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Nd:YAG laser drilling in epoxy resin/AlN composites material

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Abstract

The Nd:YAG laser drilling performance of blind vias in epoxy/aluminium nitride (AlN) composite and virgin epoxy is systemically studied through varying the average laser power, the repetition times, and the pulse repetition rate from 0.2 W to 1.2 W, 12 to 48 and 3 KHz to 20 KHz, respectively. The results show that compared with pure epoxy, the drilling conditions of blind vias in epoxy/AlN composite can be changed in a wide range, with no residue found significantly at the surface of the entrance of the blind vias. The influence of the repetition rate is more evident among the parameters of the Nd:YAG laser, such as the average laser power, laser repetition rate, and repetition times, and should be carefully controlled.

Keywords: E. Cutting; E. Forming; E. Machining; E. Powder processing; AIN

1. Introduction

Because of the tendency towards denser circuit designs and smaller devices, many technologies and equipment, especially laser drilling systems (e.g., CO_2, Nd:YAG and excimer laser systems), have been gradually developed and extensively used in the field of printed circuit boards (PCBs) manufacturing for microvias drilling on different PCBs material systems, such as epoxy/glass [1], aramid/epoxy [2], upilex-s polyimide [3] etc. Additionally, the multilayer printed circuit boards (PCBs) have generally become the preferred manufacturing process [2] for the same purpose. Until recently, the substrate materials widely used in multilayer PCBs were brominated epoxy/dicyandiamide system [4], in which FR-4 ($T_g = 125$–135 °C, $D_k = 4.1$ and $D_f = 0.02$, where T_g, D_k and D_f stand for glass transition temperature, dielectric constant and dissipation factor at 1 MHz, respectively.) is a typical one, and widely used due to its excellent electrical and physical properties, which can match the electrical and mechanical requirements for most applications [4,5] even though something of a shortage, such as higher CTE (about 60 ppm/°C), still exists.

It is well known that the copper plate is recently the inter-connective layer of the multilayer PCBs. In order to match the increasing needs for denser circuit designs, the copper wiring in laminates is also becoming thinner, and the number of laminates has increased by stages; the coordination between the thermal expansion of the epoxy resin substrate and the printed copper wiring is thus becoming much more important in view of the stresses between them, and the reliability of the metalised holes. Because of the shortcoming owned by epoxy resin/glass fibers systems in thermal conductivity, and the coefficient of thermal expansion (CTE), many attempts have been actively made on promoting such properties of epoxy resin composites through adding fillers with excellent thermal conductivity [6]. Aluminium nitride (AlN) possesses a set of excellent properties, such as high thermal conductivity (319 W/mK), high electrical resistivity (5×10^{13} Ohm-cm), lower thermal expansion (4.5 ppm/K), and good mechanical

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properties at high temperature ranges [7]; it is thus widely used in many fields [8], such as in integrated circuits, higher voltage devices, electronic packaging [6] etc.

Recently, many investigations have focused on the laser drilling process of microvias on AlN films and the characteristics prepared by different laser systems, especially excimer, so as to obtain vias with excellent taper and to prevent any cracks [9,10]. Similar research has also been done for epoxy/glass and other PCB materials [11,12]. In our previous work [13], a novel epoxy resin/AlN composite with low CTE that was fitted for the application of laminate and lead-free PCBs was developed. To the best of our knowledge, little research has been done on laser drilling properties on this kind of composite. In this work, the main objective is to compare the properties of the blind vias drilled with Nd:YAG laser systems on pure epoxy and epoxy/AlN composite, including the taper and depth of the blind vias, their surface morphologies, and the relationship between them and the drilling parameters.

2. Materials and experimental equipment

The lasers widely used in PCBs process can be broadly classified into three types: CO_2, Nd:YAG, and excimer laser, in which the Nd:YAG laser can be highly absorbed by copper [14] and is suitable for small holes drilling [15]. Thus, the Nd:YAG laser system (Model ESI 5100) operated at 355 nm was applied to the blind vias drilling experiment and spiral tool was chosen in the present work. The details of this drilling model are shown in Fig. 1 [16]. The practical approach is that a series of 90° arcs of ever-increasing radius are drilled, and each arc has a radius equal to that of the previous arc plus one fourth of the radial pitch. The beam position moves in an arc to the center of the specified hole when the laser is off. At the center of the hole, the laser turns on at the specified repetition rate and the beam position moves in a widening spiral along the spiral path. When the specified number of revolutions is completed, the laser turns off and the beam moves either to the next hole location or, if the tool is repeated, back to the center of the circle.

The work pieces used in the present study were pure epoxy resin and an epoxy/AlN composite. The size and content of the AlN powders filled in the epoxy/AlN composite were 2.3 μm and 50 wt%, respectively. Before drilling, all the work pieces were polished and cut into squares of 25 mm in length and width. The average laser power, repetition times, and pulse repetition rate were varied from 0.2 W to 1.2 W, 12 to 48 and 3 KHz to 20 KHz, respectively. The specified diameter of the blind vias was kept at 250 μm as a constant. The front surface morphologies of the blind vias were examined by scanning electron microscopy (Leica, Stereoscan 440). Before SEM observation, all the samples were coated with gold film since epoxy resin and epoxy resin/AlN are insulation materials. The morphologies of cross-sections were observed with a Leica DMLM optical microscope; the value of width and depth was measured by Boeckeler IMG-100.

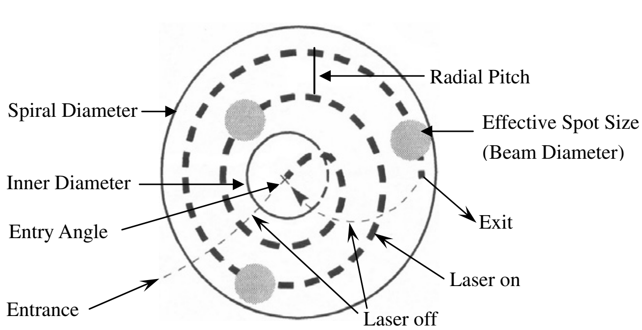

Fig. 1. Schematic representation of spiral tool.

3. Results and discussion

One of the evident differences of the vias punched with conventional mechanical process is that laser drilling results in a tapered shape; thus, the sharpness and morphologies of the blind vias are the key ones for laser drilling and should be carefully controlled. The ideal shape is shown in Fig. 2a, but as shown in Fig. 2b, the actual laser drilled blind vias are tapered, with the taper angle (α) calculated from the cross-section images by the following formula used to demonstrate the taper in the present work:

$$\alpha = \mathrm{arctg}\frac{(t_1 + t_2)/2}{d} \quad (1)$$

where d is the depth of the blind via, t_1 and t_2 are the distance from the tangent line of both edges of the via to the perpendicular line at the entrance on the bottom, respectively, as shown in Fig. 2c. A novel epoxy/AlN composite has been reported in our previous work [13] and optimised properties were obtained when the packing content of 2.3 μm AlN reached at 50 wt%. Table 1 summarises the typical values of pure epoxy resin and epoxy/AlN composite. It can be found that the performance of epoxy/AlN composite is much better than pure epoxy resin, except for the dielectric constant, especially in the aspect of CTE, which implies that this kind of novel composite is suitable for laminate PCBs. Even though many investigations have been done in the field of laser drilling processes on PCBs [17–19], it is still necessary and important to study the interaction between laser and epoxy/AlN composite.

The average laser power, pulse repetition rate, and repetition times of the Nd:YAG laser can strongly influence the morphologies of the blind vias, involving the depth, taper, surface morphologies of the entrance, and flatness of the bottom. The different substrate materials will of course influence the above mentioned properties significantly. Fig. 3 plots out the relationship between repetition times of laser percussion drilling and the depths of the blind vias in epoxy and epoxy/AlN composite, respectively, while the average laser power and repetition rate are respectively kept at 0.2 W and 3 kHz, respectively, as a constant. Fig. 3 shows that the depth increases linearly