A Multilayer Process for 3D-Molded-Interconnect-Devices to Enable the Assembly of Area-Array Based Package Types

T. Leneke and S. Hirsch

TEPROSA Otto-von-Guericke University Magdeburg, Germany thomas.leneke@teprosa.de

(Received August 10, 2009; accepted November 2, 2009)

Abstract

Three-dimensional molded interconnected devices (3D-MID) extend the range of classical printed circuit boards (PCB) to the third dimension. Electrical circuits can be routed over any surface forms. This enables innovative applications and new design possibilities. The combination of circuit carrier, housing, and further functions results in an increased density of integration with decreased process effort. One limitation of recent 3D-MID technologies is their incompatibility with modern area-array based electronic packages. Usually the high I/O count of such package types makes routing in only one electrical layer impossible and necessitates multilayer structures. To meet the future requirements of 3D-MID, a compatible fine-pitch multilayer process is developed. In combination with an established 3D-MID metallization process, it allows the flip-chip mounting of area-array packages. A sample device with three metallization layers is fabricated. The mechanical and electrical multilayer properties are investigated.

Keywords: Molded Interconnect Device, Multilayer, 3D-Packaging, Injection Molding

1. Introduction

In the 1980s a new technology started to compete with the already established standard PCB technology. Three-dimensional molded interconnect devices (3D-MID) were introduced, allowing the combination of injection molded plastic devices and electronic circuit carriers. The expansion to the third dimension enables new design capabilities and the integration of functional features into the circuit carrier. In Fig. 1 a conceptual multifunctional 3D-MID is illustrated. In contrast to a PCB, the 3-D-MID not only holds and connects electronics but may have various other functionalities as well. The additional features are usually created directly during the initial injection-molding process. Therefore, 3-D-MID not only enables new packaging solutions but also has a high potential for process simplification and cost reduction.

Since the 1980s, several 3-D-MID processes have been developed or improved. The demands were mostly defined by the ongoing miniaturization of three dimensional metallization — especially driven by the semiconductor industry. Today 3-D-MID technology is widely accepted and successful industrial mass production is proven. Especially for size critical applications such as cell phones or medical devices, 3-D-MID technology is a serious alternative to conventional PCB solutions.

One major limitation for current 3-D-MID technologies and further miniaturization is the incompatibility with modern area-array based electronic packages. Due to the lack of 3-D-MID multilayer structures, the routing of such high count I/O devices becomes impossible. To overcome this limitation a 3-D-MID multilayer process is necessary. Then, the integration of complex semiconductors becomes possible and further miniaturization is feasible.
2. Process Description

The newly developed 3D-MID multilayer process is based on an overmolding technique and is illustrated in Fig. 2. A conventional 3D-MID, as shown in Fig. 2 (a), including a metallization, is the basis for the process. The 3D-MID circuit carrier is made of thermoplastic polymer and fabricated by injection molding. Due to the 3-dimensional surface the metallization can usually not be done by standard metallization processes. Nevertheless, several techniques are available to achieve a metallization on 3D-MID. But most of them have certain restrictions and only few of them are appropriate for fine-pitch metallization, as necessary for modern flip-chip mounting. The laser-direct structuring process (LDS)\[1\] is suitable for fine-pitch metallization and for the developed multilayer process. Local areas of the 3D-MID surface are activated by a Nd:YAG laser. Since this process requires a special thermoplastic polymer with metallic ingredients, only the activated areas become seed layers for subsequent electroless plating.

To achieve a multilayer structure the metallization layer has to be covered with a dielectric layer. This layer is created by overmolding. Yet a simple overmolding of the 3D-MID cannot ensure adhesion between the initial surface and the overmolded layer. Hence the unmetallized surfaces receive a laser treatment as illustrated in Fig. 2 (b). This treatment modifies the polymer surface and has an beneficial effect on the adhesion of the overmolded dielectric layer.

After the laser treatment, the 3D-MID is re-inserted into a respective injection mold tool. That tool is slightly different from the original one. Its cavity is locally enlarged and allows the injection of an additional polymer layer. During the overmold process the combination of laser treated initial 3D-MID surface, process temperature, injection pressure, and liquid mold leads to a strong adhesion at the contact interface. The condition after overmolding is shown in Fig. 2 (c).

Electrical contact with the buried metallization is achieved by conductive vias. The vias in Fig. 2 (d) are created by laser drilling. For this process step the Nd:YAG laser can be used again. The buried metallization can act as a drill stop due to the differences in the drilling speeds of polymer and metal. The via-walls are activated during the laser drilling by the laser irradiation. Therefore, seeds for the electroless metallization are exposed and metal deposition can occur inside the vias in the same way as on the surface circuits. However, ultrasonic cleaning in isopropanol is necessary before electroless metallization to remove impurities from the laser drilling.

3. Sample Device Fabrication and Experiments

To show the possibilities of the 3D-MID technology in general and the developed multilayer process in particular, a multilayer sample device is developed. The final design is illustrated in Fig. 3. A multilayer zone is situated in the
center of the sample device. It consists of three metallization layers, two dielectric intermediate layers and laser drilled vias. Further functional elements are the culverts under the multilayer structure and a window. The structure is 30 mm wide, 50 mm long, and 18 mm high. VECTRA E820i LDS was chosen as the material. It is processible by injection molding, compatible with the LDS-metallization process, and can withstand lead-free soldering temperatures.

For the design of the injection mold tool, it is important to consider several points, such as shrinkage, filling behavior and runner geometry. Injection molding simulations have been performed to ensure a high quality injection molded 3D-MID. Details on the performed simulations and the tool design can be found elsewhere.[2] Finally, an ARBURG ALLROUNDER 320S injection mold machine was used to fabricate the multilayer 3D-MID sample device.

To create the metallization structures, the LDS process is used. A scanned Nd:YAG laser activates the desired areas of the 3D-MID for the subsequent electroless metallization. Important for the latter mounting of area-array packages is the geometrical dimension of the metallization. The 60 \( \mu \text{m} \) wide focused spot of the laser defines the minimal dimensions of the metallization. In Fig. 4, the metallized tracks on the 3D-MID are shown in detail. As depicted, the minimum track width is 60 \( \mu \text{m} \).

Besides the metallization of the 3D-MID sample device, the multilayer structure and related properties were investigated. The intermediate polymer layers were fabricated by overmolding. Since the adhesion of adjacent surfaces is very weak after simple overmolding, an adhesion-supporting process is used. Prior to the overmolding a roughening of the unmetallized areas on the 3D-MID is favorable. Thus, the surface area is increased and interlocking of the overmolded layer becomes possible. In Fig. 6, three different states of the unmetallized surface are illustrated. The untreated 3D-MID is shown in Fig. 6 (a). A rather smooth surface with small porosities is noticeable. It is defined by the quality of the injection mold tool and the handling after injection molding. Cleaning steps and any previous electroless metallization affect the surface as well. In contrast, Fig. 6 (b) shows the surface after a 5 W laser treatment with a scanning speed of 2000 mm/s. Characteristic porosities, undercuts and micro craters are generated. This ensures a good adhesion of the overmolded layer to the present surface. The ripped surface of an overmolded layer is shown in Fig. 6 (c). It is rougher than the untreated but far smoother than the laser treated surface. The orientation of the surface topology in Fig. 6 (c) is caused by shear impact during the overmold process.

To validate the adhesion between the adjacent layers, shear and pull tests were performed. Samples including two layers with an area of 1 \( \text{cm}^2 \) were cut from the sample device. A Zwick Z250 tensile tester with a shear speed of \( 10^{-6} \text{ m/s} \) was used. Fig. 5 shows the result of a shear test. A uniform rise of the shear stress can be seen, indicating a high-quality surface adhesion of the two layers. Due to the thinness of the layer, almost no plastic deformation is seen. The rupture point is located at the highest shear...
stress level and the rupture plane is the interface between the two layers, as expected. Maximum values of 355 N/cm² for the shear stress and 810 N/cm² for the normal stress are measured.

After creating a metallization and isolating it by overmolding, vias need to be created to connect respective metallization layers. The Nd:YAG laser is again used for the via drilling. During the drilling the via sidewalls are activated for the LDS metallization process. The minimum via diameter is again defined by the laser focus. However, the ratio of via diameter and via depths is limited. Too high ratios cause problems during the subsequent electroless metallization. Due to insufficient flow and wetting of the electrolyte inside the via, its metallization becomes demanding with increasing aspect ratios. Reliable via metallization is achieved down to via diameters of 100 μm (ratio 5:1). In agreement with other publications[3] the via resistance is determined using four terminal sensing and varied between 10–15 mΩ.

In Fig. 7, a 3D-CT picture of two metal layers connected by metalized vias is shown.

4. Summary and Outlook

In this paper a new multilayer process for 3D-MID is presented. It overcomes existing restrictions regarding the routing for area-array packaged semiconductors. The multilayer process is described in detail. A sample device is fabricated to examine the developed method. It is made of polymer which is compatible with the 3D-MID metallization process used and with high temperature environments, e.g., those for lead-free flip-chip soldering. The 3D-MID metallization is done by laser-activated electroless plating and allows the fabrication of fine pitch circuits with path widths down to 60 μm. Multilayer structures are generated by adhesion-enhanced overmolding. Laser drilling is used to create electrical via connections between respective metallization layers. The adhesion between adjacent isolation layers is investigated by shear and pull tests. Electrical performance is determined by four terminal sensing.

Even though the proof of concept is given and results look promising, further investigations are necessary. Individual process steps can be improved. A more highly-focused laser could enable even smaller metallization and improve the degree of miniaturization. New functional elements and materials, integrated into the 3D-MID, may open new application fields. The reliability of flip-chip connections needs to be tested.[4] Furthermore, intelligent packages, e.g., with integrated thermal management, are possible.
References


