Layer Manufacturing as a Generic Tool for Microsystem Integration

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Abstract

Nearly every microsystem application requires specific packaging solutions. In this paper we suggest a new approach to use layer manufacturing as a generic tool for microsystem integration. Three different methods to produce 3D electrical interconnects are presented. Ink jet printing is used for the ceramic layer manufacturing process, as well as for the printing of silver for circuit patterns. The technique is demonstrated for an Inertial Measurement Unit (IMU) platform. A four-sided pyramid was manufactured with layer manufacturing in ceramics and four gyroscopes were mounted on the sides of the pyramid. A demonstrator with three light diodes was also manufactured to demonstrate the possibility to produce 3D electrical interconnects in the volume of the pyramid.

Keywords: Layer Manufacturing, Microsystem 3D Electrical Interconnect, Microsystem packaging

1. Introduction

A microsystem is defined as a miniaturised system combining functions such as intelligence, sensing, processing and actuation. A microsystem is normally realised by combining two or more electrical, mechanical, optical or other functions on a single integrated chip or on a hybrid module incorporating several components. The cost for packaging is typically 40-60 \% of the total cost for a microsystem but could be up to 90 \%. It is therefore very important to find new cost-effective packaging concepts. The integration of the microsystem into a product usually restricts the shape and volume of the microsystem. Since the application variations are very large, it is very difficult to use standardised packaging concepts [1]. The approach we adopted to solve this problem was to use generic manufacturing concepts for both the mechanical and electrical integration. Our selection fell on layer manufacturing with focus on direct manufacturing. The advantages with direct manufacturing are that it does not need any special tools. The full geometric and functional information of the product is contained in a digital model, which is transferred to the production equipment. With layer manufacturing it is possible to manufacture very complex parts. It is therefore possible to manufacture packaging solutions for each specific application, making layer manufacturing a generic tool for microsystem integration. The following section provides a short overview of 3D direct manufacturing technologies.

1.1 3D direct manufacturing.

There are various principles for free-form or 3D direct manufacturing. In principle, all methods are based on a sliced CAD model of the part that contains the structural information of each layer.

1.1 Stereo Lithography

A light-sensitive monomers are polymerised by a laser beam or through a photo-mask. The 3D structure is built up layer by layer and the final part is developed by chemically dissolving non-polymerised material. Ceramics parts can be built by adding monomers to a ceramic slurry.

1.3 Layer Manufacturing Techniques

Laminated Object Manufacturing (LOM ) use ceramic tapes to build up the parts. The individual layers are manufactured by tape casting. The tapes can be structured with the help of lasers, water jets, etc. After layering the tapes to form the required shape, organic additives must be burnt off before the component can be sintered.

1.4 Shape Deposition Manufacturing (SDM)

Is also characterised by a layered build-up. In this process, prototypes are manufactured from a blend of ceramic powders and organic thermoplastics or waxes, and the compound formed is then extruded layer by layer through a nozzle. The plastic body chills after leaving the nozzle and solidifies. To form the structure, the feed nozzle or the support table is moved in the X, Y and Z directions.

1.5 Laser Assisted Sintering (LAS)

The structural information in the individual layers is formed with a laser. With the input of energy from the laser beam, the ceramic powder particles are bound to each other by melting or polymerisation of a polymer or by melting of a metal. The un-reacted material acts as support material and is cleaned off in the final stage.

1.6 Ink Jet Assisted Layer Manufacturing.

The process used in this paper is based on a thin layer of ceramic powder is sliced out. The structural information in each layer is transferred by inkjet printing. The ink binds the ceramic powder particles together. The regions of the ceramic powder bed that are not printed with ink act as a
temporary support material. Final fixation of the part is done during a post-print heat treatment where also a sintering process takes place. This is the FCubic process and the technology is a spin off from IVF. The FCubic process differs from other free-form fabrication (FFF) processes, as the actual part is created in a pre sintering process. The excess material that not been printed will be free flowing and easy to remove during the cleaning step. In a second sintering step the material is sintered to full strength. A big advantage with the FCubic process is that it is considerably faster compared to other layer manufacturing processes and it can therefore be used for direct manufacturing as well as prototyping [1, 2].

2. 3D electrical interconnects

One of the most specific problems regarding microsystem integration is how to achieve 3D electrical interconnects. Electrical interconnects in 3D have always been a challenge in electronics packaging. The traditional printed circuit board technique is in principle 2½D. The electrical interconnections between the layers are very short and can only be made perpendicular to the surface. This restricts the packaging freedom to 2D and the application must be adapted to the packaging technique and not vice versa.

With layer manufacturing, it is possible to manufacture very complex 3D geometries. In this study, a four-sided pyramid was manufactured with light diodes on the top and driving electronics on the sides (Figure 1). The six electrical interconnects from the driving electronics to the diodes were formed as tubes inside the structure. The interior of the tubes was plated with copper or silver. The power supply is connected to the corners of the pyramid.

![Figure 1 CAD design of the demonstrator with 3D tubes for electrical interconnects](image1)

Another application demonstrator is shown in Figure 3. This is an Inertial Measurement Unit (IMU) with four gyroscopes. The ideal angle of the inclined surface of the pyramid is $\alpha \approx 35^\circ$. At this angle, the noise is the same in all 3 directions and the resolution and the entire sensitive can be calculated to be independent of the direction [4].

![Figure 2 Photograph showing driving electronics and LEDs on the top.](image2)

It is the same pyramid as in figure 1 except that in this case the 3D interconnections are made by via holes perpendicular to the bottom plane (see fig 4).

![Figure 3 Inertial Measurement Unit (IMU). The gyroscopes are placed on sides of the pyramid, the thick arrows show their axis of sensitivity](image3)

Figure 4 The ceramic IMU platform with gyro components. The circuit patterns are printed with a silver ink in the FCubic machine.

The diameter of the via holes is 1.0 mm and a pin list connector is used with 0.5 mm rectangular pins and 2.54 mm pitch. The clearance between the pins and the via holes is 0.15 mm in the corners. The precision in the machine is good and it was no problem to insert the pin list into the holes.
The circuit pattern was ink jet printed with silver ink. The silver ink is based on nanoparticles of silver and the conductivity of the silver depends very much on the sintering temperature. The resistance in a uniform line was 1½ order of magnitude lower if it was sintered at 200°C compared to 120°C (Figure 5). These results were obtained for silver printed on a polymer sheet. It was therefore strange that we did not obtain any electrical conduction in the silver printed on the ceramic substrate. To overcome this problem, the ink jet printed silver was plated with electroless copper in order to obtain acceptable conductivity. The printed silver catalyses the deposition of copper so no activation of the silver is required. A close-up of the printed and plated circuit pattern is shown in figure 6.

**Figure 5** The resistance in a uniform silver line printed with ink jet and sintered at different temperatures.

The porosity in the ceramic material is about 50% in the as-received parts from the layer-manufacturing machine which may cause problem. The 3D tubes in Figure 1 have been filled with a silver paste and sintered afterwards. The silver paste, however, infiltrates the porous ceramics and causes the tubes to short circuit, see Figure 7. To overcome this, the ceramics parts have to be infiltrated with a filling material, for example ceramic slurry, glass or epoxy. Epoxy-infiltrated ceramics are very efficient, but they have thermal limitations and cannot be used for high-temperature applications. Since the silver paste used for filling the 3D tubes sinters at 500°C, epoxy-infiltrated ceramics are not an alternative for this application. An alternative process based on electroless copper plating was used. In order to achieve plating inside the tubes, the plating solution was pumped through the 3D tubes. An example of copper-plated tubes is shown in Figure 8. The plating process is based on the via hole plating technology used for printed circuit boards.

**Figure 6** Close-up photograph of the ink jet printed and copper plated circuit pattern.

**Figure 7** Short circuit between silver filled 3D tubes.

**Figure 8** Copper plated tubes in epoxy-infiltrated ceramics

### 3. Conclusions

We have demonstrated the possibility to use layer manufacturing as a tool to manufacture application-specific substrates for microsystem integration. The large geometrical freedom makes it possible to adapt the design to specific applications. A crucial factor for the success of free-form ceramics is the technique used to obtain 3D electrical interconnects. We have demonstrated three different techniques for realising 3D electrical interconnects: silver-filled 3D tubes, copper-plated tubes and pin connectors.

The Ink Jet Assisted Layer manufacturing technology used is fast and can be used to directly
manufacture components for microsystem integration. The scale effect makes this technology especially favourable for the manufacturing of small components. The prospect for this technology is quite promising but further development must be done to optimise both materials and processes before it can be utilized in commercial applications.

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References


