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Laser direct fabrication of silver conductors on glass boards

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Abstract

Laser micro-cladding has been used to fabricate metal conductors, according to a designed electronic circuit, directly onto glass boards which had been coated with a silver-containing electronic paste. The electronic pastes, composed of silver powders, inorganic binders and organic medium, thus formed the conductive metal pattern (i.e. electric circuit) along the path of the laser allowing the rest of the layer to be removed subsequently by an organic solvent. Firing in a furnace at 600 °C resulted in conductive lines with resistivity of about 10^{-5} Ω cm and with adhesive strength of the order of magnitude of megapascals.

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Keywords: Laser micro-cladding; Electronic pastes; Laser direct writing; Silver conductor; Conductor formation mechanisms

1. Introduction

Nowadays, the manufacturing technologies of printed circuit boards (PCB) and thick film circuit boards (TFCB) are developed towards smaller sizes, higher density and shorter fabrication periods in the electronics industry. The shortages of conventional manufacturing methods for PCB and TFCB, such as photochemistry and stencil (or silk screen) printing, are becoming a bottleneck in small production scale and high-accuracy demands because of their complicated procedures, long development cycle as well as poor fabrication precision; the manufacturing cost for single piece and small-scale production is therefore relatively high. Moreover, once the boards are finished, it is basically impossible to modify them. In addition the processes used cause environmental pollution. Therefore, new manufacturing techniques are required for PCB, TFCB fabrication with the characteristics of high-speed, high-accuracy, high-density and maskless so as to lower manufacturing cost and to improve fabrication efficiency [1,2].

In the past ten years, thick film circuit fabrication on glass boards is finding wider application in the electronic industry, as the glass board has higher heat endurance than resin board, good acid and alkali resistance, and the material cost is much lower than that for Al_2O_3 ceramic boards. In the meantime, laser direct fabrication of conductive patterns on glass and ceramic boards is attracting more and more attention, since it can write the metal conductors directly with the designed documents with high precision and without masks.

Different types of direct writing techniques have been developed since the 1980s. For example, laser induced chemical vapor deposition (LCVD) has been used successfully to fabricate the conductive lines such as Au, Al, Ag as well as Cu lines on SiO_xN_y, TiN, GaAs and silicon wafer [3–6]. Generally speaking, LCVD for direct writing conductive lines has the advantage of high line densities, fine structures and narrow line width (the minimum width can reach 2 μm), but its main shortcoming is the low fabrication rate, which normally is about 10 μm/s. Moreover, the apparatus for LCVD needs gas exhaust and vacuum systems, which are too expensive for many users.

Besides LCVD, other methods have been developed, such as laser-assisted forward transfer [7], laser induced

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electro- or electro-less plating [8] and laser induced decomposition of metal-doped polymer films, [9] etc. Unfortunately, these methods also have similar disadvantages to those noted above for LCVD. Therefore, there is strong pressure to develop newer, safer, faster and cheaper conductor fabrication technologies.

In order to overcome the above-mentioned shortcomings of laser direct writing methods, we present the laser microcladding of electronic pastes method for fabricating metal conductors on glass substrates. In this paper, the detailed experimental procedure to fabricate the conductive patterns is described and the main physical properties (resistivities and strength between conductor and substrate) of the conductive lines are characterized. Particular attention has been focused on the mechanism of formation of conductive lines by this method.

2. Experimental details

In this experiment, Soda glass with a softening point of about 735 °C was used as the insulator board. Commercial conductive pastes were used as cladding materials, which were composed of inorganic binders (mainly low melting point glass powders with a softening point of about 600 °C and diameters of about 1–2 μm), thermosetting resin, sheet silver powders with diameters of 3–5 μm and organic medium.

The experimental procedure is as follows: firstly, the conductive pastes were coated on glass substrate using spin-coating. The coatings were dried in a 150 °C furnace. A Fiber Laser, with a maximum output 50 W was used to irradiate the coated glass boards with a minimum spot size of about 20 μm. The scanning track was defined by the computer-aided design software application documents and the laser processing parameters were chosen according to the thickness and compositions of the conductive pastes. The scanned track of the conductive pastes, which were irradiated by the laser beam melts, re-solidifies and adheres to the glass boards, while the paste in the other areas can then be removed by an organic solvent, thus leaving the conductive lines. A schematic image of this process is shown in Fig. 1. Table 1 shows the detailed experimental conditions.

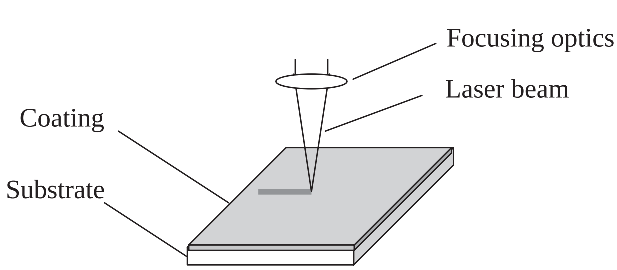

Fig. 1. Principle of laser direct writing electronic paste.

Table 1
Experimental conditions

Laser	Ytterbium fiber laser
Wavelength	1.07 μm
Power	0–50 W
Beam mode	TEM_{00}
Scanning speed of laser head	1–20 mm/s
Substrate	Soda glass (thickness: 1 mm)
Atmosphere	Air

Nikon Epiphot300 optical microscopy was used to analyze the macro morphology and measure the width of the conductive lines, and a JEOL JSM-5510LV Scanning Electron Microscope (SEM) operated at 30kV was used to characterize the compositions by Energy Dispersive Spectrometer (EDS) analysis and to obtain high magnification images of the conductive coatings.

A Dektak IIA profile meter with a precision of 50 nm was used to define the profiles of the tracks. DTA (differential thermal analysis) and TGA (thermogravimetric analysis) facilities were used to investigate the laser process in some detail. The 4-point probe technique was used to measure the resistivity of the conductive films. The adhesion strength between the resin substrate and the conductive lines was estimated by the following method: a conductor 2×2 mm square was fabricated on a resin substrate to which a wire was soldered. The strength was determined by applying tension to the wire and measuring the applied force when detachment occurred.

3. Results and discussion

3.1. Investigation of micro morphology and contour of conductors

Fig. 2 shows the morphologies of conductive coatings, from which it can be seen that the boundary and surface quality of wider lines are better than those of narrower ones. At present, we can fabricate the conductive lines with widths as small as 50 μm on glass substrates at a rate of 4 mm/s. Fig. 3 shows an SEM image of the cross section of the interface between the conductive coating and the substrate. There are no cracks in the conductive coatings and the conductors appear to be well adhered to the glass substrates. This suggests that the bonding between the conductive coatings and the substrate is similar to those made by the conventional methods sintered in a furnace. Fig. 4 shows the cross section contour of the conductive coating measured by Dektak IIA profilemeter, where it can be seen that the boundary of the coatings are very steep, and the thickness of the conductive coatings was about 20 μm and basically homogenous across the coatings.