THERMAL MANAGEMENT IN A 3D-PCB-PACKAGE WITH WATER COOLING

F. Schindler-Saefkow, O. Wittler*, D. May*, B. Michel
Nanotest und Design GmbH Berlin; info@nanotest.org
*Fraunhofer Institute Zuverlässigkeit und Mikrointegration IZM Berlin, Dept. Micro Materials Center Berlin

Abstract
The 3D-packaging technology makes it possible to stack the PCBs on top of each other and thus make full use of the third dimension. A unique space between the stacked PCB layers enables a reproducible technology without shortcuts or unconnected bumps. New applications in 3D-PDB-packages, called PCBMEMS can be realized with the combination of electric bumps and solder rings. The paper shows an fluidic cooled 11-PCB-layer with high power components. Water channels in the PCB-package dissipate the heat from the inside of the package to the environment. Heat dissipation is a bigger challenge for stacks of 3D-packages than for normal printed circuit boards (PCBs). This research paper investigates some design suggestions for a better heat dissipation. On the basis of this research paper, it becomes possible to choose the best suited PCB design. The experimental results were compared to thermal simulation results. The results of the measurements and FEM simulations show, how important it is to combine the electrical and geometrical functions of 3D packages with a thermally optimized PCB design. A better heat spreading and conduction in a 3D package makes the stack more reliable at higher power dissipation.

Introduction
A new 3D package technology for fluidic electrical applications has been developed [3]. The solder ring technology makes the package air-tight up to 8 Bar. An advantage is the combination of electric functions with fluidic distribution functions. With this combination the 3D-PCB-package technology achieves a higher integration and miniaturization. The main application for 3D-PCB-packages is the integration of stackable function layers for low-power applications (Fig. 1) [5].

![Fig. 1](image)

The investigated 3D packages have the same functional features, with air flow channels, but have no valve chips. Therefore we used a 1 W resistor and a temperature sensor. The measurement results are similar to the package of the valve modules.

![Fig. 2](image)

The biggest challenge for high-power applications is to dissipate the heat from the center of the package to the environment [1]. The combination of stackable high-power PCB layers with fluidic cooling comprises two progress technology developments. First, the stackable function layers for flip-chips, COBs with processors or memory chips with short vertical connection path in a very compact high-integration package. And second, the solution of the cooling in the inside of the package with fluidic bus and thermal management [1] to dissipate the heat to the environment.

Thermal management in 3D-Packages
Goal is the optimal heat dissipation of the source of the power from the first module in the stack over the other modules to the environment. The thermal paths (thermal via→thermal layer→ edge metallization) lead the heat thru the module.

To find out which thermal optimization feature will have which thermal effect, it was important to investigate different PCB designs. The PCB design used for the valve module is shown in Fig. 2.
The experiment and simulation with different package designs had the very impressive result that a 3D package with thermally optimized PCB design can dissipate 50% more power than a conventional one [Fig. 3]. Due to the fact that the thermal layers and vias are in direct contact, they can very efficiently dissipate the heat from the inside to the environment [1].

**The 3D-PCB-Package with water cooling**

High-power resistors and one PT100 temperature sensor are integrated in the function layer to simulate the high-power function (Fig. 4). 48 W of power have to be dissipated in 2 of these function layers with a temperature control in the center of the 3D-package.

The fluid way is shown in Fig. 5. The water flows to the edges of the package from one PCB layer to the other and directly to the bottom and the top of the function layers.

**Thermal Management in the 3D-PCB-Packages with water cooling**

The goal is the optimal heat dissipation of the source of the power inside the stack over the thermal paths to the environment or to the water channels. Fig. 6 shows the design concept for thermal paths in the 3D-PCB-package.

A PCB design with heat dissipation must have optimal metallization paths from the inside to the edges of the package. To ensure this, our packages have thermal vias for the vertical heat dissipation and metallization layers for the horizontal heat dissipation. All thermal vias and layers are in a short circuit and insulated with the electrical functions of the PCB-layout. The solder ring connects the thermal network from one PCB for a uniformly distributed heat.

The infra-red measurements in Fig. 7 show a very unique temperature of the package surface and the power components.

This method of thermal management strategies (Fig. 6) dissipates the heat from the components to the environment or to the water.
Fig. 8 left: Surface temperature **without cooling** at 3 W; right: Surface temperature **with cooling** at 48 W

Fig. 8 shows the surface temperatures of the PCB stack with water cooling at 48 W and without water cooling at 3 W of power dissipation in the Components. The surface temperature decrease from about 61 °C to only 31 °C with water cooling. The component temperatures are measured by the t-sensor in the middle of the components (Fig. 7). And is in both measurements nearly the same at about 85 °C. The water cooling is reducing the package temperature. And the PCB package can dissipate about 15 times more power.

![Graph](image1)

**Fig. 9 Power temperature diagram of the 3D PCB package**

Fig. 9 shows the dependency between the power of the electrical components and the temperature of the components. The temperature is measured by PT100 in the center of the function layer inside the 3D-package (Fig. 7). The temperature rise at 48 W does not exceed 60 K at a flow of the water of about 150 ml/min.

All PCB-layers have the same thickness and standard production specifications. All PCB-layers can be produced on the same PCB-panel. In this way, the demonstrator for this technology could be produced very cost-efficiently. In further technology developments, it is possible to change these specifications to reduce the thermal resistance and to increase the thermal heat exchange.

**Spacer stacking technology**

Low-power 3D-packages and high-power packages with or without fluidic structures can be stacked with the same technology [3]. The top-side of one PCB layer will be printed with solder paste, which is a very common SMD process step. After the place of the electrical components, all PCB-layers will be joint in the alignment tool. The solder paste between the layers is melting in a vapor-phase soldering machine.

The spacer prevents the solder balls and solder fluidic structures from too strong compression. The spacer technology uses a lacquer, or varnish with the same thickness as the solder balls (Fig. 10). This varnish is made by the PCB producer and is printed irreversibly onto the bottom surface of the PCB.

![Spacer technology](image2)

**Fig. 10 Spacer for the 3D PCB stacking technology**

Another possibility for the spacer technology is to use thin FR4 multilayer material. That material is 100 µm thick and can easily be structured by a milling machine. The spacer will be placed between the PCB layers in the stacking process.

![Solder bumps](image3)

**Fig. 11 Solder bumps stacked with and without spacer**

The spacer for the stacking technology of 3D-PCB-packages leads to very unique solder balls and solder rings. Fig. 10 shows 3D-packages with and without solder rings. The spacer technology for PCB stacking has an invention patent.

![X-ray picture](image4)

**Fig. 12 X-ray picture of the 3D PCB package**
Fig. 12 shows a x-ray picture of the package. It shows the solder rings, the many thermal vias and the electrical bus. The solder rings are closed to ensure that the water will not get in contact with the PCB material. The water channels themselves are metallised with copper and a thin gold layer (see Fig. 6). That is important for a reliable package with no humidity effects in the PCB material.

Outlook and Conclusion

The PCB stacking technology with spacer is a very simple solution for a reproducible process. No complex extra materials or process steps are necessary. The stacking technology of electrical or fluidic/electrical PCBs is compatible with the standard SMD technology.

The importance of water-cooled electronics is rising. New products are possible with 2, 4 or more power component layers in a water-cooled 3D-package, because the water circulation in a high-power 3D-package is the solution to dissipate the heat of the power component.

The 3D-PCB-package can be optimized if the electrical components get a better heat exchange with the water. This can be realized with micro channel coolers, thinner function PCB layers, or thermally conductive underfiller material between the components and the 3D-package.

Micro channel coolers can be very efficient but there is a big pressure drop. And that means that there a pump with these expansive specifications is needed.

Water pumps can be very expansive. It makes no sense to develop a cheap water cooling package which needs very expansive water pumps. The cross section of the water channels is very large (2 x 1.5 mm²). That means that we need a pump with a high flow rate to have a satisfying heat exchange. These pumps are small and inexpensive. That is the concept of water cooling equipment already available on the market (Fig. 13).

Nonetheless, the 3D-PCB-package shows the way to an integrated water cooling solution for a growing and already large market.

References

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