser drilling has emerged in recent years as the most widely accepted method of creating microvias in High-Density Interconnect (HDI) and chip packaging devices. Most commercially available laser drilling tools are currently based on one of two laser types: CO₂ lasers with wavelengths in the far infrared portion of the spectrum, and frequency tripled or quadruple solid-state UV lasers with fundamental wavelengths in the near infrared portion of the spectrum¹⁾.

This paper presents a method of forming blind vias with frequency tripled solid-state lasers, at a wavelength of 355nm, focusing on direct resin drilling processes.

Previously, vias have been typically formed with these lasers without shaping the beam profile but focusing the beam on a work piece. Via size was controlled by using a de-focused beam and/or moving the beam in a circular motion (trepanning) or spiral motion^{2)~5)}. When this method is used for direct resin drilling process, via shape tends to be easily affected by the beam spatial profile, while beam profile affect on via shape is less in direct copper drilling because of high fluence requirement for that process. Also, due to the characteristic of Gaussian beam profile, difference of intensity between the beam center and edge makes controlling via diameter and damage to the metal layer complex.

The technique described here uses an imaging configuration that projects an image of a mask (aperture) onto the work piece, and also uses beam shaping optics that enable illumination of the aperture with evenly distributed laser beam.

2. Principles of Projection Imaging

A schematic of Projection Imaging is shown in Figure 1. The beam coming out from the laser is first collimated by an up-collimator (telescope), then shaped from Gaussian profile into near top-hat profile by beam shaping optics. The shaped beam is passed through a round aperture, and an image of the illuminated aperture is projected onto the work piece through imaging optics. Galvo mirrors move the beam over the telecentric scan lens to change position on work piece.

The advantages of this technique are that:

- Via size/shape are precisely determined by aperture size /shape.

Fig.1 Schematic of Projection Imaging and Beam Profile

- Damage to metal layer is controlled more precisely and easily with shaped profile beam.

With a thermally activated process, there's no threshold exists. However, significant ablation is observed only above a certain fluence, which we henceforth denote as the threshold fluence, ϕ_{th} . ϕ_{th} depends on the particular material, its microstructure and concentration of physical and chemical defects, and on the laser parameters, in particular the laser wavelength and pulse duration (dwell time). Typical values for metals are within the range $1\text{--}10\text{J}/\text{cm}^2$, and with organic materials between 0.01 and $1\text{J}/\text{cm}^2$ ⁶⁾. Therefore, the "top-hat" profile permits the fluence delivered to the work surface to be set below ϕ_{th} for the metal layer across the entire imaged spot.

3. Drilling Results

Arrays of via were drilled on $45\mu\text{m}$ RCC® resin with top copper etched away, varying fluence and number of laser pulses applied to the material. Fluence was varied by changing laser pulse repetition frequency (PRF). The via taper criterion was chosen as bottom diameter to be 75% of top diameter. Top and bottom diameter of drilled via were then measured under an optical microscope in order

Fig.2 Pure Drill Time of 62 and $75\mu\text{m}$ via on $45\mu\text{m}$ RCC® resin with different PRF

Table 1. Summary of Drilling Result

Ideal Spot μm	PRF kHz	Laser Pulses	Drill time ms	Fluence over spot J/cm^2
75	8	25	3.125	3.790
	10	30	3.000	2.811
	12	35	2.917	2.027
	15	45	3.000	1.263
62	9	25	2.778	4.078
	11	30	2.727	3.012
	13	30	2.308	2.182
	15	35	2.333	1.587
	17	45	2.647	1.179
	20	60	3.000	0.823

to determine number of laser pulses required meeting the criterion at each fluence. Figure 2 shows the pure drill time ($=1/\text{PRF}$ times # of laser pulses required) of drilling 75 and $62\mu\text{m}$ via in $45\mu\text{m}$ RCC® resin, and detailed results are summarized in Table 1. Different design beam shaper was used for aperture sizes that projected 62 and $75\mu\text{m}$ spot on work piece in order to get higher transmission through aperture mask. The $1/e^2$ beam spot of the beam shaper for $62\mu\text{m}$ spot size was smaller than the one for $75\mu\text{m}$ consequently the energy through fixed size aperture is higher with the one for $62\mu\text{m}$ spot. If pulse energy before aperture is the same, the shaper used for $62\mu\text{m}$ via provides roughly 1.2 times higher work-surface fluence than that for $75\mu\text{m}$ (Figure 3). Or, if fluence is the same, laser output energy to drill $62\mu\text{m}$ can be lower.

We see two obvious things in Figure 2: 1) Drill time is shorter at smaller via size 2) PRF that gives shortest drill time shifts to higher values as via size becomes smaller.

Figure 4 shows basically same result as Figure 2, but x axis is fluence in place of PRF. In this chart, we observe that the fluence range that gives shortest drill time is somewhere from 1.5 to $2.5\text{J}/\text{cm}^2$.

From Figure 5 to Figure 10 show scanning electron microscope (SEM) pictures and optical microscope pic-

Fig.3 Intensity comparison of two different beam shapers

Fig.4 Pure Drill Time of 62 and $75\mu\text{m}$ via on $45\mu\text{m}$ RCC® resin with different fluence

Fig.5 62μm via (1) [$\phi \equiv 4.078 \text{ J/cm}^2$]

Fig.6 62μm via (2) [$\phi \equiv 3.012 \text{ J/cm}^2$]

Fig.7 62μm via (3) [$\phi \equiv 2.182 \text{ J/cm}^2$]

Fig.8 62μm via (4) [$\phi \equiv 1.587 \text{ J/cm}^2$]

Fig.9 62μm via (5) [$\phi \equiv 1.179 \text{ J/cm}^2$]

Fig.10 62μm via (1) [$\phi \equiv 0.823 \text{ J/cm}^2$]

tures of 62μm vias on 45μm RCC® Epoxy resin with different fluence¹⁾. As seen in #1 and #2, damage to bottom copper surface is significant at above 3.0 J/cm². Since shortest drill time process was observed below 3.0 J/cm², process doesn't have to be too aggressive in order to minimize drill time. In other words, higher fluence process gives neither shortest drill time nor good quality.

4. Experimental Results of Etch Depth Per Pulse

In order to pursue more detailed study of fluence vs. drill time, an experiment to acquire etch depth per pulse (material removal rate) was conducted with the shaped

Fig.11 Plot Example of Depth of Drilled Via vs. Number of Laser Pulses Applied on the Material. Data shown was taken at fluence $\equiv 1.15 \text{ J/cm}^2$

beam, varying fluence by changing pulse repetition frequency and varying number of laser pulses applied on a material, N . Material used for the experiment was 70-80μm RCF® resin with top copper etched away. Depth of the drilled via was measured by using WYCO 2000 white-light interferometric profilometer. Etch rate at each fluence was then calculated by fitting a linear equation. Figure 11 is an example of fitting a linear equation for a fluence $\equiv 1.15 \text{ J/cm}^2$. As laser pulses are applied to the material, the laser removes some volume of material and eventually reaches the metal layer. That why depth is saturated around 80μm depth in Figure 11. The slope of a linear equation was considered as etch depth per pulse for a given PRF or fluence.

Figure 12 and Figure 13 show ablation rate, χ , obtained in this material as a function of fluence, ϕ . Figure 12 uses logarithmic scale in x axis, and Figure 13 uses linear scale. Since the logarithmic fit looks straight in Figure 12^{7,8)}, the increase in ablation rate with increasing fluence, $d\chi/d\phi$, becomes smaller at certain point. In Figure 13, we used linear scales and examined the fluence at which $d\chi/d\phi$ starts decreasing within the preferred fluence range for the blind via drilling process. We see $d\chi/d\phi$ changes at around 2.25 J/cm²; therefore, we say that ablation is more efficient below 2.25 J/cm² for this material's process. We think the reason drill time was not shorter at higher fluence is because that there are two competing effects: 1) the lower $d\chi/d\phi$ at higher fluences, 2) the lower PRFs at which the lasers available today can deliver $\phi \geq 2.25 \text{ J/cm}^2$. Higher fluence can remove more material per laser pulses, but it is usually deliverable at lower PRF.

Although the material and thickness are different, the result of this experiment and the drilling results shown in Figure 2 and Figure 4 seem to match.

Fig.12 Empirical Ablation Rate of RCF® Resin, logarithmic scale

Fig.13 Empirical Ablation Rate of RCF® Resin, linear fit

5. Process Scale Up

62μm vias were drilled on 45μm RCC® Epoxy resin using a Nd:YVO₄ 3rd harmonic laser, which has higher pulse energy at higher pulse repetition rate or which PRF is higher with same pulse energy, in order to scale up the process. (i.e., Pulse energy and average power are shown in Figure 14 and 15. The Nd:YAG 3rd harmonic laser has higher pulse energy at lower PRF while the pulse energy of the YVO₄ laser exceeds that of the YAG laser at higher PRF.) The maximum average power of the YVO₄ laser exceeds that of the YAG laser. This is basically the difference in these laser characteristics.

Fig.14 Pulse Energy Comparison

tics.

Figure 16 shows a comparison of the drill times obtained for 62μm via on RCC® Epoxy resin between two different solid-stage UV lasers. The same methodology and criterion were used as discussed in section 3. We see that the shortest drill time with YVO₄ laser shifts to higher PRF.

Figure 17 shows the same drill time data plotted as a function of fluence. Again, the fluence range that gives the shortest drill time is very comparable for the two lasers.

Fig.15 Average Power Comparison

Fig.16 Pure Drill Time Comparison of 62μm via on RCC® Epoxy Resin between 3rd Harmonic YAG and 3rd Harmonic YVO₄ Laser

Fig.17 Pure Drill Time Comparison of 62μm via on RCC® Epoxy Resin between 3rd Harmonic YAG and 3rd Harmonic YVO₄ Laser

6. Summary and Conclusion

Incorporating imaging and beam shaping technology enable us to control via diameter and damage to bottom layer copper. This technique also allows us to conduct empirical studies of the relation between material ablation and metal layer damage, optimized fluence and ablation rate. Through our study, we found that higher fluence is not necessary to give the shortest drill time in processing typical organic dielectric materials. In our experiment, conditions that give the shortest drill time seems to be in the range of 1.5 to 2.5J/cm² in drilling Epoxy resin, which is good because significant damage to Copper layer seems to start occurring above 3.0J/cm². However, the number could be different with different materials. We also scaled up the process with a different, higher power laser, and found that the optimal process seems to be in same fluence range. In order to optimize laser via drilling process, a key to success will be how fast the laser can deliver pulse energies yielding the optimal range of fluences. Higher power and higher PRF will be the approach for the future.

Acknowledgements

The authors gratefully acknowledge the sentences correction support of Gail Smith.

(2001.3.16-受理 2001.5.14-再受理)

References

This paper was updated based on the paper presented at 14th JIEP Annual Meeting.

- 1) C.Dunsky, H.Matsumoto, Bonnie Larson : "High Quality MicroVia Formation with Imaged UV YAG Lasers", Technical Proceedings of IPC Printed Circuits EXPO 2000, S-15-5, April, 2000
- 2) A.Cable : "High Speed Ultraviolet Laser Via Formation for Chip on Flex and Chip Scale Packages", Proc. FLEXCONTM, 1996
- 3) M.Owen, et al. : "The Introduction of UV YAG Laser Drilled Microvias in PCB's", Proceedings of PC World Conference, 1996
- 4) A.Cable : "Improvement in High Speed Laser Microvia Formation Using Solid State Nd:YAG UV Lasers", IPC Works '97, High Density Interconnects Conference, Oct 5-9, 1997
- 5) H.Matsumoto : "Drilling Technology with UV YAG Laser", Proceeding of the 12th JIEP Annual Meeting, pp.83-84, March, 1998
- 6) D.Bäuerle : "Laser Processing and Chemistry", Springer, ISBN 3-540-66891-8, pp.236-237, 2000
- 7) For Example, R.Srinivasan, B.Braren : "Ultraviolet Laser Ablation of Organic Polymers", Chemical Reviews, Vol.89, pp.1303-1316, 1989
- 8) For Example, James Brannon : "Excimer Laser Ablation and Etching", American Vacuum Society, ISBN 1-56396-245-4, 1993