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Cold Chemical Lamination Tests of Grooved Internal Cavities in LTCC for Thermal Management

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Abstract

This paper presents the fabrication of a micro heat pipe, in Low Temperature Cofired Ceramics (LTCC), as a cooling solution for electronic packaging. The micro heat pipe structure, produced using the ESL 41020 tape, is based on a grooved internal cavity, which ensures the process of cooling since it guarantees the evacuation of heat, by the use of working liquid. The manufacturing of the micro heat pipe with the standard LTCC fabrication process gives inflated cavities and deformed grooves. To improve this we make use of cold chemical lamination and test the cetyl alcohol as a sacrificial volume material, (SVM). The tests performed show that the cold chemical lamination did not improve the structure; neither did the cetyl alcohol with a hot lamination.

Key words: Micro heat pipe, Hot and cold lamination, SVM (sacrificial volume material), electronic packaging, ESL 41020.

Introduction

Thermal management of electronics is a subject of increased interest due to, among other things, the recent development of portable and wearable electronics that leads to the miniaturization of those devices, while at the same time there is a demand on their increased performance. For devices that contain high or medium power amplifier chips, the removal of the heat generated by these chips must be efficient and if possible passive, i.e. without adding any external power supply. One way to solve this is to include a heat-pipe to remove the heat from the heating element to a cooling zone. This solution is used in smartphones and portable computers. The heat pipe is a passive cooling device in the form of a rectangular or circular tube that displaces heat through the change of state of a liquid as water or alcohol. Its principle is described in [1].

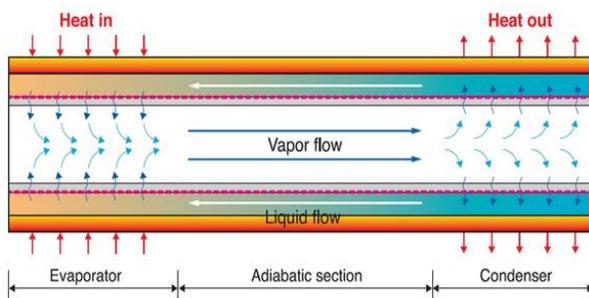


Figure 1. Principle of heat pipe, from[1]

Miniature heat pipes in copper have been successfully embedded in organic printed circuit boards [2]. These miniature heat pipes are not adequate for integration in ceramic materials due to

the coefficient of thermal expansion (CTE) mismatch: the miniature heat pipes' CTE is approximately 17 ppm/°C while ceramic materials have a much lower CTE, about 6 ppm/°C for Low Temperature Co-fired Ceramics, (LTCC) and 6.5 ppm/°C for Al₂O₃. For packaging solutions, using ceramic materials, it is thus interesting to try to fabricate heat pipes within the ceramic material itself. For such an objective, the LTCC, with its multilayer structure and layer-by-layer fabrication technique, seems to be a good choice, which also has been shown by [3] and [4]. We have earlier reported on the work of fabricating such micro heat pipes, [5] where the emphasis was on the lamination procedure and the parameters' settings as time, , in order to not damage the micro heat pipe grooves. The topic in this paper is on the use of different cold chemical lamination adhesives without the use of sacrificial volume materials and on the use of the cetyl alcohol as SVM material with hot lamination to produce internal cavities in the LTCC, without deformation.

Background

A micro heat pipe in LTCC is subdued to the same fabrication constraints as channels for micro-fluidic systems. In general, these structures are fabricated on LTCC materials from Ceramtec, Heraeus or Dupont, as presented in **Erreur ! Source du renvoi introuvable.** In this work, we have used a material from ElectroScience Laboratory, the ESL41020 [6], which is commonly not used for internal channels or internal cavities.

Table 1. Internal cavities or channel structures in LTCC

Material	Type of structures	Publication
Unknown	Microheatpipes	[4]
Ceramtec GC	Channels	[7], [8]
Heraeus CT707	Channels	[7], [8]
Heraeus CT800	Channels	[7], [8]
DuPont 951	Microheatpipes, Microreactor, channels	[3], [9], [10]
Heraeus CT700	Channels	[11]
ESL41020	Microheatpipes	[5], This work

For ESL41020 we have shown how to produce micro heat pipes using ten layers for the complete structure [5]. The first result showed a twofold problem, swelling and deformation of the grooves, as presented in

Figure 2. Cross section of a micro heat pipes fabricated in ESL41020. Left; the cavity is swollen and the intended square shape of the wick grooves is rounded. Right; improved result

Figure 3 left. These problems were partly resolved by changing the lamination parameters and Figure 2 right gives the resulting prototype.

This solution was achieved after several tests of different sacrificial volume materials such as PMMA, fugitive tape (ESL49000) and of the extended firing profile impact.

Dimensions mentioned in Figure 3 represent parameters that influence the operation of micro heat pipe. In [5], they are calculated to dissipate 1.5W. So to ensure the working of micro heat pipe, all dimensions must be correct.

Table 2 show calculated vs obtained micro heat pipe dimensions.

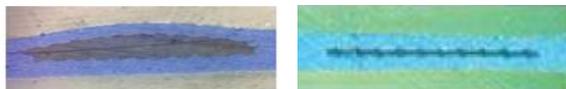


Figure 2. Cross section of a micro heat pipes fabricated in ESL41020. Left; the cavity is swollen and the intended square shape of the wick grooves is rounded. Right; improved result

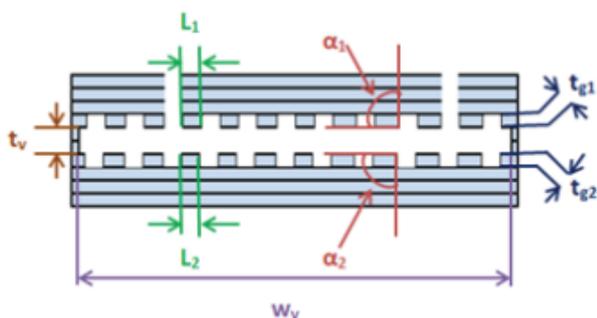


Figure 3. LTCC micro heat pipe structure

Table 2. LTCC micro heat pipe dimensions

	Wanted dimensions (calculated to dissipate 1.5 W)	Obtained dimensions in figure 3 left	Obtained dimensions in figure 3 right
W_v	4 mm	4 mm	4 mm
t_v	0.15 mm	0.45 mm	0.15 mm
t_{g1} and t_{g2}	0.075 mm	0.05 mm	0.075 mm
L_1 and L_2	0.3 mm	0.45 mm	0.3 mm
α_1 and α_2	90°	120°	100°
N: Number of grooves	20	20	20

In [5], a tweaked hot lamination technique is used, i.e. after stacking the layer stack is placed in a uniaxial press and laminated at 70 bar, during 5 minutes at +50 °C. This is not the standard procedure as proposed by the LTCC tape manufacturer (210 bar, +70°C and 10 minutes). This method improves the cavity structure, but the grooves are still slightly deformed. Their shape is important for micro heat pipes to serve as wick to return the condensed vapor from the condenser to the evaporator, thus further improvement is desired.

Cold lamination with low pressure is a method in which adhesive tapes based on polyacrylate are used between every two successive LTCC layers while working in an ambient temperature and with a low pressure of around 5 MPa. Unlike standard lamination, cold lamination with low pressure reduces deformations for very fine and 3D structures such as cavities and micro-channels. This type of lamination works well for open cavities, however it is not suitable for closed structures because the organic decomposition of the adhesive tapes during firing inhibits the outgassing [11]. Hence, cold lamination with low pressure is not suitable for our grooved internal cavity since there are no natural gas outlets.

A better possibility to achieve these enclosed cavities could be to apply cold chemical lamination based on the use of adhesive solvents, which slightly dissolve the surface of LTCC layers. Several types of adhesives can be used: alcohol-based, water-based, honey-based, saliva-based and commercial thinner adhesives. According to [11], the adhesives which offer the best results are honey and saliva without need of added temperature nor pressure. According to the same reference, the alcohol and thinner solvent are strong and affect the tapes too much whereas the water is ineffective. Based on these results, we have chosen to try the chemical

lamination at room temperature with no added pressure using honey or saliva as adhesive without any sacrificial volume material (SVM) to protect the structure.

Cold Chemical Lamination Approach and Methodology

Ten tapes of 2" × 2" were prepared with the cut out of alignment holes, grooves and cavities (Figure 4). The structure contains six micro heat pipes with six different width and number of grooves as explained in Figure 5. These parameters are chosen to study the influence of cavities width on the structure of micro heat pipes laminated with a cold chemical lamination.

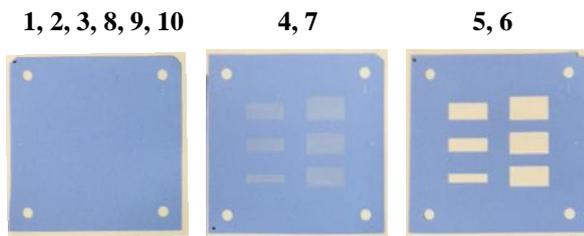


Figure 4. LTCC micro heat pipe layers

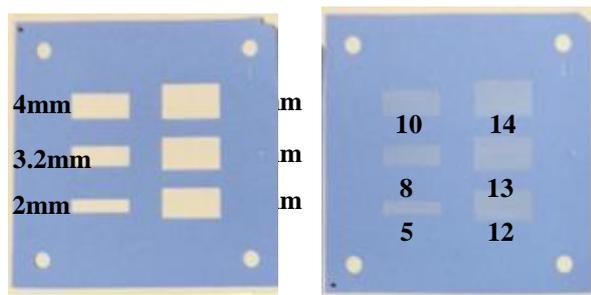


Figure 5. Width (left) and grooves number (right) of different designed micro heat pipes

During the stacking of LTCC layers on the alignment fixture, a thin layer of the adhesive was added manually using a cotton swab before the next layer was placed. For each layer, less than 60 seconds elapsed between the adhesive application and the positioning of the next layer.

After having stacked ten layers, the layer stack was taken off the fixture, placed between two high temperature-resistant release films specifically engineered for lamination and then subjected to a vacuum extracting machine (Hellas) during 10 minutes, to empty any air pockets in the stack. Finally, the stack was fired in a static furnace (Nabertherm) using the standard firing profile as given by the manufacturer.

In the saliva case, we noted that the saliva dries very quickly, which causes a lack of the adhesion between the LTCC tapes. It also results in very soft tapes, which makes them difficult to handle during stacking.

The use of honey as an adhesive is easier in the stacking step and results in a good bond between the layers. However, it is important to limit the

amount of honey in order for it to not be absorbed by the tape. We found that it should not be more than four dots of 2 mm diameter to cover the tapes of four square inch surface.

Analysis of the Cold Chemical Lamination Case

To analyze cold chemical lamination, two cuts, AA and BB, were made after firing crossing the middle length of the six micro heat pipes. Figure 6 gives the position of the two cuts vs the position of cavities in LTCC layer.

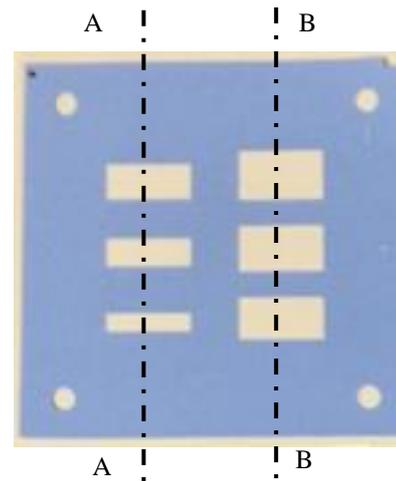


Figure 6. AA and BB cutting plan for the analyze of cold chemical lamination

Photographs of the two samples and their cross sectional views are shown in Figure 7 and Figure 8.

In the saliva prototype, the AA cross section show that micro heat pipes that have a width of 2.0 and 3.2 mm have a rectangular structure, however the grooves are broken. Micro heat pipe, which have a width of 4.0 mm have fallen in top layers due to the absence of SVM, nevertheless some of the grooves remain intact. The other three micro heat pipes (BB cross section) show the same results as the 4.0 mm one. For all micro heat pipes, an important delamination at all layers is visible and inflated parts are present on a large portion of the surface of the LTCC structure.

When it comes to the prototype laminated with honey, Figure 8, we notice that, unlike saliva, the grooves are not broken. All micro heat pipes show deformed cavities with fallen in top layers, again, due to the absence of SVM. The delamination is present in all layers. We have no inflated parts but some “bubbly” features are seen over the surface of the LTCC substrate.

Thus, as compared to the results found in [11] where the DuPont 951 tape was used, we can conclude then that even if honey gives better grooves than the saliva for the ESL41020 tape, it is not good enough to pursue any further. Instead, we will have to apply some pressure and heating during

the lamination procedure. Additionally, when it comes to preserving the internal cavity shape, an SVM material is essential to ensure that the cavity will not fall in. Some kind of SVM material can help to produce a perfect internal cavity without the need of a cold chemical lamination; it can be used with the standard LTCC fabrication steps. One of these SVM materials will be tested in the next section.

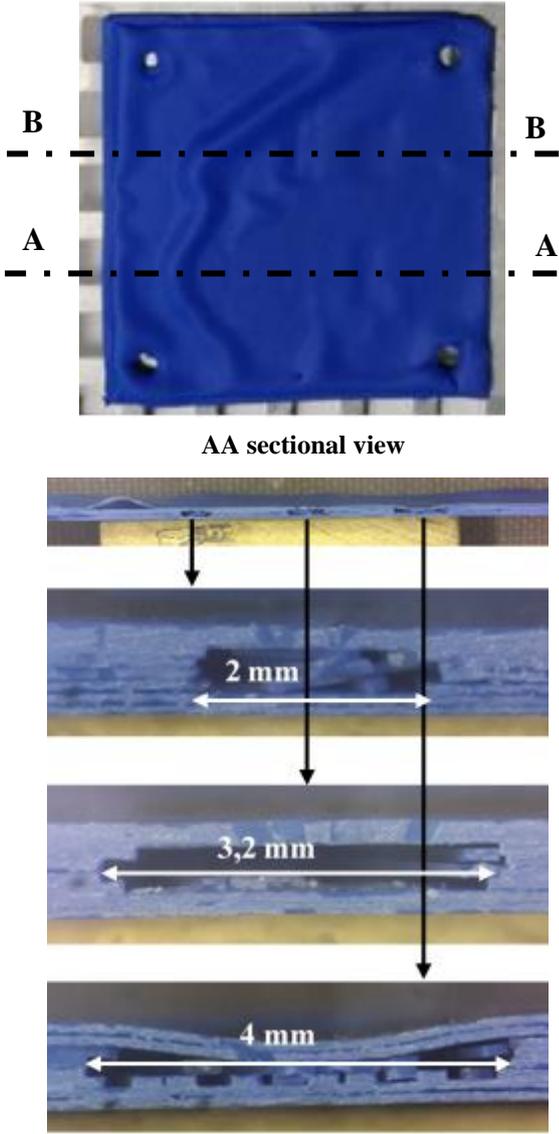


Figure 7. Photos of ESL 41020 substrate laminated by cold chemical lamination with saliva as adhesive: substrate surface view (top) and section view (bottom)

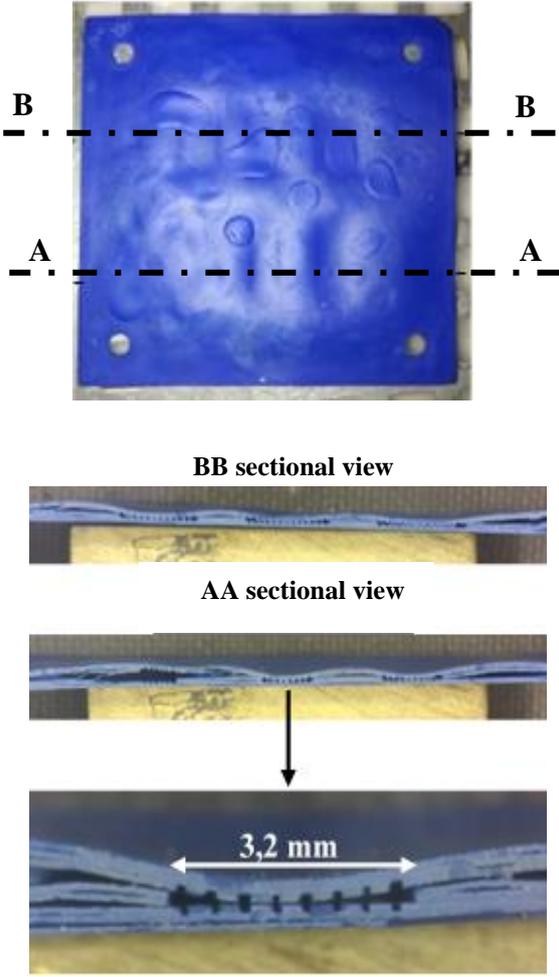


Figure 8. Photos of ESL 41020 substrate laminated by cold chemical lamination with honey as adhesive: substrate surface view (top) and section view (bottom)

Cetyl Alcohol SVM Test

An SVM is a material used in LTCC fabrication procedure when the structure contains cavities. This material is placed inside cavities in order to maintain its form during the manufacturing process. The SVM material is burned away during the firing cycle. ESL manufactures a sacrificial volume material, ESL49000, that comes in sheets of 100 to 150 μm thickness[13]. This material was used in [5] but resulted in deformed grooves.

In [12] two types of SVM for micro channels are compared : cetyl alcohol and carbon-black paste. According to the tests carried out, the cetyl alcohol offers better results in terms of quality and size of the channels. This type of SVM is compatible with internal cavities and does not release gas in the firing stage, which should be beneficial to avoid inflated features.

Following these results, we chose to test the cetyl alcohol for our internal grooved cavities to see

if this change might improve the quality of the grooves. The results will be compared to those using the fugitive tape ESL49000 as presented in [5]. Since, for cetyl alcohol SVM material, no carbon dioxide gas is formed during the firing, no chimney structure is needed in the layers above the micro heat pipe.

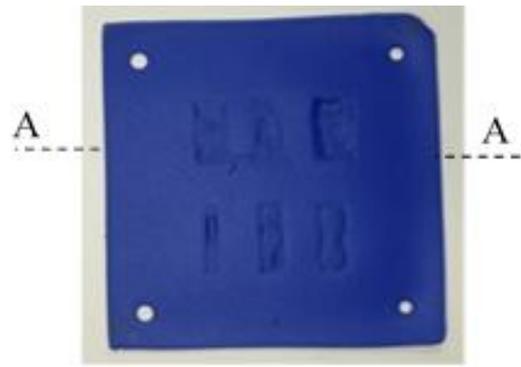
The cetyl alcohol (CA) comes in solid pellet form [14], Figure 9. In order to fill the LTCC structure, we place it in a bowl on a hotplate where it melts at +47°C. When liquid, using a pipette, it is transferred into the cavities of the LTCC stack made up of three base layers, the lower grooved layer and the two-vapor chamber layers placed on the alignment fixture. The fixture is placed on a hotplate to keep the temperature high enough for the cetyl alcohol to stay liquid during the manipulation. While in the pipette, the cetyl alcohol is prone to solidify (Figure 10) which implies that the filling procedure must be accomplished very quickly. After having filled the lower grooves and the vapor chamber, the upper grooved layer and top layers are stacked at room temperature. Next, the stack is sealed with isopropanol (IPA) at the corners, lifted off the alignment fixture and placed in the vacuum machine for 10 minutes before lamination at 210 bar, during 10 minutes at 68°C and fired using the standard profile.



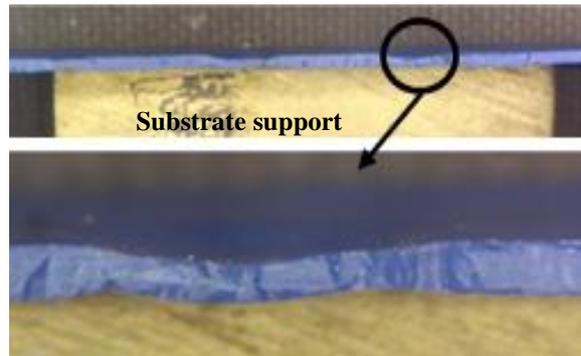
Figure 9. Cetyl alcohol filling



Figure 10. Cetyl alcohol solidified in the pipette after 30 seconds



AA sectional view



Cetyl Alcohol Prototype Analysis

The resulting prototype is presented in Figure 11 .

Figure 11. CA prototype: substrate surface view (top) and section view (below)

It is obvious that the cetyl alcohol has not worked out properly. The reason is the lamination parameters where the uniaxial press' plates are heated to 68°C. The cetyl alcohol is consequently in liquid form when the pressure is applied (210 bar for 10 minutes), gets absorbed throughout the structure and dissolves the LTCC tapes. Thus, the vapor chamber and the grooves completely disappear during this fabrication step as proven by the cross section in

Figure 11.

Conclusion

We can conclude that cold lamination is not exploitable since our objective is to do closed internal structures. A better solution could be the cold chemical lamination, for which we tried two adhesives: saliva and honey. Using saliva results in delamination between layers, the grooves are damaged even though the vapor chamber is well preserved for a micro heat pipe width less than or equal to 3.2 mm. For a cavity without grooves, the saliva might be used if the lamination is done with increased pressure and temperature.

The cold chemical lamination using honey results in preserved grooves, yet the vapor chamber is fallen in even for small widths, and there is a

severe delamination between the layers. Thus, the use of SVM and hot lamination is required.

In the CA SVM case, the handling is complex and the hot lamination leads to an absorption of the CA that completely deforms the structure. Therefore, a test of this SVM with a lamination temperature less than 47 °C (melting temperature) can give a better result.

To further improve the micro heat pipes, SVM in powder form is an interesting option since it will be possible to fill the grooves if the powder granularity is small enough.

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