LTCC-based Ceramic Substrates for Identification of Trustworthy Electronics

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***Abstract* — The technology of low temperature cofired ceramics (LTCC) is already established in the production of reliable and robust electronic assemblies (e.g., multi-chip modules, system-in-package) as well as in safety-critical areas. With the incorporation of additional features based on surface profiles modular protection functions and barriers will be developed as a contribution to trustworthy electronics. Both obvious and hidden structures are investigated in a modular way, which in combination ensures a one-to-one tamper-proof identification.**

Keywords — trustworthy electronics, obvious and hidden structures, embossing, LTCC

I. Background

In an increasingly digitalised world, electronic counterfeiting and manipulation pose a great threat to the sovereignty of companies and business locations and the security of society, possibly accompanied by significant economic losses [1, 2]. In the research project VE-CeraTrust identification and modular protection functions and barriers will be developed and investigated as a contribution to trustworthy electronics. Low Temperature Cofired Ceramic (LTCC) multilayer technology is applied for special applications, e.g., which requires long term stability, harsh environment stability or active cooling. The embossing of LTCC-tape has been demonstrated already in several investigations [3,4]. Nevertheless, additional equipment or processing steps did not lead to commercial application.

II. Motivation And Experimental

A. LTCC Manufacturing

The scope within the project is to incorporate additional security and functionalities during the running production, without time or cost intensive processing. The tape casted unfired ceramic material is used to build up multilayer boards with integrated current lines, filled vias and passive components. In Fig. 1 the process flow of low temperature cofire ceramic (LTCC) manufacturing is shown. Punching equipment is widely used for the creation of vias which were finally filled by screen printing method. The so called green tape consists of alumina and glass powder mixed with organic components acting as binder and plasticiser agent [5].

Several paste systems on the basis of gold or silver for current lines are available. Furthermore milling (not shown in Fig. 1) can be applied to build up cavities after lamination. The ceramic substrates are sintered typically within box furnaces at approx. 850°C peak temperature. In addition, layers on top may be screen printed and treated in postfiring processing followed by optical inspection, electrical testing and singulation of the modules.

In the last 25 years many designs and different applications for LTCC were realized by VIA electronic GmbH. The adaption of design, adjustment of processing parameters or the selection of material system are considered to realize the best performance and high quality in the final product and application.

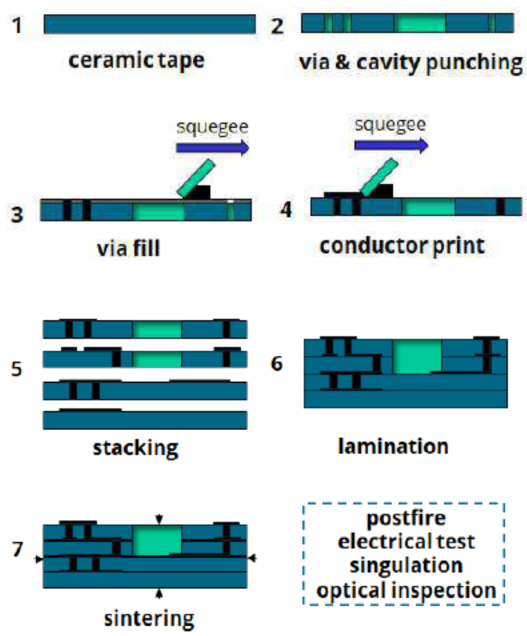

Fig. 1. Process flow of LTCC manufacturing: before or after step 3 or before step 7 embossing was applied (using punching equipment).

B. Embossing of Tape

In LTCC technology the green tapes with typical thicknesses from 50µm up to 250µm are punched to realize vias or cavities, this means through holes are created with pins typically in a range from 50µm up to several millimeters in

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diameter or opening. In our investigations we used a standard punching equipment from KMS to create a defined surface pattern by embossing the pin into the surface of laminated layer stack (two or four layers of laminated green tape). The LTCC material were used, namely Micromax™ GreenTape™ 951PX from company Celanese ("951") and green tape from KOA Group Japan ("KGS") with nominal thickness of 250µm and 160µm. The tapes were laminated with standard processing parameters to achieve a typical layered stack.

The embossing with the pins created a plastic deformation of the green tape in the shape of the pin itself (cylindrical bore with dead end). Pattern were realized by multiple embossings, e.g., lines by pitches lower then the pin diameter. Different pitches were applied to investigate the readability and improve the topology after sintering (e.g., 90% and 110% of the pin diameter). The pattern were related to data matrix codes with 16 x 16 „cells" and the name of the project „VE CeraTrust" (see Fig. 2). The size of the data matrix codes differs with the pin diameter (100µm, 80µm and 50µm) and by the applied pitch.

Fig. 2. Data matrix code used as reference for the embossing, "VE VeraTrust" (vertically flipped)

In addition, three different target values of embossing were investigated to evaluate the robustness of the green tape. Due to the fact that the depth of embossed cells differs within the data matrix code according to close proximity of cells (embossed / not embossed cells) a range of achieved depth will be reported. The target value of embossed depth were: 10µm / 40µm / >50µm.

The embossing of the tape was realized at three different processing steps in the LTCC process flow (see also Fig. 1):

1. Embossing after lamination → sintering
2. Screen printing of paste → embossing → sintering
3. Embossing → screen printing of paste→ sintering

III. Inspection Methods

Optical inspections were applied with standard equipments, which are available for production such as optical and digital microscopy (e. g. Keyence VHX-7000). The depth of the cells of embossed data matrix codes were measured with laser scanning microscopy at IKTS to verify the measurements achieved by optical inspections.

In addition, X-ray microscopy (Cheetah System from the Company Comet Yxlon GmbH) was applied by IKTS, Dresden. The background of this measurement was to evaluate and detect optically „unvisible" data matrix code pattern, which were covered with metal paste after embossing (embossing → screen printing of paste → sintering). The embossed cells of the data matrix code were filled with metal paste after the embossing.

The readability of the embossed data was checked with Keyence SR-X100 code reader, adapted with optical lens. The analysis was supported by AI software algorithms. However, lighting plays the important role and best performance was achieved with dark field illumination approach.

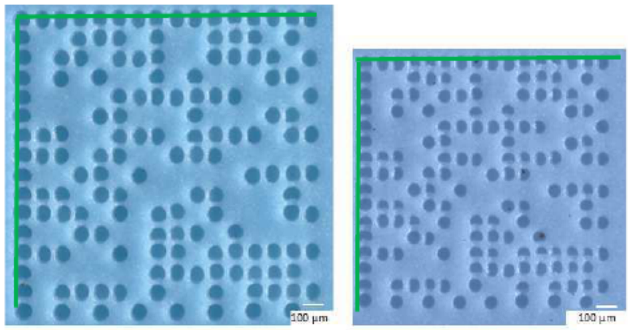
IV. Results And Discussion

The typical shrinkage in lateral direction and related thickness of the substrates were detected after sintering.

The results of three different embossings within the process flow, as described in section II, are reported in the following.

A. Embossing of Tape followed by Sintering

In the first experiments embossings were performed with 100µm and 80µm pin diameter in GreenTape™ 951PX, see Fig. 3.

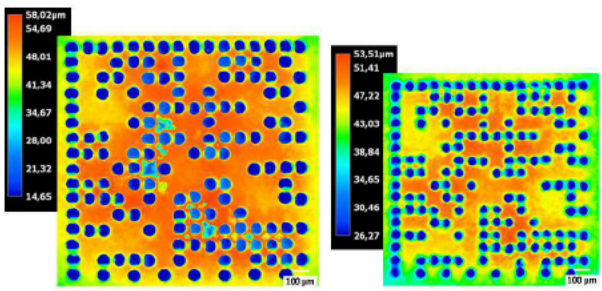


a) b)

Fig. 3. Embossed data matrix codes in Micromax™ GreenTape™ 951PX after sintering, 110% pitch between the cells: a) 100µm pin diameter (dimensions≈1.4mm x 1.4mm), b) 80µm pin diameter, (≈1.2mm x 1.2mm)

In the finder pattern at the top and left side of the code (highlighted by green line) the reduced pitch results in slight deformation of the former cylindrical cells. Nevertheless the code was successfull readable with the described equipment and software.

The embossed depth measured with laser scanning microscopy and optical microscopy were in the range of 30µm to 45µm (see Fig. 4) after sintering.



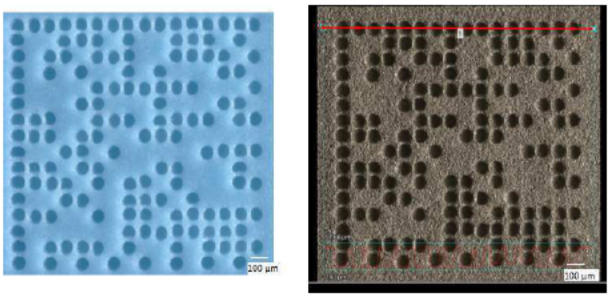
a) b)

Fig. 4. 3D images of data matrix codes after sintering, a) 100µm pin diameter, b) 80µm pin diameter, samples corresponding to Fig. 3

With the variation of embossing depth the plastic deformation of the tape increases. In case of target values of embossing depth >>50µm the deformation and risk increase to destroy the green tape. This leads to particle generation and for some cells tape material is pressed into the neighbouring cells. Thus, the control and monitoring of the embossing depth will be of high interest in the upcoming investigations.

B. Screen printing of Paste followed by Embossing and Sintering

To increase the flexibility and readability of the data matrix code we investigated the embossing of metal paste on top of the green tape. The metal paste was screen printed and dried with standard conditions followed by the embossing of the data matrix codes. The achieved layer thicknesses of the metal paste were printed layer: ≈26µm, dried layer: ≈13µm, sintered layer: ≈8µm. Fig. 5 shows optical images without and with applied metal paste.



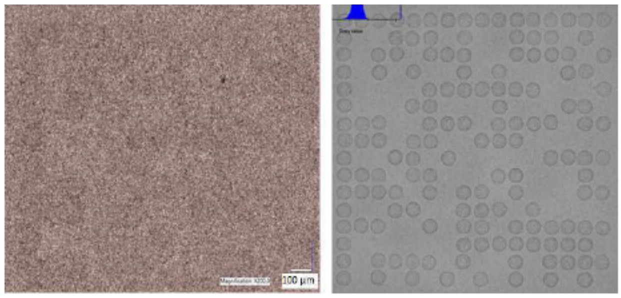
a) b)

Fig. 5. Embossing of data matrix codes a) without and b) with metal paste as top layer, 100µm pin diameter, optical image after sintering

The embossing was successfully achieved on the layer stack as a combination of plastic deformation of paste and tape material in one processing step. The embossing depth was not significantly changed or reduced due to the metal paste. The readability was successfully approved for this type of embossing as well. As a conclusion the embossing of dried metal paste is feasable within the described parameters.

C. Embossing followed by Screen Printing of Metal Paste

The starting point of the investigations were embossed data matrix codes in green tape with lowest embossing depth of approx. 10µm. This type of data matrix codes were covered by screen printing with a homogenous metal paste layer and corresponding thickness of printed layer: ≈26µm, dried layer: ≈13µm, sintered layer: ≈8µm. The scope was to fully cover the matrix code and prevent any detection via optical inspection. After sintering the samples were investigated by X-ray microcopy by IKTS, Dresden - Fig. 6 b) shows typical images.



a) b)

Fig. 6. a) optical image of data matrix code covered with metal paste after embossing, b) X-ray inspection image, 100µm pin diameter

Comparing the two images in Fig. 6 we conclude that the coverage was successful and hidden structures can be easily incorporated into the LTCC technology to increase truthworthy of electronics. These structures might be detected only by high efforts or intensive reverse engineering and may work as individual security features to track products.

V. Conclusion

The embossing of green tape and the creation of readable data matrix codes within the standard process flow of LTCC technology was demonstrated. Standard punching equipment was used and lowest pin diameter of 50µm was applied. The embossing depth below 50µm results in stable processing. To increase the contrast and readability also embossing of dried metal paste layers on top was investigated.

The coverage of embossed data matrix codes with metal paste was successfully shown and hidden structures can be easily incorporated into the ceramic substrates, which might be detected only by high efforts or intensive reverse engineering and may work as individual security features for products and minimize the risk of counterfeiting.

Acknowledgment

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