Micro-fluid Channel Embedded in LTCC Board Using a Low-Cost Fabrication Method

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Abstract. In electronic communication device fabrication, the high density integration of chips and devices in board requires the board to have good heat dissipation performance. Embedding micro-fluid channel into LTCC board is an optimal way. In this paper, a low-cost fabrication method of LTCC board with embedded micro-fluid channel was proposed. The experimental results demonstrated the effectiveness of this method for preventing the micro-fluid channel from excessive deformation or collapse. Owing to use silver pastes instead of gold pastes, the fabrication cost of LTCC board was reduced by more than 20%, which would promote the application of LTCC boards in commercial use, such 5G communication and embedded systems.

Introduction

Low Temperature Ceramic Co-fire (LTCC) technology is a multilayer interconnection board fabrication technology, containing the main process of via/cavity formation, via-filling, conductor printing, lamination and Co-firing. Owing to the advantages of low thermal expansion, low transmission loss and low dielectric loss, which are suitable for the use of high current, high temperature and high frequency communication, LTCC board has been widely used in space communication, image processing and microsystem integration. In microsystem integration, the passive components and chips are highly integrated in board, which raise a problem for the heat dissipation of board. To solve this problem, integrating micro-fluid channels in board is an optimal way.

So far, the researchers have made encouraging works for integrating micro cavity and fluid channel in LTCC board. Tick T et al. used pressure-assisted sintering to integrate micro waveguide cavity in LTCC board for 160GHz waveguide antenna [1]. To form the micro waveguide cavity, they formed the cover, wall and bottom of the cavity separately through lamination process, then bonded the three separate parts together and sintered to form a 1.3mm×0.615mm micro waveguide cavity. Hansu Birol made a micro pressure sensor with accuracy up to mN [2]. The sensor was made by LTCC board, embedded a curve micro-fluid channel with the length of 3mm and arch height of 0.02mm. Gongora Rubio et al. used sintering shrinkage control technology to make a micro gas flow sensor with micro-fluid channel on LTCC board [3]. The micro-fluid channel was fabricated for gas passage and thermistor placement. S. Holzwarth et al. made a microsystem including 8x8 DBF antenna array, radio frequency circuit and micro-fluid channels on LTCC board [4]. This microsystem can achieve a return loss below -10dB within the bandwidth of 29.5-30GHz. Wang et al. fabricated a non-closed cavity on the surface of LTCC board for microwave transmitting and receiving application [5]. In order to form the non-closed cavity, LTCC scraps were used as insert mold during lamination and sintering process to prevent cavity deformation.

Compared to PCB board, the manufacturing cost of LTCC board is expensive, because the LTCC board mainly uses gold as the inner conductor material. This hinders the application of LTCC boards in commercial use, such as 5G communication. In this paper, a low-cost fabrication method of LTCC board with embedded micro-fluid channel was proposed. Silver was utilized as the inner conductor material instead of gold. The surface gold layer, which was designed for chip/wire bonding, was made by chemical plating. An organic material was used to fill the channel before the
lamination process. This material acted as sacrificial layer and evaporated in the late stage of sintering process to prevent the channel from excessive deformation during lamination and sintering process.

**Material and Micro-fluid Channel Model**

LTCC board materials were shown in Table 1. Different from conventional method, the via and print paste were silver instead of gold to cut costs. In addition, there were only two types of paste, which were convenient for material management of commercial mass production.

| Item       | Type                   |
|------------|------------------------|
| Ceramic tape | Ferro A6M              |
| Via paste  | YF 33-0590290          |
| Print paste | YF 33-0590175          |

Micro-fluid channel model was shown in Fig. 1(a). The micro-fluid channel was consisting of 2 main fluid channels and 8 branch channels. The design sizes of these channels were listed in Table 2. The micro-fluid channel was embedded in a LTCC board of 25 layers, as shown in Fig. 1(b). The liquid joints were soldered to the LTCC board surface as the import and export of coolant.

| Item         | Width(mm) | Height(mm) |
|--------------|-----------|------------|
| Main fluid channel | 2.2       | 0.762      |
| Branch channel        | 1         | 0.635      |

![Figure 1](image)

Figure 1. Micro-fluid channel model and the import and export of coolant.

**Experimental Procedures**

The experimental procedures were shown in Fig. 2. Ferro A6M tape was cutting into 25 sheets of 8 inch × 8 inch. The protective films of these sheets were removed by seal removal system. Then these sheets were put in constant temperature and humidity system for 24 hours to release residual stress. High speed punching machine was used to punch the holes, main fluid channels and branch channels (Fig. 3(a)). After punching process, the holes for transmission and heat dissipation were filled by silver via-filling paste using print filling machine. The graphics and lines were printed by virtue of silver printing paste and printing machine.
Strip filling materials were shown in Fig. 3(b). The filling materials were made of polypropylene carbonate particles through casting process. The thickness of filling material was 0.04mm. These filling materials were stacked and laminated into blocks. The lamination parameters were listed in Table 3. According to the width and thickness of fluid channels in previous punching process, the filling material blocks were cutting into strips.
Table 3. Lamination parameters for making filling materials into blocks
(After holding pressure stage, decompress to 0kN).

|                  | 1st stage pressurization | 2nd stage pressurization | 3rd stage pressurization | Holding Pressure stage |
|------------------|--------------------------|--------------------------|--------------------------|------------------------|
| Pressure (kN)    | 20                       | 40                       | 60                       | 80                     |
| Time (s)         | 10                       | 10                       | 10                       | 10                     |

The following experiment was divided into two groups. In the first group, the main fluid channels and branch channels were filled by strip filling materials (Fig. 3(c)). Then the sheets with filled fluid channels, holes, printing lines and graphics were made into LTCC boards by stack, lamination and sintering process. The lamination parameters and sintering setting curve were shown in Table 4 and Fig. 4. The strip filling materials volatilized in sintering process through the import and export of coolant, which were on the surface of the LTCC board. In the second group, the main fluid channels and branch channels were not filled for comparison. Finally, the surface gold layers of these two groups of LTCC boards were made by chemical plating.

Table 4. Lamination parameters for LTCC board (After Peak pressure stage, decompress to 0kgf/cm²).

|                  | Warm-up stage | 1st stage | 2nd stage | 3rd stage | 4th stage | 5th stage | 6th stage | 7th stage | Peak Pressure stage |
|------------------|---------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|---------------------|
| Pressure (kgf/cm²) | 0             | 35        | 105       | 120       | 140       | 160       | 195       | 235       | 275                 |
| Time (s)         | 600           | 120       | 120       | 0         | 0         | 0         | 0         | 0         | 600                 |

Figure 4. Sintering setting curve.

Results and Discussion

Through the above experimental procedures, the obtained LTCC boards were shown in Fig. 5(a). From the appearance of the boards, the boards made with filling materials (the filled boards) had flat and complete appearances. While the boards made without filling materials (the unfilled boards) had significant collapse on the board surface. To investigate the reason of collapse, some of the boards were cutting by abrasive cutting machines, according to the cutting line as shown in Fig. 5(b). The positions of the cutting lines corresponded to the collapsed sites. Fig. 6 showed the microscopic measurement results of the LTCC boards on the cutting line sites. The micro-fluid channels in unfilled boards had obvious deformation, and the top and bottom of these deformation channels are recessed inward. It illustrated that the collapse on the unfilled board surface were caused by the deformation of the micro-fluid channels. For comparison, there is no obvious deformation on the micro-fluid channels of the filled boards, owing to the supporting effect of the filling materials.
The boards made with filling materials  
(a) Obtained LTCC boards  
The filled boards  
(b) Cutting line sites  
The unfilled boards  
Figure 5. Obtained LTCC boards and the cutting line sites.

The boards made without filling materials  
Figure 6. Microscopic measurement results of the LTCC boards on the cutting line sites.

The dimensions of the micro-fluid channels gauged by measuring microscopic were listed in Table 5. The micro-fluid channels deformation of filled boards were far less than the channels of unfilled boards. The maximum error between actual size and design size of the micro-fluid channels in filled boards were 7%. It demonstrated that filling sacrificial materials can effectively suppress the deformation or collapse of micro-fluid channels.

Table 5. Measuring dimensions of the micro-fluid channels (Deformation ratio were calculated basing on the design sizes listed in Table 2).

| Channel sizes in filled boards | Deformation ratio | Channel sizes in unfilled boards | Deformation ratio | Channel sizes in filled boards | Deformation ratio | Channel sizes in unfilled boards | Deformation ratio |
|--------------------------------|-------------------|---------------------------------|-------------------|--------------------------------|-------------------|---------------------------------|-------------------|
| Main fluid channel            |                   |                                 |                   |                                 |                   |                                 |                   |
| 2.13                           | 3.2%              | 1.84                            | 16.4%             | 0.71                           | 6.8%              | 0.63                            | 17.3%             |
| 2.15                           | 2.3%              | 1.82                            | 17.3%             | 0.72                           | 5.5%              | 0.62                            | 18.6%             |
| Branch channel                 |                   |                                 |                   |                                 |                   |                                 |                   |
| 0.95                           | 5%                | 0.81                            | 19%               | 0.61                           | 3.9%              | 0.54                            | 15.0%             |
| 0.93                           | 7%                | 0.84                            | 16%               | 0.60                           | 5.5%              | 0.52                            | 18.1%             |

For further verification, the liquid joints were soldered to the surface of the filled board. Deionized water was pumped in and out of the micro-fluid channels through the liquid joints for 1 minute, as shown in Fig. 7. The flow rate was 0.6L/min, with the pressure of 200Kpa. In the test of water passage, there was no bubble on the surface of the filled board, which illustrated that there was no leakage of the micro-fluid channels in the filled board. Fig .8 showed the X-ray images of the micro-fluid channels before and after the water passage test. There was no significant change
between the images of micro-fluid channels before and after the test. It proved that this fabrication method for embedding micro-fluid channel in LTCC board is effective in practical use.

Figure 7. Water passage test.

(a) X-ray images of micro-fluid channels before the water passage test

(b) X-ray images of micro-fluid channels after the water passage test

Figure 8. X-ray images of micro-fluid channels before and after the water passage test.

The costs of this fabrication method were listed in Table 6. For comparison, the costs of traditional method were also listed in Table 6. Attributed to use silver via and printing pastes instead of gold pastes, the fabrication cost of LTCC board was reduced by more than 20%. The cost reduction would promote the application of LTCC boards in commercial communication use.

Table 6. Costs of this low-cost fabrication method and traditional method (RMB).

|                        | Costs of this low-cost fabrication method | Costs of traditional method |
|------------------------|------------------------------------------|-----------------------------|
|                        | Amount  | Unit price (RMB) | Sum (RMB) | Amount | Unit price (RMB) | Sum (RMB) |
| Ordinary printing screen | 10      | 640 per block | 6400 | 10 | 640 per block | 6400 |
| Resistance screen      | 1       | 900 per block | 900 | 1 | 900 per block | 900 |
| Precision Printing screen | 1      | 900 per block | 900 | 1 | 900 per block | 900 |
| Via-filling screen     | 10      | 500 per block | 5000 | 10 | 500 per block | 5000 |
| Material                  | Quantity | Cost per Unit | Total Cost |
|---------------------------|----------|---------------|------------|
| Silver via paste          | 150000   | 0.005 per hole| 750        |
| Gold via paste            | 150000   | 0.03 per hole | 4500       |
| Resistance paste          | 2        | 60 per layer  | 120        |
| Resistance paste          | 2        | 60 per layer  | 120        |
| Silver printing paste     | 6        | 50 per layer  | 300        |
| Gold printing paste       | 6        | 300 per layer | 1800       |
| A6M tape                  | 25       | 200 per layer | 5000       |
| A6M tape                  | 25       | 200 per layer | 5000       |
| Chemical plating          | 1        | 500 per layer | 500        |
| Bonding layer paste       | 1        | 750 per layer | 750        |
| Total (RMB)               |          |               | 19870      |
| Total (RMB)               |          |               | 25370      |

**Conclusions**

In this paper, a low-cost fabrication method of LTCC board with embedded micro-fluid channel was proposed. In the experimental procedures, the micro-fluid channels were filled by strip sacrificial materials, which could prevent the micro-fluid channels from large deformation during lamination and sintering process. The experimental results showed that filling sacrificial materials could effectively suppress the deformation or collapse of micro-fluid channels. Through the water passage test, this fabrication method for embedding micro-fluid channel in LTCC board was proved to be effective in practical use. Owing to use silver pastes instead of gold pastes, the fabrication cost of LTCC board was reduced by more than 20%, which would promote the application of LTCC boards in commercial use, such 5G communication and embedded systems.

In the future work, this fabrication method will be introduced to curved antenna manufacturing for promoting the LTCC technology application on smart skin antenna and embedded micro-electro-mechanical system.

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