A Plastic BGA Singulation using High Thermal Energy of 2nd Harmonic Nd:YAG Laser

Kyoung-cheol Lee*, Kwang-Yeol Baek and Cheon Lee***

Abstract – In this paper, we have studied minimization of the kerf-width and surface burning, which occurred after the conventional singulation process of the multi-layer BGA board with copper, polyethylene and epoxy glass fiber. The high thermal energy of a pulsed Nd:YAG laser is used to cut the multi-layer board. The most considerable matter in the laser cutting of the multi-layer BGA boards is their different absorption coefficient to the laser beam and their different heat conductivity. The cut mechanism of a multi-layer BGA board using a 2^{nd} harmonic Nd:YAG laser is the thermal vaporization by high temperature rise based on the Gaussian profile and copper melting point. In this experiment, we found that the sacrifice layer and N_2 blowing are effective in minimizing the surface burning by the reaction between oxygen in the air and the laser beam. In addition, N_2 blowing reduces laser energy loss by debris and suppresses surface oxidation. Also, the beam incidence on the epoxy layer compared to polyimide was much more suitable to reduce damage to polyimide with copper wire for the multi-layer BGA singulation. When the polyester double-sided tape is used as a sacrifice layer, surface carbonization becomes less. The SEM, non-contact 3D inspector and high-resolution microscope are used to measure cut line-width and surface morphology.

Keywords: BGA singulation, multi-layer material, Nd:YAG laser, absorption coefficient, thermal vaporization, sacrifice layer

1. Introduction

Recently, the microelectronics industry is moving toward smaller feature sizes – light, thin, short and small. The BGA (Ball Grid Array) is one of the microelectronics applications such as the flip-chip technology used in a flash memory, camcorder, car navigation system, HDD (hard disk drive) and GPS (global position system), etc. The requirements of high performance and high quality for the IC packages result in seeking new technology and processes to fabricate more integrated, precise and efficient elements. IC packages need to be separated from a BGA board in which the packages are formed at the last phase of manufacturing. Much effort has been put into the development of the various applications of the laser process so that through-holes in a PCB (printed circuit board) can be processed with a UV laser [1-3].

Various techniques using laser-material interaction have been developed in order to perform tasks such as copper circuit repairs and silicon micro-processing of local area, BGA soldering, functional thin film deposition and pulsed laser ablation of solid substrates [4].

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Pulsed laser ablation of solid materials has been extensively applied in the laser material interaction and device fabrication. The initial process of laser ablation is an interaction of the light with the solid target surface. Ablation is not a single event, but is a complex of many overlapping and separate events, as it described in many reports [5-8]. Some of the events include absorption, electronic excitation, rapid heating, plasma generation, photolysis, sputtering, melting, ejection, decomposition, oxidation, vaporization, sublimation, condensation and solidification. Much research has been undertaken to investigate the laser ablation in a vacuum or ambient air, aiming at various applications such as material removal, cutting, drilling, marking and welding. Especially, the laser cutting technology has shown its utility in many areas of recent productions due to its precision and effectiveness, including the automotive industry. The objects to be cut with the laser are usually metals, semiconductors and polymers formed of only one component material. The laser cutting process of such a material is easy to control, since these kinds of materials show the homogeneous property of optical absorption. However, a BGA board usually is a multi-layer material, which consists of several materials such as copper, polyethylene and epoxy with glass fiber. Fig. 1 shows the schematic structure of a BGA board made of multi-layers [9]. It is very difficult to cut the material because it contains several basic materials with different mechanical, heat and optical properties. Therefore, in this study, we will concentrate our attention on how to use laser thermal energy to separate IC packages from a multi-layer BGA board.

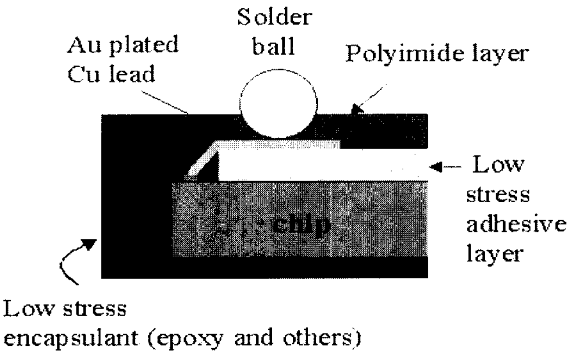


Fig. 1 The schematic structure of a BGA board with multi-layers

The singulation system is equipment that cuts the BGA board as an independent unit. The conventional singulation system is diamond-saw separation, which not only requires the use of much water to flush the debris formed in the course of sawing, but also occasionally spoils the copper wire in the IC circuit along the edge of the cut (this kind of phenomenon is called burr) in the case of manufacturing high-integrated IC packages with a much thinner BGA board. A high intensity laser beam can be directly irradiated to a narrow region to instantly evaporate material with a very small heat affected zone. This ability to cut any kind of material at a restricted zone using an effectively focused laser beam distinguishes the laser process from other conventional ones. In this work, we developed a possible laser cutting technology for non-homogeneous materials such as a BGA board composed of multi-layers and the minimization of carbonization in the polymer layer.

2. Experiment

The BGA board is cut by the second harmonic wavelength of pulsed Nd:YAG laser (λ=532 ㎚,repetition rate=10 Hz) that has a maximum laser energy density of 234 kJ/㎠. The laser beam was irradiated on both sides of BGA board of which one is a polymer layer and the other is an epoxy layer. We observed a kerf-width and surface damage for each method. Fig. 2 shows two different methods for the beam incident side.

For this experiment, the most important step is to select the correct kind of laser to cut the multi-layer BGA board. The BGA board consists of several materials, copper and polymer with very different optical properties. It is very difficult for the copper to absorb an infrared laser beam and easy for it conduct heat to the deep package. The total effect will result in a very poor cut edge as shown in the conventional techniques. UV laser light is a very good light source for this copper cutting application. But there is no such laser with a high power output. We used a laser energy density of 234 kJ/cm^2 and second harmonic wavelength (λ=532 ㎚, repetition rate=10Hz) of a pulsed Nd:YAG laser. The laser beam was focused by convex lens onto the BGA board with a focal length of 200 ㎜. Fig. 3 shows the schematic diagram of the BGA cutting system using Nd:YAG laser. The sample BGA board was placed on an X-Y-Z motorized stage controlled by an encoder mike controller. During the laser singulation process, an N_2 blow was used to remove the debris created and to reduce the energy loss while the process was proceeding. This nitrogen gas was blown into the laser beam scan direction. The nitrogen gas primarily removes material from the cut zone while protecting the lens from the smoke emitted from vaporized material. It also enables more effective coupling of the laser beam with the parent material.

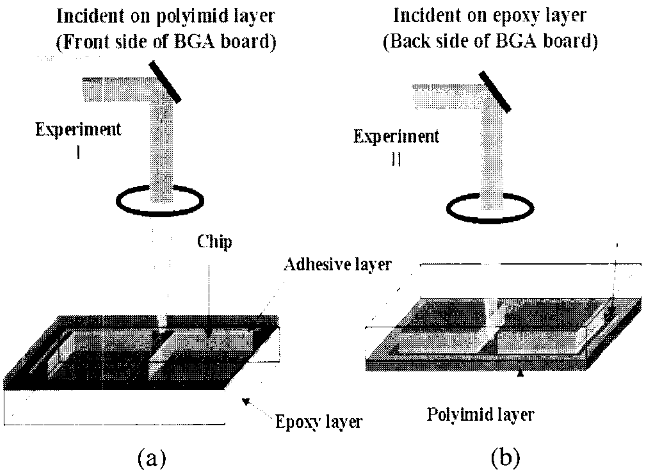


Fig. 2 (a) Laser beam incidence on polyimide layer (b) Laser beam incidence on epoxy layer

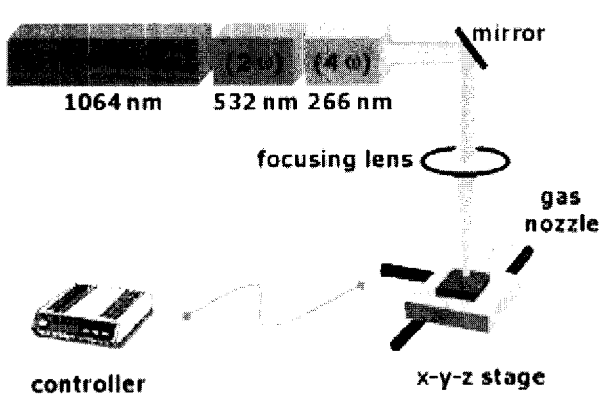


Fig. 3 The schematic diagram of a plastic BGA singulation system

The gas pressure was 22.5 mTorr and 45 mTorr. A non-contact 3D inspector of the Optical Gauging Product Co. (smart scope 250) was used to measure the cutting line-width. The surface damage and cross sectional image were examined by high-resolution microscope and SEM (scanning electron microscope). The samples used in this study are coated with photo-resist and two side tape material to attempt the decrease of the surface damage and kerf-width as written in Table 1. The photoresist (AZ1512) is evenly coated with the thickness of 1.1 ㎛ on samples.

Table 1 The conditions of three types of samples

Board	Surface condition (Sacrifice layer)
Plastic BGA	No coating
	Photoresist coating
	Two side tape coating

3. Results and Discussions

Laser processing such as material ablation using a pulsed laser, has been presented well for many years. We divide the beam-solid interaction process conceptually into three phases. One is absorption and thermalization of the pulsed beam energy into substrates. Another is the actual ablation of the target material. The other is relaxation that means the return of the target to a static state. Each phase has its own physical phenomena. The BGA board consists of several materials: copper, solder balls of Sn and Pb compound and polymer with very different light-absorbing properties. Especially, it is very difficult for the copper to absorb the infrared laser beam and easy for it to conduct heat to deep package. UV laser light is best suited to this application, although quite efficient ablation can be achieved even in copper, which reflects more than 98% at 1 ㎛. However, it is not easy to find a laser with enough energy to cut the copper layer. Therefore, we chose frequency multiplied Nd:YAG laser with a wavelength of 532 ㎚ as a singulation tool. The absorption coefficient of the irradiated surface determines the efficiency of the laser material processing. The absorption coefficient of copper and epoxy are roughly 0.4 and 0.8 [cm^{-1}] at the wavelength of 532 ㎚ (Nd:YAG laser), respectively [1]. To compare the singulation characteristics of the BGA board, the laser beam was irradiated onto the polyimide and epoxy layers in two different way as shown in Fig. 2.

3.1 Incidence on polymer layer

Table 2 presents the characteristics of metal materials of which the BGA board consists. The multi-layer BGA board has a copper layer and metallic solder-balls of a Sn and Pb compound. So it is very difficult to cut the board with a fine-shaped edge.

Table 2 The electrical resistivity and melting point of Cu and Sn-37%Pb

Characteristics	Cu	Sn-37%Pb (Solder ball)
Electrical resistivity	1.7×10^{-8} Ωm	1.46×10^{-7} Ωm
Melting point	1060 °C	183 °C

Fig. 4 is a cross-sectional SEM image of a BGA board cut by a second harmonic wavelength of a pulsed Nd:YAG laser (λ=532 ㎚, repetition rate=10Hz). Because the beam intensity has Gaussian distribution, the cut samples have a Gaussian profile [10]. Therefore, we confirmed that the cut mechanism of a multi-layer BGA board using 2nd harmonic Nd:YAG laser is the thermal vaporization by high temperature rise based on the Gaussian profile and copper melting point. The existence of broad surface damage on the top as shown in Fig. 4 is due to the difference between excellent thermal conductivity of copper and beam delivery time to the bottom of the sample.

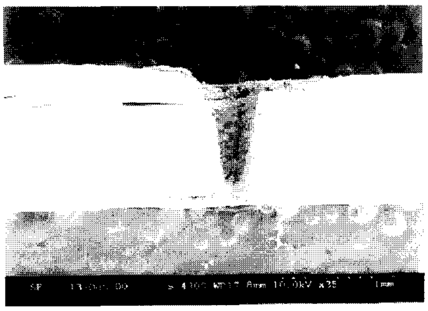


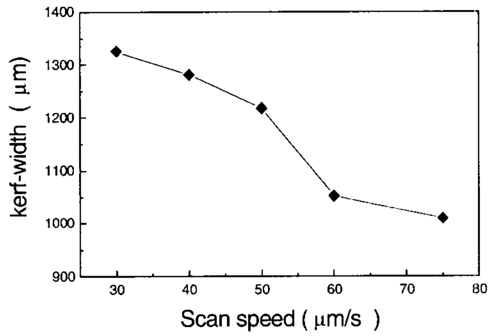
Fig. 4 The cross-sectional SEM image of cut BGA board (laser energy density: 234 kJ/cm^2, beam scan speed: 30 μm/s)

Fig. 5 (a) presents the kerf-width tendency of an original BGA board measured by a non-contact 3-D inspector without any treatment such as photoresist coating or N_2 blowing during the singulation process. The kerf-width is decreased with an increase of the scan speed. It is a general characteristic in the laser-material processing that shorter laser dwell-time cause smaller surface damage. In this study, the complete cut of the BGA board is realized only at a beam scan speed of less than 30 ㎛/s.

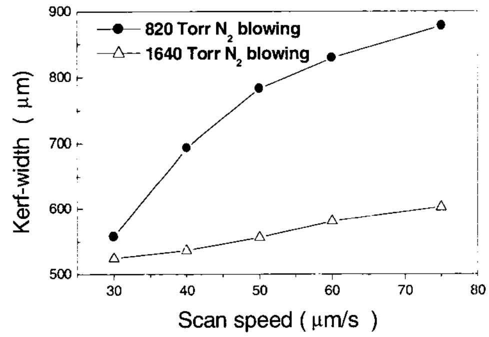
In Fig. 5 (b), we can see the increase of the kerf-width with the increase of scan speed. The samples in this experiment are not coated but N_2 blowing was conducted during the singulation process of the BGA board. The scan speed is directly proportional to kerf-width. The kerf-width of the samples with N_2 blowing with the pressure of 820 Torr is narrower than that of 1640 Torr. This means that an

N_2 blowing pressure of 820 Torr is a more effective coupling pressure to cut the BGA board with the avoidance of the energy loss by debris.

In our experiment, the perfect cutting of all layers of the BGA board is realized only at the critical beam scan speed of 30 μm/s. The copper layer did not cut at beam scan speed faster than 30 μm/s. The kerf-width in the graph of Fig. 5 (a) and Fig. 5 (b) shows the reverse inclination with beam scan speed. It is thought that the copper layer contained in the multi-layer BGA board is deeply affected by this phenomenon. Over a beam scan speed of 30 μm/s, the thermal energy of the laser beam is only irradiated on the top polymer layer of the BGA board without proceeding into the copper layer by N_2 blowing that has the inclination of 30 ° in the beam incident direction. Therefore, the compulsive thermal diffusion into the surroundings by N_2 blowing during the singulation process of BGA board increases the surface kerf-width. As shown in the Fig. 5 (b), the kerf-width of the samples conducted with N_2 blowing of 820 Torr is inclined to become broad fast compared to that of 1640 Torr. It means that the more intense N_2 blowing of 1640 Torr is effective to remove the debris, which interferes with the efficiency of the beam focusing characteristics around the beam irradiated area.



(a)



(b)

Fig. 5 (a) Kerf-width variation of BGA board as a function of beam scan speed (laser energy density: 234 kJ/cm^2) (b) Kerf-width variation of BGA board with N_2 blowing and beam scan speed (laser energy density: 234 kJ/cm^2)

3.2 Incidence on epoxy layer

Fig. 6 shows the surface images of the ablated area on the epoxy layer coated with photoresist and polyester double-sided tape taken by high-resolution microscope. In this experiment, the beam scan speed was 50 μm/s and the minimum kerf width of 220 μm with the exception of the carbonization part is obtained. When double-sided tape is inserted between the polymer layer and work-piece as a sacrifice layer, surface carbonization becomes less. In Fig.s 6 (a) and (b), the average values of the carbonization part are 640 and 240 μm, respectively. Carbonization part of the ablated line in the case of the sample coated with the double-sided tape was decreased by 68 % compared to that of photoresist. This result is caused by the reduction of the contact area between the ablated surface and the atmosphere. Therefore, the BGA board singulation using 2nd harmonic Nd:YAG laser is good in the case carried out in the nearly sealed state at which the reaction of the polymer surface and air is minimized. From this point of view, it does not mean that minimum carbonization of the ablated area is realized whenever the contact area is reduced through any kind of material. The absorption coefficient, thickness of the covered material and beam scan speed are the feature parameters in the attempt of minimum carbonization. In our experiment, the epoxy layer occupies over 60 % of the volume constructing the BGA board. When the laser beam intensity is regarded as Gaussian distribution, the epoxy layer is more suitable for the incidence layer of the laser singulation than polyimide in order to reduce the damage of polyimide with copper wire.

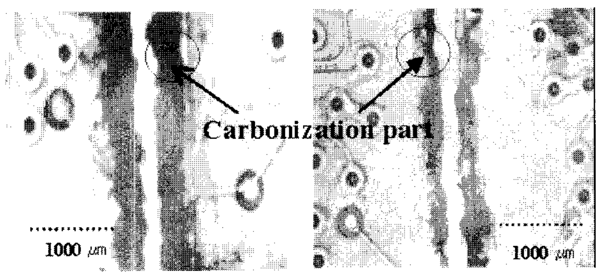


Fig. 6 Comparison of carbonization parts of line ablated by the laser irradiation on the samples coated with photoresist (a) and double-sided tape (b) (scan speed: 50 μm/s, laser energy density: 234 kJ/cm^2)

4. Conclusion

The BGA board consists of several materials: copper, solder balls of Sn and Pb compound and polymer with different light-absorbing properties. In our experiment, we described a few characteristics of a BGA board singulation technology second harmonic wavelength of pulsed

Nd:YAG laser (λ = 532 nm, repetition rate = 10 Hz). Laser singulation of a BGA board has a bright prospect as a new and practicable singulation method for the future IC manufacturing technology. The selection of sample side for laser incidence on cut profile is very important. Beam incidence on the epoxy layer compared to polyimide was much more effective to reduce damage of polyimide with copper wire for BGA board singulation. Also we could find a threshold value for BGA singulation using a 2nd harmonic Nd:YAG pulsed laser. When the polyester double-sided tape is used as a sacrifice layer, surface carbonization is reduced. This means that the cutoff of the contact area of the polymer layer and atmosphere is effective in minimizing carbonization. Table 3 shows the optimum values of BGA singulation in our study. The results indicate that BGA singulation using laser is feasible and practical.

Table 3 The singulation condition of BGA board

Components	Value
Laser fluence	234 kJ/cm^2
Scan speed	50 μm/s
Sacrifice layer	Polyester double-sided tape
N_2 blowing pressure	1640 Torr
Minimum kerf-width	220 μm

Acknowledgements

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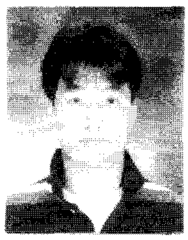

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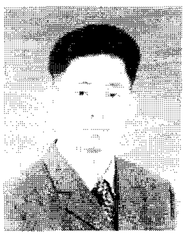

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