DESIGN AND PRODUCTION OF PRECISE THICK FILM CIRCUITS USING PHOTOLITHOGRAPHIC TECHNOLOGY

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Fodel® Photoprintable Thick Film Pastes made by DuPont guarantee that printed circuits made by using these pastes benefit from both the recognized reliability of ceramic materials and the higher image density that is common for the thin film circuits by increasing the density in the X-Y plane by 400-500% compared to the conventional screen printing process. This is achieved without a reduction of technological tolerances by improving lines and spaces resolution and by reducing the size of vias. In this paper we are going to review the design and fabrication of a multichip module (MCM) by using photolithographic methods to create thick film layers in hybrid circuits.

Keywords: Fodel® Photoprintable Thick Film, photolithography, thick film hybrid integrated circuits.

1. INTRODUCTION

The need of increased functionality of ICs while reducing their sizes at the same time is motivating manufacturers to increase image density in the X-Y plane and the number of layers in the Z-direction. Currently, typical multichip modules (MCMs) manufactured by using thick film technology have density of lines, spaces, and vias of about 20 mills (0.5mm) and 5-6 conductive layers. Higher density is achieved by increasing the technological safe clearance admissible for such materials.

To combine low cost of screen printing technology and high density provided by materials for thin film circuits in the production of a thick film circuits is a challenge. The advancement of materials used for thick film circuits influences the improvement of resolution of pastes printed over thick film circuits and in most cases improvement is apparent in reduced lines width and reduced lines spacing, thus considerably reducing the overall surface of the hybrid integrated circuits (HIC).

Fodel® Photoprintable Thick Film Pastes by DuPont provide density of the thick film technology for circuit production, which is comparable to the density of thin film materials. Such performance is achieved by combining thick film inorganic materials with photoactive materials. Fodel® materials use the inorganic constituents such as in conventional thick film technology-metal powders, metal oxides, glass powders and refractory materials, as the backbone of the composition and as source of the final performance properties after the circuit is fired. The organic components used on photoresistive films - polymers, photoinftiators, monomers and stabilizers - are added to these inorganic materials and provide the photolithographic patterning capabilities of these pastes. They are easily processed in practice, using ultra-violet (UV) light exposure and mild aqueous carbonate solutions for circuit pattern formation. Under these conditions polymerization or crosslinking of that particular polymer chain is accomplished. When lit up with UV light irradiation, the radical crosslinking reaction is completed and insoluble negative image of the original pattern is formed (so called "latent image") from the Fodel® paste. The "latent image" is not visible until it is developed in an appropriate solvent, which dissolves and removes unused paste from the substrate. Using the photographic method with Fodel® Photoprintable pastes provides undistorted image of layers. Elimination of distortion can be particularly beneficial for the attachment of components on the superficial layers. This improvement allows for circuits with higher density to be produced as compared to using thick film circuit production methods or other conventional technologies.

The technology using Fodel® pastes is easy to use, requires a small capital investment and it is susceptible to automation. [1], [2]

Fodel® 6778 silver-palladium conductor is a photoprintable thick film composition specially developed to be compatible on alumina substrates and low-temperature cofire ceramic, which makes possible achievement of a very high circuit density. Minimum allowed line width is 0.05mm and minimum allowed line spacing is 0.05mm. It features very low specific resistance (5mΩ/□) and viscosity of 40-100 Pa.s, without image distortion and good solder acceptance. [3]

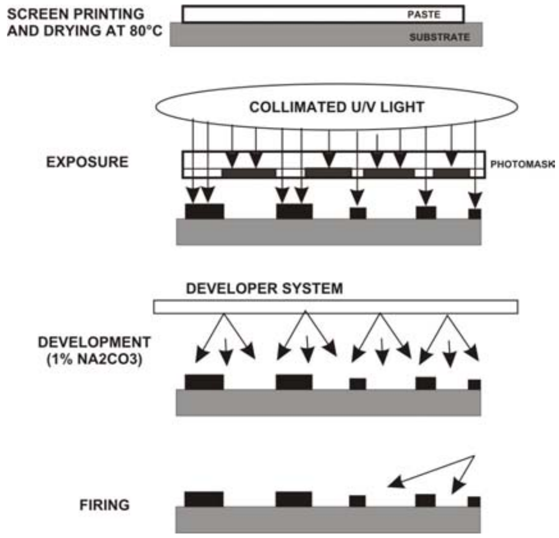

Figure1. Fodel® processing sequence

Fodel® pastes processing as technology is a combination of the conventional thick film process and photoimaging (screening). The process sequence is given in block-diagram in Figure 1. [4]

2. Problem Statement

A customer has requested us to design and produce a printed inductive element that shall meet predetermined electrical criteria and parameters and at the same time shall be fitted on the smallest surface possible.

The parameters that were obtained after constructive calculations for the inductive element are as follows:

- Geometrical form: Archimedean spiral with 100 spins
- Width of printed conductor lines: 70 μm
- Spacing between lines: 80 μm

The center and the end of the spiral are connected to output lead pads that will be used for cable soldering for further building-in of the coil in the modular system. Conventional conductive paste thick film HICs by DuPont is used for the pads. Fero's 7015c dielectric is printed between the first conductor of which the "body" of the inductive element is formed and the second conductor that makes the output lead pads

In order to minimize element's surface, conventional printed conductors that are used in thick film process are replaced with silver conductor 6778 by DuPont.

Because of the required high precision and because of difference in techniques used to screen print each layer, a great deal of attention needs to be paid to correct alignment of layers by means of printed alignment marks which are set in appropriate places in the photographic mask (photomask).

3. MANUFACTURE AND TECHNOLOGICAL PROCESSES. PRODUCTION RESULTS.

In order to optimize production process the following requirements of conductive paste's producer were observed:

Light used: To prevent accidental polymerization, Fodel® materials should be handled under yellow or amber light, where no UV or blue wavelengths are present. Such lighting conditions were used at every place where pastes were printed, dried, exposed and developed.

Thinning: This composition is optimized for screen printing and no thinning is required. In case of losses from evaporation, the manufacturer recommends slight adjustment with thinner 9450 to achieve required viscosity.

Substrates: DuPont recommends using Alumina 96% substrates. Substrates of other compositions and from another manufacturer may adversely effect the precise screening of image.

The work that has been done to design and manufacture the product, while strictly observing the existing manufacturing technologies and recommendations of the materials producer, was done in the following order:

- First screen printing with conductor by Fodel®

Design of photomask: We designed a photomask to screen print conductive paste Fodel® 6778. Two 0.5mm alignment marks with square shape are placed on the mask image. These marks are at 0.05mm from the edge of substrate. Distance between the alignment marks should be at least 40mm according to requirements of photolithography tools maker. Two alignment marks are placed on the mask for the first photolithography as well. The photomask, as it was designed, is shown in Fig. 2.

Screen Printing: Before screen printing of paste we carefully mixed it by hand for 1-2 minutes using a clean burr-free spatula. Screen printing is done at room temperature (20°-23°C). A single layer of conductive material is printed with a 200-mesh (40µm wire) or 280-mesh (30µm wire) stainless steel screen. The print speed we used was about 2-3 inches/second.

Drying: Fodel® pastes, as opposed to standard thin film pastes, contain photoinitiators and monomers to form pattern. Part of material components are temperature sensitive and can not be exposed to temperatures of 120°-150°C while drying, as this is done with standard thick film pastes, therefore they are dried at a lower temperature. After screen printing, the printed layer is dried for 15-25 minutes at 85°C in a well-ventilated oven or on a conveyor drying equipment. It is important to mention here that a higher temperature or drying for a longer period would reduce photosensitivity of material.

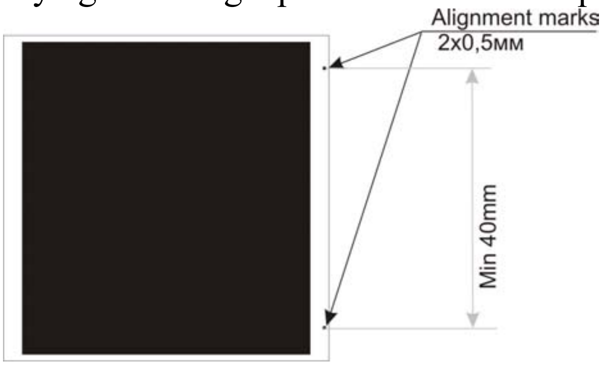

Figure2. Photomask for first screen printing

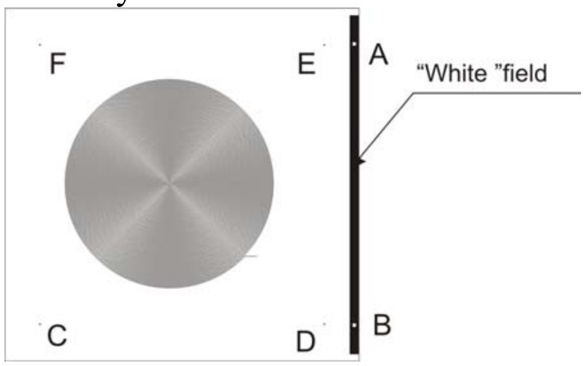

Figure3. Photomask for first photolithography

- First photolitography

Design of photomask: The photomask was designed as a positive image which is later turned into a negative by means of photo processing because Fodel® pastes are negative-active, i.e. the sections of image which are exposed to UV light become unsolvable during the process of development. Two 0.52mm alignment marks (A, B) are placed on the mask. Once the mask image is turned into a negative, they become white and envelop the marks from the first screen printing. Marks are used for rough alignment of the photo-lithography mask over the layer that was screen printed so that no shift from orthogonal axes occurs. Because the positive mask will be turned into a negative, the alignment marks become "black" and so that it could be seen where they cover the alignment marks of the first screen printing, we have designed them in a "white" field, otherwise they may not be visible when screen printed pattern is covered with the photomask. Alignment marks C, D, E, and F – 4 x .2mm will be used to align the two photolithography layers. The mask for the first photolithography is shown in Figure 3.

Photolithographic process is done in two stages – exposure and development.

Exposure: We expose the paste printed over the substrate (18-24 μm dried thickness) with the appropriate photo tool using Hg ultraviolet light source with wave length λ=365nm. The recommended exposure energy range is 500-1200 mJ/cm² depending upon desired line and spacing resolution. UV light with mentioned wave length is absorbed by the photoinitiator components which lead to polymerization of radicals by hydrogen abstraction. The radicals thus formed then react with the carbon-carbon double bonds of the monomer molecules, forming a new radical that grows a polymer chain. These steps are referred to as "initiation". After that these radicals can undergo second reaction with monomer molecules extending in the polymer chain multiplying themselves in series of processes.To expose pattern we used photolithographic tool made by Karl Suss Company. (Exposure time is directly dependent on the power of lamp in exposure photolithographic tool; in this case exposure time was set to 500 seconds.)

The development step completes the pattern formation on the substrate. Chemistry mechanism of this development step is the following: Carbonate reacts with carboxylic acid that is present as organic binder in the Fodel® paste, neutralizing it and forming carboxylate salt that can then be hydrated and dissolved in the aqueous developer. When the organic binder or the "glue" of the Fodel® paste is dissolved and removed from these areas, the discrete inorganic particles are also removed by water. Polymerized areas of the pattern withstand developer's action because in these areas a three dimensional polymer matrix was formed during exposure and it is preventing removal (washing away) of the image. We make the development with 0.6-1.0% Na_2CO_3 solution at 27-30°C. Total development time depends upon thickness of Fodel® paste. After development we removed non-exposed material from substrates with water and dried them with warm air.

Firing: The next step of technological process is firing. We work with Fodel® materials in the same manner as with conventional thick film materials – approximate time for firing is 60 minutes with a peak firing temperature of 850°C maintained for 10 minutes. These firing conditions are sufficient to remove the photosensitive contents of material.

- Second screen printing with conductor by Fodel®

We made the second screen printing with the conductive paste observing the same technological guiding principles: printing and drying. This screen printing process prepares substrate for second photolithography. There are two reasons to perform two photolithographies: first, to obtain optimum thickness on conductive layer and second - to avoid breaking of wire (lines) in case that there has been undesired pollution on substrate in the course of exposure or development. When the photomask was designed, the alignment marks that were already placed on substrate during first photolithography and which must stay outside of printable area, were taken in consideration. It is very important here to correctly align both photolithography patterns. The photomask for second print screen is shown in Figure 4. Figure 5 shows substrate's photography as conductor paste was printed on it for the second time.

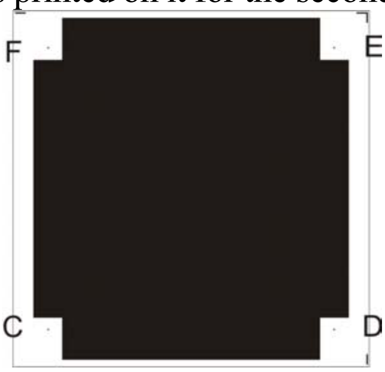

Figure4. Photomask for second screen printing

Figure5. Substrate after second screen printing-photography

- Second photolitography

Design of photomask: We create new 4 marks to align this printing with next layers. Marks C, D, E, and F are placed in "white field" so that they remain visible when the negative photomask is applied onto substrate. We enlarge their dimensions to 0.22mm to envelop the marks from the first photolithography. The technology process is the same as the first photolithography. As a result we obtained conductive layer with thickness of 17µm after firing.

Next step in manufacture of MCM is consistent with to technological process of thick film hybrid integrated circuits production: we screen print dielectric, second type of conductor and encapsulant.

For maximum protection against environmental conditions low temperature glass encapsulant QQ550 or high temperature glass encapsulant 8190 are recommended to cover 6778 conductor lines. The result, the completed substrate, which satisfying to the given condition, is shown in the picture in Figure 7.

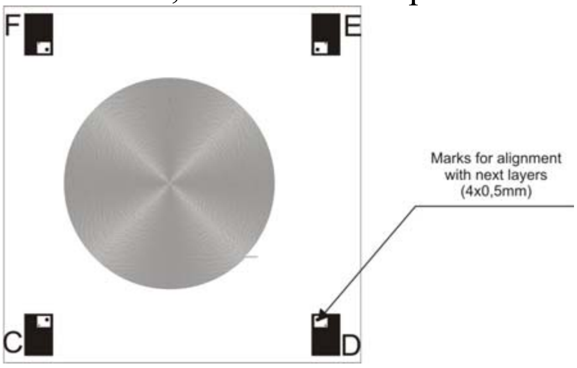

Figure6. Photomask for first photolithography

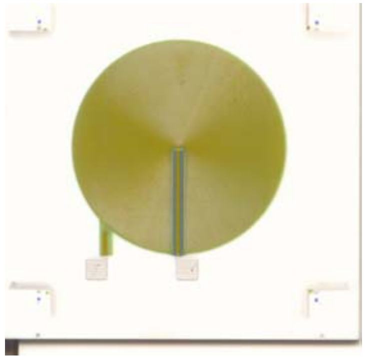

Figure 7.

4. Conclusion

The need for increased density, improved performance and reduced cost in electronic components and packages continues to drive innovations in the electronics industry.

By using photolithography pastes Fodel® we combine thin film technology of printing the paste (by screen printing) with the accuracy of photolithography as we find out following advantages of this method:

- The technological process is inexpensive and it doesn't require big capital investment and doesn't contain procedures that are difficult to carry out.
- We easily combined Fodel® pastes with materials commonly used for creation of thick film circuits – pastes and substrates.

The main result of using these pastes is that we have drastically reduced photolithographic image's surface and as a consequence – the surface of the entire multi chip module. This has led to reduced manufacturing costs. It will inevitably lead to further wide spread use of this type of photolithographic pastes in the production of thick film circuits.

5. References:

[1] DuPont Microcircuit Materials – "Fodel® Advantage. Thick film Photoprintable Compositions"-web pages; http://www2.dupont.com

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[3] DuPont Electronic Materials-"Ceramic Circuit Materials and Technologies, Fodel® 6778 Conductor, Photoimageable Thick Film Compositions" web pages; http://www2.dupont.com/MCM/en_US/products/fodel.html

[4] „Fodel® Photoprintable thick film; Material and processing" – Terry R. Suess, Michael A. Skurski. Proc. SPIE Vol. 2105, Microelectronics, proceedings of the 1993 International Symposium. Edited and Assembled by the 1993 Technical Program Committee and ISHM Staff, p.483