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Three-Dimensional Molded Interconnect Devices (3D-MID)

Materials, Manufacturing, Assembly and Applications for Injection Molded Circuit Carriers

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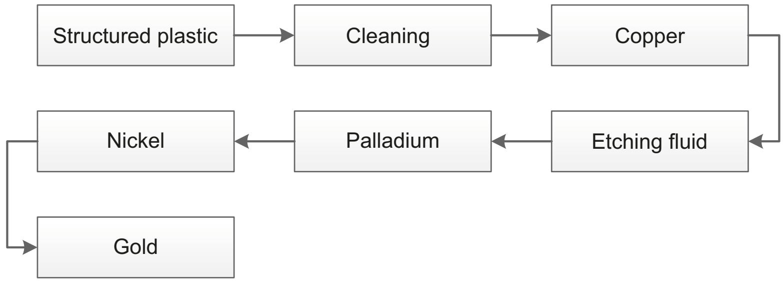

FIGURE 3.28 Flowchart for beaker metallization

etching solution is followed by seeding in a palladium bath. Seeding is required to start nickel/phosphorus metallization in the next step. Application of a very thin gold finish concludes metallization. Thorough cleaning with deionized water is necessary between all these steps in the process.

Beaker metallization is intended for short runs and for process evaluation. As many as ten parts can be metallized in each pass, although this depends on the size of the parts. All the baths have to be analyzed and corrected after each pass. Only then is the next metallization pass possible. Obviously, the number of parts that can be metallized is limited by the time needed to perform these analyses and also by the relatively long dwell times in each bath. It can take two to three hours to complete a pass, depending on how thick the plating has to be.

ProtoPlate LDS®

A joint development of LPKF Laser & Electronics AG and Enthone GmbH, this metallization process was intended specifically for prototyping. It is a bath metallization process for copper plating LPKF-LDS®-structured parts. No in-depth knowledge of chemistry is required, and the bath can be used for experimenting with metallization. The bath has three components based on Enthone LDS Cu 400 PC. Mixing all the components yields an activated copper bath that remains usable for a two-hour time window. Copper layers up to 15 µm thick can be plated in this time. The spent chemicals can be returned in the original packaging to the manufacturer for disposal [132].

This metallization bath is widely used in prototyping, particularly for testing different structuring parameters of the LPKF-LDS® process. It has a footprint of 50 × 40 cm and plugs into a standard socket outlet. The fact that it works only with copper is a drawback, as is the short life cycle [106].

Selective metallization by wet-chemical methods is currently the state of the art, although many complex processes call for special know-how and correspondingly costly equipment.

Various Metallization Coating Systems

Very widely differing connection technologies necessitate metallization layers of varying composition. Each process (soldering, conductive-adhesive gluing, wire bonding, pin contacts) has its own set of requirements for the surface finish. Cu-Ni-Au metallization is the conventional approach, but electroless Cu/Sn and Cu/Ag metallizations are other possibilities.

Excellent solderability, superb bondability with aluminum wires, and long storability are all characteristics of Cu-Ni-Au coatings. Multiple solderings are totally unproblematic. The only drawbacks are cost and the restricted suitability for bonding with gold wires [41].

Tin coatings are very solderable and the manufacturing costs are low, but they have weaknesses in terms of storability and bondability. Tin coatings, moreover, are repairable. The defective tinning can be removed to expose the copper, which can then be regenerated and retinned. A high level of copper depletion during soldering or in storage on account of diffusion effects and the problems associated with multiple soldering also constitute disadvantages [13, 41].

Silver, like tin, is eminently solderable and the coatings are relatively economical. Once again, problems such as storability and the extreme thinness of the coatings tend to complicate handling. As with tin, Cu diffusion takes place during the soldering process. Low mechanical loadability and high potential for electromigration are further drawbacks [41].

3.2.3 Thickness and Roughness of Coatings

MID applications are now widely used for signal transfer, electrical circuitry in sensor applications, and for antennas. A low power requirement is common to all these fields. This settling of past and present MID applications at the low end of the power range has a great deal to do with possible plating thicknesses associated with chemical metallization.

Possible Thicknesses in Relation to Metallization System

Electroless metallization is characterized by deposition rates of only a few µm per hour. This obviously means a certain dwell time in each bath, and this in turn is partly responsible for the costs of metallization. Copper plating thicknesses of well over 10 µm are theoretically possible with conventional industrial metallization equipment. However, the question of economy arises at this point. Standard practice in applications calling for thicknesses in excess of 10 µm is to resort to galvanic buildup, applying copper at deposition rates of around 1 µm per minute.

Beaker metallization is limited to about 10 µm of copper per bath pass, because the bath has to be analyzed and rebalanced as soon as a defined time has elapsed. A ballpark figure for growth rate is approximately 1 µm every ten minutes. Hypothetically speaking, copper can be plated in thicker layers even by beaker deposition. Repassing the copper-plated plastic part in the analyzed and rebalanced copper bath makes it possible to build copper layers thicker than 10 µm. The cost effectiveness of the process should not be the primary variable. The thickness of the copper buildup with the ProtoPlate LDS® process is limited by the life of the bath. The maximum plating thickness is 8 to 15 µm.

Much the same applies for the other metals that can be deposited on a conductive underlayer of copper. The deposition rate for nickel in chemically reductive metallization baths is roughly 6 to 12 µm per hour. It takes about 20 to 30 minutes to deposit a gold finish with a maximum thickness of 0.1 µm. Because the coatings are thinner, beaker metallization is much more closely comparable to other metallization configurations.

Smoothing

Since it is capable of producing conductor structures measuring less than 100 µm, LPKF-LDS® technology in particular has potential for bare-chip assembly. The surface roughnesses of the metallized coatings currently hamper contact by bonding. The plastic surfaces roughened by lasering are reflected in subsequent metallization (unlike galvanic baths, chemical metallization baths cannot be used for smoothing), so the surfaces have to be smoothed after being lasered. The possible methods of smoothing with dies and CO_2 snow jetting are outlined below [185].

Laser-structured plastic surfaces can be die-embossed using purely mechanical pressure, a combination of mechanical and thermal energy, or a combination of mechanical pressure and energy in the form of ultrasonic vibration. Figure 3.29 illustrates how mechanical force is applied in die embossing. The relatively soft laser-structured surface is flattened by the die. This is followed by conventional chemically reductive metallization [185].

In theory, die embossing with purely mechanical pressure loading can be done with soft, elastically deforming dies or hard dies. The advantage of elastic dies is that they do not have to be matched to each conductor structure, so one die can be used for very different geometries. By the same token, conductor tracks can be smoothed all the way to the edges. However, research has revealed that the smoothing effect that elastically deformable dies can apply to laser-structured surfaces is at best no more than slight. Hard dies, on the other hand, can achieve good smoothing results. Even so, the differences in quality are considerable. If die and substrate surface are off parallel the result is an offset in the embossed plastic (Fig. 3.30) [185].

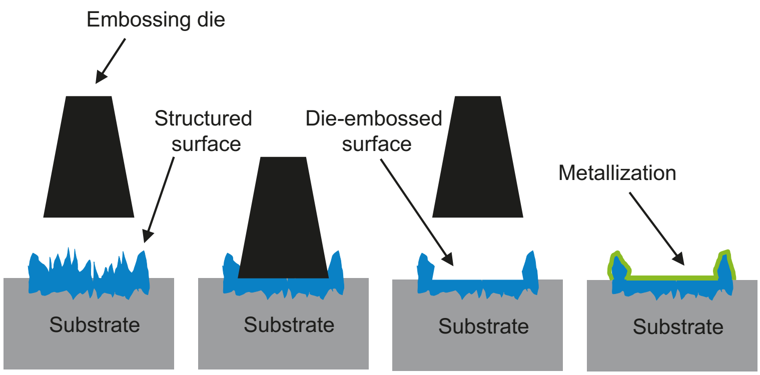

FIGURE 3.29 Diagrammatic illustration of smoothing by die embossing as in [185]

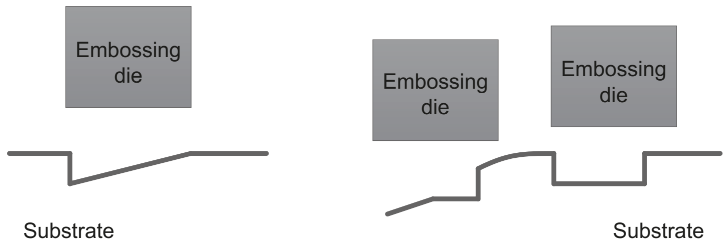

FIGURE 3.30 Possible faults due to lack of parallelism as in [185]

A circular die geometry in combination with a sequence of overlapping embossing strokes promises the most success in purely mechanical embossing. Reduction of around 50% in roughness has been achieved in research. Reliable wire bonding, however, is still not sufficiently viable [185].

One way of further reducing laser-structured roughness is to combine mechanical die-embossing pressure with ultrasonic energy transfer. Suitable die geometries transfer the ultrasonic vibrations selectively to the surface. Research has shown that there is no appreciable benefit to be obtained by employing ultrasonics. Differences in the smoothed surface were due entirely to die pressure, not ultrasonic power [185].

A combination of mechanical and thermal energy is another option for die-emboss smoothing. The die is heated. With the heater suitably calibrated the temperature at the die tip can be precision-set. This method returns a considerable reduction in surface roughness compared to purely mechanical die-embossing cycles. The temperature is crucial. No additional smoothing effect is evident if the temperature is either too high or too low. Die temperature depends on the specific melting temperature and has to be set for each plastic. With optimized process parameters, roughness can be minimized to the extent that wire bonding is possible. However, increasing smoothing gives rise to problems with edge metallization.

Force and temperature combined press the metallization so far into the surface of the plastic that a continuous structure is no longer detectable [185].

In the CO_2 snow-jet process, solid CO_2 ice crystals bombard the surface of the plastic at ultrasonic speed. A combination of mechanical, thermal, and chemical properties means that CO_2 snow can be used for cleaning and for smoothing. Figure 3.31 shows in diagrammatic form how the method is employed for smoothing. The liquid CO_2 coming from the nozzle produces a mixture of CO_2 gas and CO_2 snow that is accelerated to ultrasonic speed by a jacketing ring jet of compressed air [1].

This method can be used to smooth both laser-structured and metallized surfaces. By comparison with simple die embossing, the process is characterized by numerous process parameters. Traversing speed of the CO_2 nozzle, nozzle-to-surface distance, and angle and width of jet are only some among many. These parameters have been studied in detail by researchers. The slower the traversing speed, the smoother the finished surface. No relationship could be established between nozzle-to-surface distance or nozzle angle and surface roughness. CO_2 snow-jetting can bring peak-to-valley height R_Z down to below 10 µm, which is enough for bondability [185].

Smoothing laser-structured flats is possible, but it involves an additional process step and requires the appropriate equipment. Another point to bear in mind is that laser parameters such as frequency and power are responsible for the roughness of the plastic surface. Consequently, if smoothing is a possibility it is also important to look to optimization of LPKF-LDS® laser structuring [185].

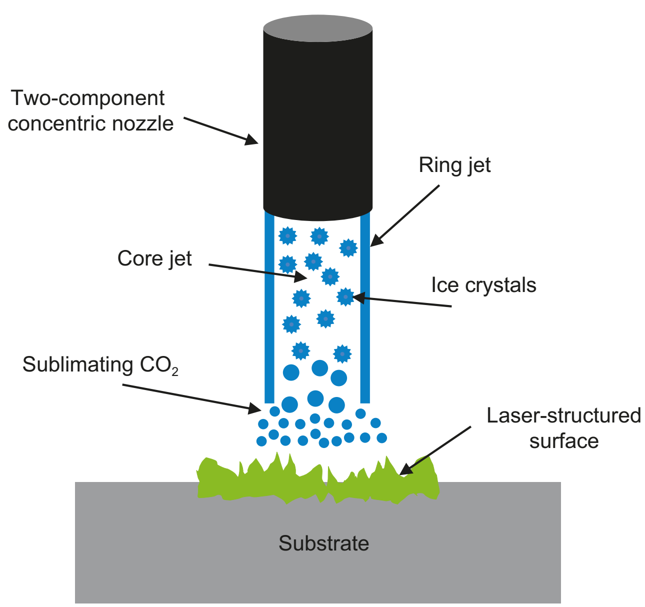

FIGURE 3.31 Diagrammatic view of CO_2 snow-jet smoothing as in [1]