Research on film thickness of conductive line formed by laser micro-fine cladding and flexibly direct writing technique

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The conventional technology could not fulfill the rapidly growing need for fine conductive lines for its inherent limits. Therefore, in this study laser micro-fine cladding and flexibly direct writing technique is used to obtain conductive lines with high precision and reliability. In the case of different substrates and parameters, film thickness will be different. Film thickness directly influences the reliability and stability of conductive lines with exception of quality and running speed. Therefore, we focus on developing the optimal parameters for the different substrates to achieve expected film thickness and make conductive lines have good performance and quality.

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It is a general tendency that electronic components and equipments are produced in tiny sizes, leading to hard requirement on fabrication of inner co-adjacent patterns. At present, the conventional screen-printing technology is usually adopted for the patterns generation, however, screen-printing has many shortcomings such as the corresponding paste with the substrate and line width, complicated process, long cycle, etc.. Especially, mask technology causes the line width to be limited in the range of 100−125 μm with bad marginal flatness[1]. All shortcomings seriously impact its application. A new direct writing technique was developed for solving the above problems. This approach simplifies the process, provides a rapid prototyping and agile manufacturing, but it has the disadvantages of costly equipments, difficultly controlled line width and film thickness, hard work environment, and narrow applied range, etc.[2−8]. At the same time, the traditional laser cladding technique has the merits of cladding film firmly bonded with substrate, low dilution rate between materials, easily controlled film thickness and width, small distortion, even and dense structure of film, and high productivity. Therefore, we combined the laser cladding and direct writing techniques and performed a novel technology, "laser micro-fine cladding and flexible direct writing technique" named by Professor Zeng[9,10]. Namely, adopting conductive pastes as materials of cladding coating, and then making use of laser scanning and combine computer assisted designing and manufacturing (CAD/CAM) function, it can flexibly directly write precise and densified conductive line with high resolution without the help of mask technology. It is proven to possess the prominent merits like high accuracy, easily controlled line width and thickness, wide applied range, flexibility, and efficiency. It cannot only be applied to the intelligent mass production but also generate and repair patterns.

Thickness of film has a decisive effect on the quality of conductive line, therefore, the relation between the thickness of conductive line fabricated on dielectric substrates and processing parameters should be carefully studied. The process flow of laser micro-fine cladding and flexibly direct writing conductive lines is as following. Making conductive coating on glass and ceramic substrates by rotating machine, drying, laser scanning, cleaning, sintering, and testing film thickness. Main principle of fabricating conductive lines is how to make use of the complex reaction between organic binder and low melting glass in paste when laser scans the coating. Moreover, the conductive phases or the conductive phase and substrate are welded together, the non-scanned coating keeps primary characteristic and breaks away from substrates when the substrates are appropriately cleaned, the laser-scanned coating adheres on substrates, conductive lines are formed on the substrates.

In this paper, 1.07-μm optic fiber laser is adopted, whose least spot diameter is 20 μm and peak output power is 50 W. Conductive paste is mainly composed of silver system. The laser manufacturing system (LMS II) was developed to perform laser micro-fine cladding and direct writing. Sodium-calcium glass and Al_2O_3 (purity 96%) are used as substrate materials, the substrate thickness is 1 mm. By adjusting processing parameters, laser micro-fine processing is done. After heat treatment, film

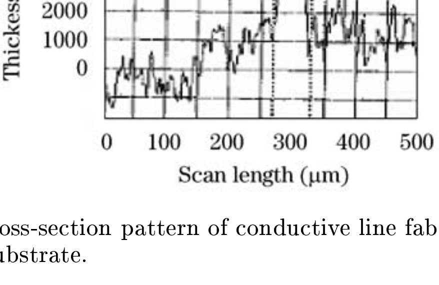

Fig. 1. Cross-section pattern of conductive line fabricated on ceramic substrate.

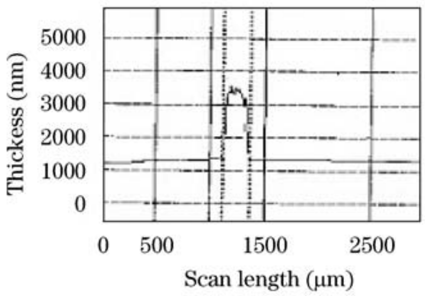

Fig. 2. Cross-section pattern of conductive line fabricated on glass substrate.

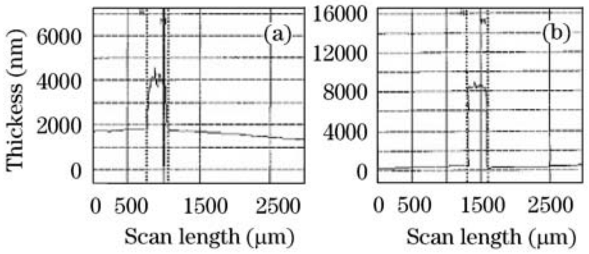

Fig. 3. Cross-section pattern of conductive line fabricated with different thinners. (a): 20 wt.-% thinner; (b): 15 wt.-% thinner.

thickness of conductive lines is tested by surface profilemeter.

Figure 1 shows the cross-section pattern of conductive line fabricated on ceramic substrate. Here Al_2O_3 is used as the substrate material, the other parameters are: laser power 10 W, laser scan velocity 1 mm/s, defocused length −4.675 mm. From the experimental results shown in Fig. 1, it can be seen that because of the bad surface finish of ceramic substrate, the film surface of conductive line appears large fluctuation, which leads to the big change of film thickness so that the response and running speed of the circuit are not stable or reliable, therefore we ought to strictly control the roughness of substrate.

Cross-section pattern of conductive line fabricated on glass substrate is shown in Fig. 2. Here sodium-calcium glass is used as substrate materials, the processing parameters are the same as those for ceramic substrate. From the experimental results, it can be found that the thickness of film on glass substrate will be decreased under the same circumstance.

From Figs. 1 and 2 we can see that using different molding technologies and different substrate materials, the performances of conductive lines got under the same conditions are very different. The main factors influencing film thickness are the surface structures and property of substrate. Because the ceramic substrate has a reticular stereo microstructure, its surface contains lots of holes and surface finish is bad. This results in the bad evenness of film thickness, and reduces the ultimate performance and quality. The experimental results show that film average thickness is 3690.1 nm on ceramic substrate and 3033.1 nm on glass substrate under the same conditions. Namely, film thickness on glass substrate is smaller. The thinner the film is, the higher the performance of components is. Therefore, glass substrate can be selected to replace for ceramic substrate to improve the running and response speed of components with high reliability and stability.

Viscosity of the paste is different due to different contents of organic thinner and decreases with the increasing contents of thinner. This results in the different flowing property of liquid composite matter so that the film thickness and property of conductive line have a great discrepancy. Considering the influence of thinner on the performance and quality of conductive line, we chose the main parameters as: laser power 15 W, scanning velocity 5 mm/s, defocused length −4.675 mm. The experimental results are shown in Fig. 3. Viscosity of the paste is deceased while increasing the content of thinner, and the flowing power is enhanced in course of rotated action. From Fig. 3 we can find that with the decrease of viscosity of paste, film thickness of conductive line is reduced, e.g. the film average thickness is 3661.1 nm in Fig. 3(a) and 8211.5 nm in Fig. 3(b). However, the increase of content of thinner results in the low main functional phases and solid contents per unit volume, bad film compact property, and bad conductive property. To solve the above problem, a given viscosity of paste should be used to achieve good film compaction.

Figure 4 shows the cross-section pattern of conductive lines fabricated with different defocused length. Spot size of laser action on film surface is extended with the increase of defocused length, and the absorbed energy per unit volume of film is decreased. It will influence the film thickness and final properties of conductive line. Accordingly we change the defocused length to evaluate the film thickness of conductive line with the following parameters: laser power 5 W, scanning velocity 1 mm/s, and thinner ingredient ratio of 20%. The experimental results in Fig. 4 show that the film average thickness is 1857.6 nm with −4.675-mm defocused length, while it is 3531.5 nm with −8-mm defocused length. That is to say, the bigger the defocused length is, the thicker the film thickness is.

The relationship of conductive lines with different laser scanning velocities are indicated in Fig. 5. The parameters are chosen as: processing power 15 W, defocused length −4.675 mm, thinner ingredient ratio of 20%. The film thicknesses are 1995.7 nm in Fig. 5(a), 3661.1 nm in Fig. 5(b), and 4107.9 nm in Fig. 5(c), respectively. This shows that the film thickness increases with the increase of scanning velocity. When the laser scanning velocity increases, the time that laser acts on the film will be reduced so that the energy and matter deliveries cannot perform completely. Lots of organic matter is

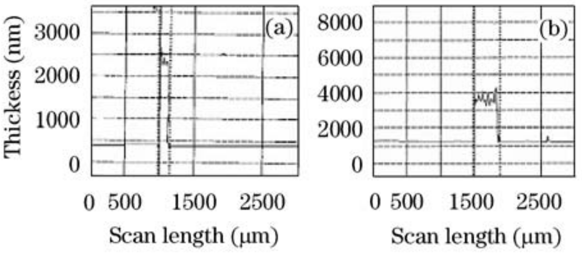

Fig. 4. Cross-section pattern of conductive line fabricated with different defocused lengths. (a): Defocused length is −4.675 mm; (b): −8 mm.

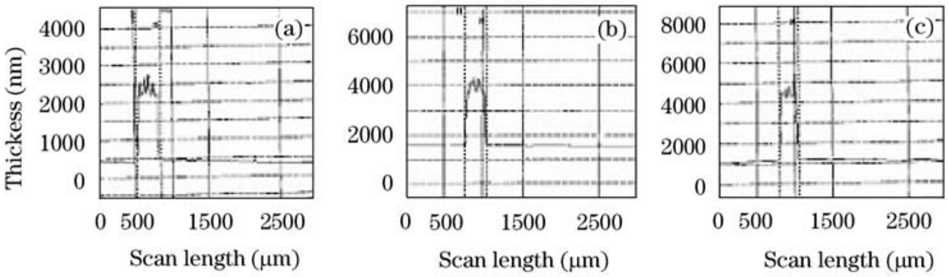

Fig. 5. Cross-section pattern of conductive line fabricated with different laser scanning velocities. The scanning velocity is 1 mm/s (a), 3 mm/s (b), and 5 mm/s (c), respectively.

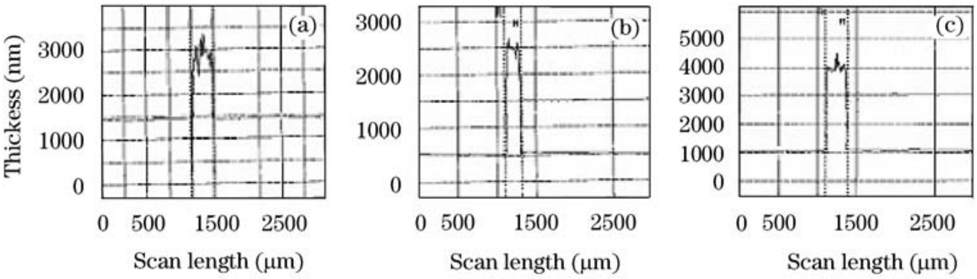

Fig. 6. Cross-section pattern of conductive line fabricated with different laser powers. The laser power is 15 W (a), 10 W (b), and 5 W (c), respectively.

remained in the film. The composite, solidified reactions between organic high polymers as well as volatilization and combustion are not enough so that shrinkage action is reduced. Solid binder is liquefied. The main functional phases are extremely separated and the film thickness increases.

Figure 6 shows the relationship of film thicknesses with laser processing powers. The following parameters are adopted: scan velocity 1 mm/s, defocused length -4.675 mm, thinner ingredient ratio 20%. The film thicknesses are 1990.0 nm in Fig. 6(a), 2199.7 nm in Fig. 6(b) and 3781.5 nm in Fig. 6(c), respectively. This shows that film thickness decreases with the increase of laser power. With the increase of laser power, energy acting on the film enhances, the composite, solidified reactions between organic high polymers as well as volatilization and combustion are enough and shrinkage action is improved, the film thickness is reduced.

Organic solvent is volatilized a lot when the conductive pastes are evenly coated on substrates in the rotating machine and dried in oven. Organic binders react with each other in the course of heating and come into new polymers which adhere solid particles to substrates, films are contracted and solid particles are pulled tight, but the course is minor to the properties of ultimate conductive lines. The interaction between laser and matter is a course of rapid heating and cooling when laser scans dried films, complex reactions will lead to the different properties of conductive lines, so the mechanism of laser interacting with conductive film should be primarily studied When laser scans dried films, they absorb energies and the organic solvent is volatilized and combusted. The low-melting glass binders are softened and melted, and then recur to capillary force and flow along the boundary of conductive particles to fill up pores remained by organic substances. The glass liquid goes down because its density is higher than that of conductive metal particles, so that it can hardly be adhered between conductive particle and substrate. Simultaneously, the conductive particles rise and are rearranged, the films are contracted further more so that the compactness of film is improved.

Combining the mechanism of laser interacting with conductive films, the above experimental results show that different film thicknesses of conductive lines are obtained when substrate, film materials, and work condition are changed. It will lead to the circuit difference in running and response speeds, reliability, and stability. For ceramic and glass substrates, the structures, properties, and interactions with laser and film materials are different so that the different film thickness will be got. However, the main factors affecting film thickness are the transmission coefficient (ceramic substrate: 72 W/mK; glass substrate: 0.76 W/mK)[11] and surface finish. The former controls the interaction of laser and film and the latter controls the course of film forming. Because ceramic has a three-dimensional (3D) network structure, surface finish is bad and its friction force with paste is big, lots of pores exist on the surface. Big friction resistance makes the contents of paste staying on substrate increase, so that the film is thicker. Glass substrate has a better surface finish than ceramic substrate because it adopts the float molding technology. Less contents of paste stay on substrate so that the film is thinner. Therefore, we chose glass substrate to obtain optimal work condition. The viscosity of paste is lower and the flowing power is higher when content of thinner in the paste is considered. So the film of conductive line turns thin. However, contents of main functional phases and solid binder per unit volume are lessened with the increase of content of thinner. The compact property and conductibility of film is reduced. Paste distributes on the whole substrate surface after rotating operation. Organic solvent with low melting point is volatilized in the course of drying and organic matter takes solidified reaction and comes into high polymer. The film is shrunk and solid phases are strained. Film thickness is decreased again. In the subsequent process of laser scanning, the energy of laser acting on the film is high when the scanning velocity is lower and the laser power is higher (or the defocused length is less). The reaction between film materials or film and substrate are performed abundantly, organic matter is volatilized entirely. Flowing and filling action of solid binder phases is enhanced so that shrinkage degree of film is enhanced and the thickness is decreased. Therefore, the thin film is got and the performance of conductive line is improved.

In conclusion, we can reach the following conclusions, conductive lines has been successfully fabricated on glass substrate by the technology of laser micro-fine cladding and flexibly direct writing. This technology is simple and flexible. Moreover, combined with CAD/CAM, it can fabricate conductive lines with high precision, resolution, and stability without the need of mask. The conductive lines fabricated on glass substrate under different conditions can meet the requirement in electronic industry.

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