

## The Technology Research on AlN 3D MCM

Hao Zhang Song Cui Junyong Liu  
East China Miroelectronic Research institute  
Hefei 230022 China  
E-mail: from02@126.com

### Abstract

*3D MCM technology, a kind of advanced MCM, which develops on 2D MCM technology, It can provide higher density, smaller size and more functions. In order to improve the heat-sinking capability and reliability, the material of AlN with high thermal conductivity, thermal expansion coefficient matched with Si can be used as co-fired multilayer substrate. In this research, the advantages of two kinds of materials are combined as to fabricate the module of AlN 3D MCM.*

*Key words: AlN 3D MCM High temperature co-fired*

## 1 Introduction

Evolving from 2D MCM, 3D MCM introduces the IC chip 3D integration technology as well as multilayer interconnected technology of hi-density chip, of which the unique excellence is characterized by higher assembly density and capability, more system functions and I/O, lower power consuming and cost, and smaller size. Therefore, the pursuit of perfected assembly density, smaller size and more functions calls for the development from 2D assembly to 3D assembly.

In the meantime, with the improvement of assembly density and capability and the increase of system functions, 3D MCM heat-sinking capability and reliability are to be properly treated. AlN has secured such excellence as high thermal conductivity, thermal expansion coefficient matched with Si; improved mechanical intensity; selected electricity performance; and environmental friendliness. Apparently, the features enjoyed by AlN meet the demand of 3D MCM for heat-sinking capability and better reliability.

The analysis above demonstrates that the research of AlN 3D MCM and the development of hi-power density module do enjoy a wide prospect for application in such electrical equipment as aerospace and mainframe computer.

## 2 Experiment

The research adopts the high temperature co-fired method of ceramic material and W metal to fabricate multilayer substrate, on which related chips and parts are installed. Meanwhile, several 2D MCMs ( $\geq 4$ ) are stacked and interconnected by clapboard holing metallization and circumjacent interconnection to fabricate stacked AlN 3D MCM. The whole process comprises of the following several aspects.

### 2.1 Co-fired spacer rod and 2D MCM substrate

3D MCM structure not only needs to stack and interconnect various 2D MCM substrates, but to separate them with spacer rod and BGA solder ball, which demands high flatness of 2D MCM substrates and spacer rod, and shrinkage consistency. In practice, stack together spacer rod and substrates for the immediate success in molding; improve co-fired conductor paste; optimize sintering parameter.

### 2.2 Vertical interconnected by BGA solder ball

Package, assembly and vertical interconnected require a proper temperature grads and technological sequence. 3D MCM vertical connection is to be acquired by selecting hi-temperature solder ball and low-temperature solder, screening separation solder balls twice to remain the same size, utilizing the

automatic contraposition effect of Pb/Sn solder and metal, using contraposition clamp for vertical interconnection.

### 2.3 AlN 3D MCM Package

Kovar frame and AlN ceramic soldering are introduced to package and parallel seam welding technology is adopted to seal.

### 2.4 Technological Method

The fabrication of AlN 3D MCM substrate mainly consists of the fabrication of 2D multilayer substrate and the package of 3D MCM. The process flow of technology is schematically shown in Fig.1 and Fig 2 below.

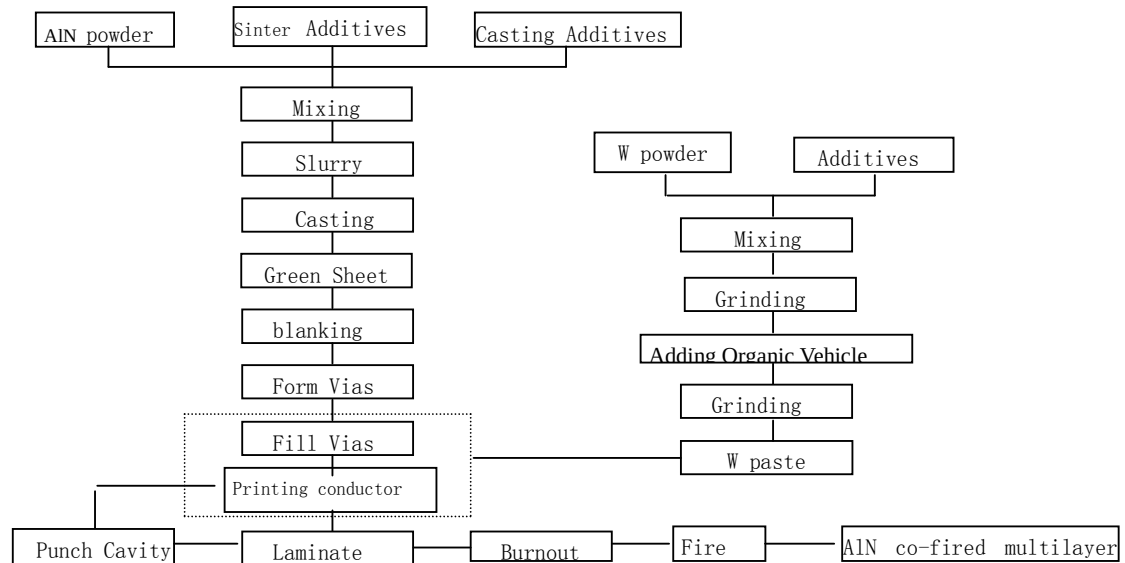


Figure1: technology process flow of AlN co-fired multi-layer substrate fabrication

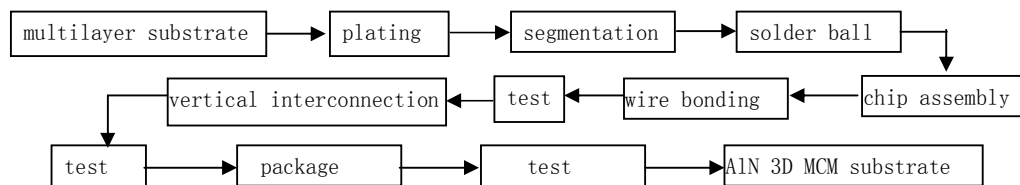


Figure 2 : AlN 3D MCM substrate assembly process flow

## 3 Result and Discussion

### 3.1 General technological scheme

3D MCM enjoys two forms of side interconnection and circumference interconnection. This paper focuses on the stacked form of four 2D MCM substrates to fabricate 3D MCM substrate. Circumference

interconnect is taken between 2D MCMs and BGA is introduced in I/O of the whole module.

This technology metalizes multilayer substrate by screen printing. Likewise, prepare a piece of clapboard slightly thicker than a chip, on which holes parallel to the marginal ones of the substrates are formed. Then, substrate and clapboard are stacked and co-fired together with

high temperature. Afterwards, the substrate is stacked and interconnected with another one by

BGA solder ball or anisotropy conductor film

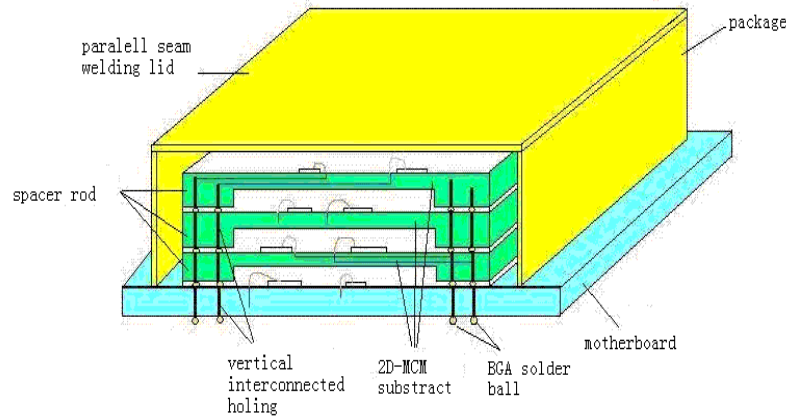


Figure 3 AlN 3D MCM substrate structure

Circuit on each substrate is connected with the lower one by circumference hole or spacer rod and ultimately out from the back side of the bottom board (motherboard). At the same time, design a metal-sealed frame 2mm wide in the outer rim of circumference hole in a motherboard surface. After plating, we weld metal lid and its frame, and then fabricate the four pieces of 2D substrate, interconnect vertically, and solder the coverboard with parallel soldering method. Thus, the whole 3D MCM substrate is sealed. The general structure is schematically shown in the Figure 3.

### 3.2 3D MCM interconnected design

3D MCM vertical interconnection is led out from one side, that is, in one direction to each 2D substrate. In assembly, the second substrate is turned 90 degree to form a vertical angle with the first spacer rod. Repeatedly, 3D module with 4 pieces of 2D substrate is fully utilized in four

directions. During the testing, the performance of one piece of 2D substrate may be tested on each side of I/Os.

### 3.3 Matching optimization research on W paste and AlN ceramics

3D MCM substrate requires more strictly the flatness and conductor electricity resistance of 2D multi-layer substrate, so it is necessary to have the optimization research on the matching of W paste and AlN tape. By analyzing the matching mechanism of the material with some relevant experience, we put into W different proportions of  $Y_2O_3$ , CaO, AlN. Under  $1800^\circ C$ , the materials sinter in the same heat preservation time and temperature ascending speed. Sheet resistance to metalization, adhesion strength to tape and substrate flatness are analyzed to observe its performance and partial results are shown in table 1.

Table 1: The matching between AlN tape and various W paste

| NO. | W (%) | AlN (%) | Y2O3 (%) | CaO (%) | Al2O3 (%) | sheet resistance | adhesion strength | flatness |
|-----|-------|---------|----------|---------|-----------|------------------|-------------------|----------|
| 1   | 100   |         |          |         |           | low              | low               | camber   |
| 2   | 97    | 3       |          |         |           | low              | lower             | camber   |

|   |    |    |     |     |  |       |        |                  |
|---|----|----|-----|-----|--|-------|--------|------------------|
| 3 | 95 | 5  |     |     |  | low   | higher | slight<br>camber |
| 4 | 90 | 10 |     |     |  | lower | high   | flat             |
| 5 | 80 | 20 |     |     |  | high  | high   | flat             |
| 6 | 95 |    | 2.5 | 2.5 |  | low   | high   | slight<br>camber |
| 7 | 90 |    | 5   | 5   |  | low   | high   | flat             |

We may conclude from the table 1 that the more additives and sheet resistance and adhesion strength increase, the better the flatness becomes. Apparently, high sheet resistance is the last result we prefer to expect. Considering the three aspects above, we may see that W paste of No. 4,7 have secured fairly good experimental results and the total amount of sintering catalyst is under control within 10 ~ 15% on average.

### 3.4 Technological improvement experiment of AlN 2D MCM substrate

The design and technological implementation of 3D MCM is a rather complicated process and a minor failure in each step may lead to the total collapse of the process. In this case, we are particularly strict in the selection of 2D substrate. The subsequent technological amelioration in sintering betters the contraposition precision and substrate flatness.

Sintering has great impact on AlN co-fired substrate capability. Sintering temperature, temperature ascending speed and temperature descending speed, temperature preservation time and sintering condition are all influential to the substrate capability.

AlN tape shrinks from 1300°C, and pure tape between 1600 ~ 2000°C. W sintering temperature is no low either. Once sintering temperature is too high, on one hand, the shrinking rates of AlN and W sintering will mismatch and the subsequent stress will camber substrate, on the other hand, W will have

chemical reaction with N<sub>2</sub>, C in high temperature

and such compounds as WN<sub>2</sub>, WC generated

increase sheet resistance. Now, we put some

CaO ( 2% ), Y<sub>2</sub>O<sub>3</sub> ( 2% ) into AlN powder to

decline sintering temperature. However, once the temperature is too low and W and AlN fail to sinter to a certain extent, they will not achieve the expected density. At the moment, AlN tape is characterized as darkish in color, lower in thermal conductivity and thermal insulation electricity resistance, small in shrinkage rate and density. As for W, it is inclined to become dark after metalization, shelling powder and falling off. Thanks to the experiment, we ultimately secure the optimal sintering temperature and resolve the above-mentioned problem.

Temperature ascending speed will also affect the substrate flatness and compactness. Once the temperature ascends too fast, crystal particle will grow faster and the subsequent prompt shrinkage is detrimental to the purification of AlN tape thereby to cause substrate camber and thermal conductivity decline. Reversally, W and AlN will shrink too fast, and thermal stress will show its form apparently to camber substrate. Table 2 indicates the impact of different temperature ascending speed on multilayer substrate flatness. Hereby,

we select temperature ascending speed 3 ~

5°C/minute. In temperature descending, we take the measure of gradual reduction of thermal

electrical current.

Table2: Impact of temperature ascending speed on substrate flatness

Speed of temperature ascendance

| Speed of temperature ascendance ( °C/min ) | number of qualified (pieces) | number of unqualified (pieces) | finished product rate | flatness                        |
|--------------------------------------------|------------------------------|--------------------------------|-----------------------|---------------------------------|
| 3                                          | 18                           | 2                              | 90%                   | fairly good                     |
| 5                                          | 16                           | 4                              | 80%                   | good                            |
| 10                                         | 4                            | 16                             | 20%                   | Serious camber,occasional craze |

Table 3 demonstrates the variety between W paste,AlN tape density and the change of heat preservation time. According to the figure, W density will no longer change after around 2 hours'heat preservation, while AlN tape density

comes to stablize after around 4 hours' increase.

Longer heat preservation time is beneficial to AlN tape purification and thermal conductivity growth.

Table 3: variety between W paste,AlN tape density and the change of heat preservation time

| Time of heat preservation | 0.5h  | 1h    | 2h    | 3h    | 4h    |
|---------------------------|-------|-------|-------|-------|-------|
| W                         | 18.97 | 19.01 | 19.04 | 19.04 | 19.04 |
| AlN                       | 3.02  | 3.1   | 3.22  | 3.23  | 3.25  |

However, the more time W heat preservation occupies, the more chance it will react, increase sheet resistance and decrease adhesion strength. Taking all the cases into consideration, 4 hours heat preservation is optical <sup>[4]</sup>.

Under high temperature, both AlN and W are inclined to oxygenate (AlN and W start to oxygenate above 900°C and 340°C respectively in the air) . Therefore, sintering must be executed under the protection of nitrogen. Impurity of nitrogen or lowness of gas flux will

cause minor oxygenation,decline of substrate thermal conductivitye and increase of W conductor sheet resistance. With the experiement, highly purified nitrogen is selected to become the protecting gas, whose flux ranges from 5 to 10 litre per minute. Figure4 is the sintering curve of co-fired substrate from the experiement.

After the applification of ameliorated experiement technology, we secure a 2D co-fired substrate below in figure 5, whose capability meets the demand for 3D MCM substrate drawing.

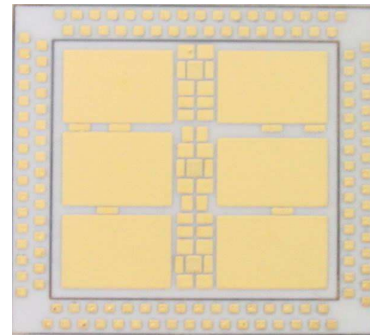
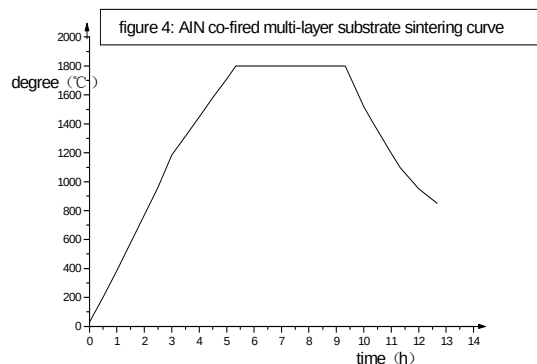


Figure5: sample of 2D MCM substrate

### 3.5 The making of spacer rod

Spacer rod and 2D MCM substrate are stacked to be co-fired together. During the process, adding silicon rubber or clipped green tape to the cavity will uneven interior side and jam the space. In response, we design moulds exclusively stacking the cavity and the outer frame respectively. The slight difference between the upper moulds are not affected under the isotonic pressure. To demould easily, we install a mobile spiral shell at the top of stacked upper mould in the center. unscrew it in stacking; screw on it in taking mould.

In making spacer rod, punch vias firstly at the rim of the pattern on AlN green tape, print, punch it into a frame and stack, deglue, sinter

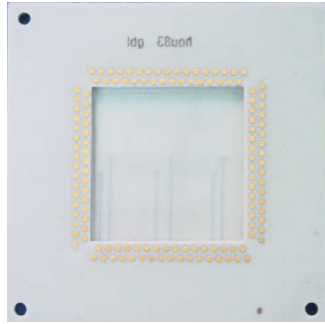


Figure6: co-fired sample of AlN and spacer rod

differs greatly under the high temperature, we introduce low temperature Pb/Sn solder to seal with reflow soldering technology thereby to reduce this stress and increase the soldering reliability. The result proves fine and seal capability meets the needed requirement.

### 3.7 Vertical interconnected technology research

We seek vertical interconnection by placing Pb/Sn soldering ball on soldering pad by spacer rod. Owing to the temperature grads different from other technology, we select a solder ball at 295°C. Lay it down properly, stick up chips and wire bond, and then interconnect vertically. Since the metal on the Pb/Sn and solder pad secures a good soakage, it enjoys a self-alignment effect, which is beneficial to

together with 2D MCM substrate. Due to the identical technology, contraposition precision is improved, shrinkage consistency is ensured, a vertical interconnection is reduced and module stability is secured. Figure6 shows us the made spacer rod.

### 3.6 Package technology

The package in the research adopts parallel seam welding, weld together the Kovar frame and assembled, vertically interconnected metal seal ring, parallel seam weld lid after completion.

Considering that tube shell soldering is proceeded after the assembly and vertical interconnection, meanwhile the thermal expansion coefficient of AlN and Kovar

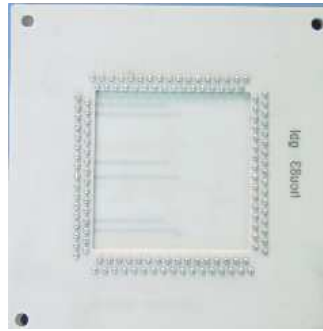


Figure7 sample of vertical interconnection

vertical interconnection contraposition. The size of solder ball fails to be identical, which may cause an empty meet in the process of vertical interconnection. What makes the matter worse is that melting condition of solderballs is not identical either and it will also bring forward short circuit among them.

The principle of soldering ball size selection follows that the size of solder ball is slightly smaller than solder pad. At the same time, the solder balls with the identical size have difference as well, which may cause variance on the same side, inconvenient in testing and vertical interconnection. To resolve this problem, we filtrate the size of solder balls at first to ensure the elimination of the balls with too big or too same size; secondly, by modulating the

technological parameter of the balls, we may achieve the identity of the melting condition of different solder balls. The result has demonstrated us the positive aspect.

Vertical interconnection contraposition demands highly on precision and handiwork contraposition is hard to be guaranteed. Therefore, we design and fabricate contraposition clamp, of

which both sides are closely placed against 2D substrate rim and package inner side. Clamps are taken out after the solder. All the substrates are connected.

By exploring the above-mentioned key technology, we fabricate the sample of AlN 3D MCM substrate in figure 8.

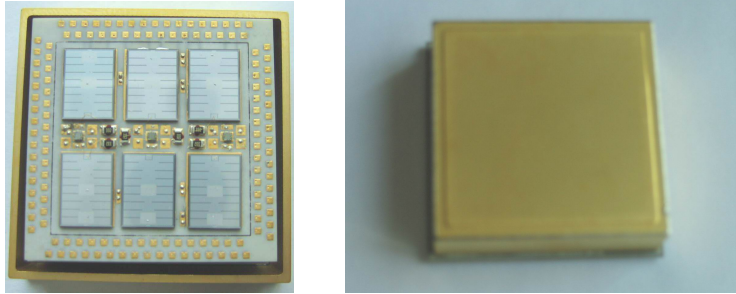


Figure 8: sample of AlN 3D MCM substrate (samples of unsealed lid and sealed lid respectively are on the left and on the right.)

## 4 Result of Experiment

Capability index of AlN 3D MCM samples

fabricated after the research is demonstrated below in table 4.

Table 4 Sample capability index of AlN 3D MCM

| Index project                                       | Practical index                       |
|-----------------------------------------------------|---------------------------------------|
| 2D MCM substrate layers                             | 5 layers                              |
| Number of stacked layers                            | 4                                     |
| Thermal conductance of AlN substrate                | $\geq 172.3 \text{ W/m}\cdot\text{k}$ |
| I/O number of 3D package                            | 132                                   |
| Metal adhesion strength                             | $\geq 20.9 \text{ N/mm}^2$            |
| solderability                                       | good                                  |
| Camber                                              | $10 \mu\text{m}/50\text{mm}$          |
| Conductor sheet resistance (surface plating Ni, Au) | $6.663 \text{ m}\Omega/\square$       |
| wire bonding strength ( $\Phi 25 \mu\text{m}$ Au)   | $\geq 6.5799 \text{ gf}$              |
| Chip shearing strength                              | $\geq 3.21 \text{ gf}$                |
| BGA shearing strength                               | $> 10 \text{ gf}$                     |

## 5 conclusion

The research reveals the manufacturing

technology of AlN 3D MCM substrate by exploring the above-mentioned key parts.

## Reference

- [1] S.L.Palmquist,R.J.Jensen,W.f.Jacobsen,and R.K.Spielberger . Design and Characterization of Three-Dimensional Aluminium Nitride Multichip Modules. IEEE Multi-chip Module Conference 1994:177-182
- [2] K.J.Lodge et al . Prototype Packages in Aluminium Nitride for High Performance Electronic Systems. IEEE 1990 ( 3 ) :103-110
- [3] Zhang Jingguo , Yang Bangchao. Three-Dimensional Multichip Modules.Electronic Components and Materials , 1994 ( 4 ) :28-30
- [4] Cui Song et al. The study on the high temperature co-fired AlN multilayer substrate technology Hybrid Microelectronics Technology 2000 (1) :26-34