Hot Pin Pull Method – New Test Procedure for the Adhesion Measurement for 3D-MID

Christian Goth[1,a], Thomas Kuhn[2,b], Gerald Gion[2,c] and Jörg Franke[2,d]

[1]HARTING Mitronics, Leugenestrasse 10, 2500 Biel 6, Switzerland

[2]Institute for Factory Automation and Production Systems (FAPS), Friedrich-Alexander University Erlangen-Nürnberg, Fürther Straße 246b, 90429 Nürnberg, Germany

[a]Christian.Goth@HARTING.com, [b]Thomas.Kuhn@faps.fau.de
[c]Gerald.Gion@faps.fau.de, [d]Joerg.Franke@faps.fau.de

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Abstract. The adhesion test of metallic structures on MID (Molded Interconnect Devices) parts is an unsolved issue. So far no method really works reliably. The test methods which are conventionally used are the pull-off test and the shear-test. Both show large standard deviation and the reproducibility is not assured. Nordson DAGE has introduced the new micro-material testing system 4000Plus. This device enables a new test method for the determination of the adhesion strength of MID structures using the hot pin pull (hot bump pull) method. Copper pins (tinned or untinned) are heated up with a user defined temperature profile, soldered to a metallized structure on the MID and then removed vertically upward, while the force is recorded. In this contribution investigations with this new test method are presented.

Introduction

The quality of circuit tracks is of high importance for following assembly processes and has a significant impact on the reliability of 3D-MID products. A decisive feature in this context is the adhesion of the metallic structure to the substrate. The adhesion force is influenced by the material, the injection molding process (molding direction/geometry/molding parameter/flash thickness), the laser process (power/frequency/velocity/hatch), the cleaning process (ultrasonic/water jet/CO_2 snow jet), the metallization process and also by the following assembly processes. The assembly process itself requires a good adhesion, depending on the connection technology and the impact to the substrate/conductor track: ultrasonic power by wire bonding, shear stress due to high temperature range by gluing/soldering, point load due to stud-bumps in the flip-chip process or the force transmission of pins by press-fit technology [6].

There are various possibilities to measure the adhesion strength of metallic structures, but so far no method really works reliably for 3D-MID, manufactured by LDS or two-shot technology. This is due to the bonding mechanism of the metallic structure, the electroless chemical plating process and the available test methods which are adapted from the printed circuit board (PCB) technology. The bonding mechanism is based on a mechanical adhesion. Therefore, a micro rough surface created by laser structuring or etching is necessary. After the electroless plating process the metallization is relatively thin (Cu: 5-15 µm, Ni: 5-15 µm, Au: 0.1 µm). [1] [2]

Methods usually used for the determination of adhesion strength are peel test, shear test and pull-off test (Fig. 1) [1] [2] [5]. The peel test is well known from PCB technology, but minimum layer thickness is > 20 µm according to DIN EN 60249 [3]. Therefore, this test is only suitable for LDS and 2-shot MID with thick layers built up in galvanic processes. The shear test can be performed with or without electronic components. Without electronic components the test is difficult to proceed because of thin metallization layers and beads as a result of the laser process. A special feature in this context is the micro chisel, developed in [5]. The micro chisel is used to peel a structured metal coating or a conductor track while forces in x- and z-direction are recorded and analyzed. With electronic components the shear test is equal to the test known from PCB technology with the specialty that in MID technology usually the component with solder joint and metallization is sheared. Thus, this is an indirect method to determine the adhesion. For the pull-off test standard tensile machines can be used [4]. But the impact by manual soldering/gluing the wire or pin to the metallization and also the temperature influence are high. Both suitable tests for LDS and 2-shot MID, the shear test and the pull-off test, show high standard deviation and require relative large areas for the test – minimum 3.0 mm circles for pull-off test or solder pads for shear test according to the component size. [1]

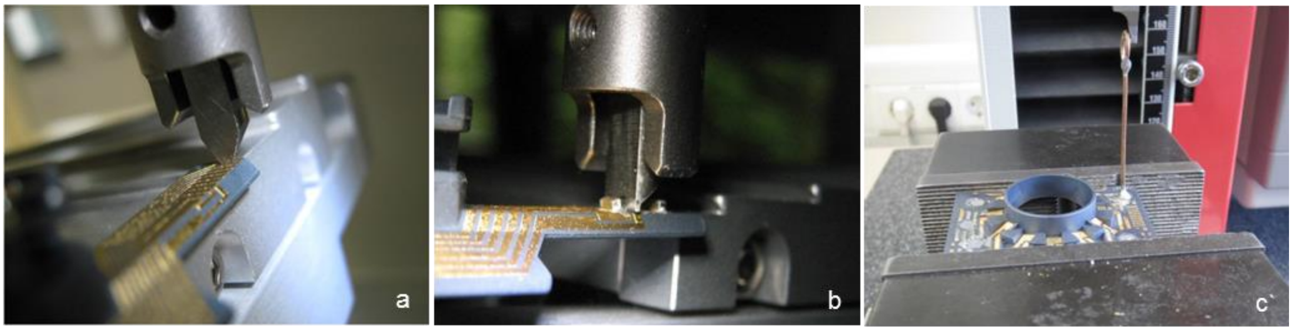

Fig. 1: Shear test of circuit tracks (a) or electronic components (b) and pull-off test (c)

Nordson DAGE has introduced the new micro-material testing system 4000Plus. This device enables a new test method for the determination of the adhesion strength of MID structures, the hot pin pull (hot bump pull) method. In the following contribution investigations with this new test method are presented.

Test method and materials

In addition to various conventional bond and material test methods, the testing system DAGE 4000Plus features the hot pin pull method as a new type of the pull-off test (Fig. 2). For this method a special heatable cartridge is used and can be programmed to apply a time-temperature reflow profile.

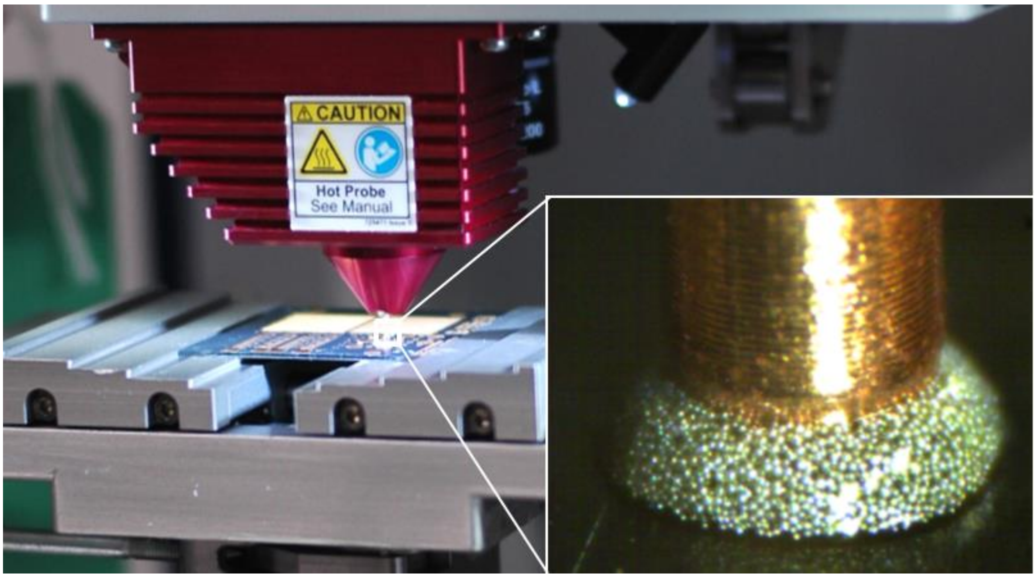

Fig. 2: Hot pin pull test with untinned pins

Straight copper pins with a diameter of 900 µm are inserted into the cartridge and held in place by a spring-loaded mechanism. The copper pins are available with a tip radius of 100 µm, 300 µm or 450 µm in tinned or untinned versions. Via motorized axes the pin is then positioned either directly on the plain test structure (tinned pin) or into a previously dispensed solder paste on the test structure touching the metallized surface (untinned pin). Once the test has been started, the pin temperature ramps up according to the defined temperature profile. Thereby the pin is soldered to the metallized test structure. The cooling is achieved by pulsing compressed air along the pin and onto the test sample. As soon as the defined test temperature T6 (Fig. 4) is reached, the clamping mechanism of the cartridge fixes the test pin and the pull-off process is automatically executed, while the force is recorded.

Because the hot pin pull test is a new test method the basic studies include important and fundamental topics like size of the test pads, influence of temperature profile, wetting of test geometries as well as a possible integration into series production with the focus on the test method itself. Although the results show a huge impact of the used substrate materials on the determined adhesion strength, influencing factors caused by materials or parameters in the different production processes were not considered more closely in this contribution. All investigations were performed with untinned pins and low melting SnBi solder paste. The substrate materials of the specimen were PA6T/X (Vestamid HTplus TGP 3586) and LCP (Vectra E840i LDS). The layout was laser structured and conventionally metallized with Cu-Ni-Au. With the exception of the investigations on the integration into series production the test layout consisted of circles.

Results

Size of test pads. As described above the pull-off test requires test circles with a minimum diameter of 3.0 mm. For smaller pads the measurement uncertainty increases. Because of the pin geometry and the semi-automatic process, smaller areas are possible with the hot pin pull method. To verify this, investigations with test circles with a diameter from 0.6 mm to 3.0 mm for the material Vestamid HTplus TGP 3586 were performed. This means areas from 0.28 mm^2 to 7.07 mm^2. The implementation requires an adaption of solder paste volume and temperature profile for the different pad sizes. Constraint of the test was entirely removed metallization and a completely wetted pad.

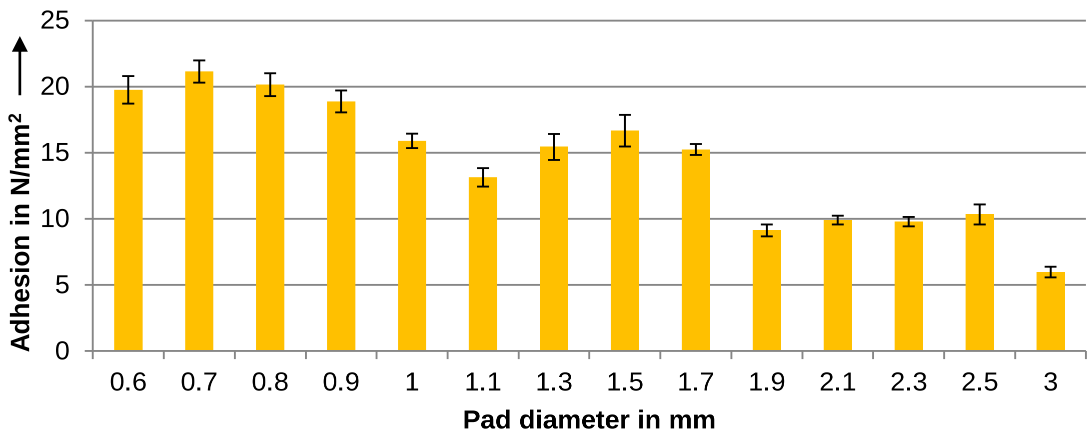

Fig. 3: Evaluation of the hot pin pull test for pad diameters from 0.6 mm to 3.0 mm

The test series shows that the hot pin pull test can be performed with pad diameters up to 3.0 mm. The effect already known from the pull-off test also occurs here: With increasing pad diameter the adhesion in N/mm^2 decreases (Fig. 3). For all pad sizes the standard deviation is relatively low compared to the conventionally used test methods. Even if the amount of solder paste and the temperature profile were not optimized in detail for each pad size.

It is obvious that changing the temperature profile shows an impact to the adhesive strength. In the test series the temperature profile changed at 1.3 mm, 1.5 mm, 1.9 mm and 3.0 mm. Therefore, it is only possible to compare results in detail of tests with the same parameters for the test procedure.

Temperature profile. A further influencing factor of the test method is the temperature profile that is required to solder the pin to the test pad. These investigations were performed with the material Vectra E840i LDS and test circles with a diameter of 1.0 mm. The temperature profile was adapted to the reflow soldering profile recommendation of the used solder paste (SnBi). The required temperature and time period for the reflow process mainly depends on the type of solder paste but parameters like the volume of solder paste or the wetting properties of the metallization must be considered as well. In this test series a peak temperature of minimum 170 °C with a period of 20 seconds was necessary to ensure a complete wetting of the test pads (Fig. 4). The peak temperature T3 subsequently was increased in steps of 40 °C up to a temperature of 330 °C, whereas the further parameters stayed unmodified.

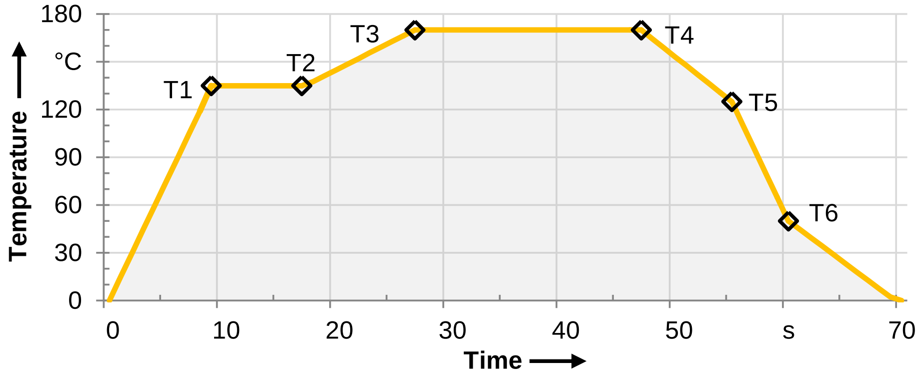

Fig. 4: Temperature profile with a peak temperature of 170 °C

The results show that a significant increase of the peak temperature leads to a decrease of the determined adhesion strength values (Fig. 5). It is obvious that this effect depends on the substrate material and could be enhanced for less temperature-resistant materials. In order to not unnecessarily influence the adhesion by the test method itself the temperature profile should basically be defined as soft as possible.

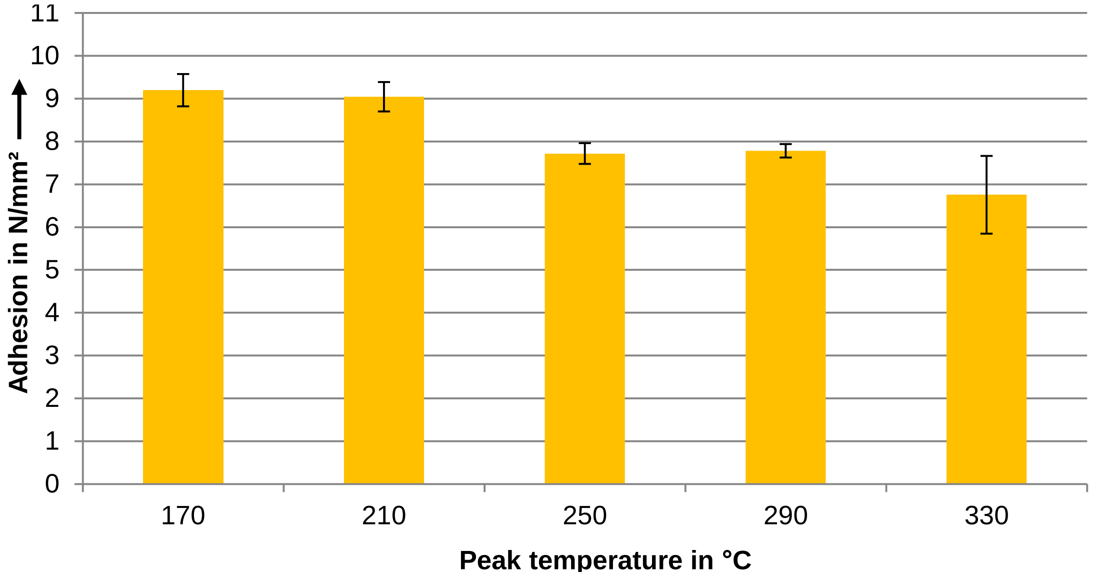

Fig 5: Evaluation of the hot pin pull test for temperature profiles with different peak temperatures

The used HBP 2.5 cartridge compensates the expansion and contraction of the copper pins during the heating and cooling process by adjusting the z-axis position of the cartridge. The compensation algorithm is based on the pin length, the temperature change and the thermal expansion coefficient of copper. A force effect among the test structure caused by the pin expansion/contraction could not be detected.

Wetting of test structures. The complete wetting of the test structure with solder as exemplarily shown in Fig. 6, c is another criterion that has to be fulfilled for the reproducible testing with the hot pin pull method. Decisive factors that influence the wetting are beside the amount of solder paste and the configured temperature profile the properties of the metallized surface (roughness, impurities, etc.). If the test structure is not completely wetted with solder during the pull-off process, the metallization is usually just partly pulled off the substrate (Fig 6, a). By an uncontrolled rip out of a part of the whole metallized area additional forces result which do not enable an insulated consideration of the adhesive strength from the metallization to the substrate. Even if the complete metallization is removed with only partially wetted test structures (Fig 6, b), the uneven distribution of the pull-off force leads to not reproducible influences on the measurement. This behavior could especially be determined at metallization with a thick nickel layer.

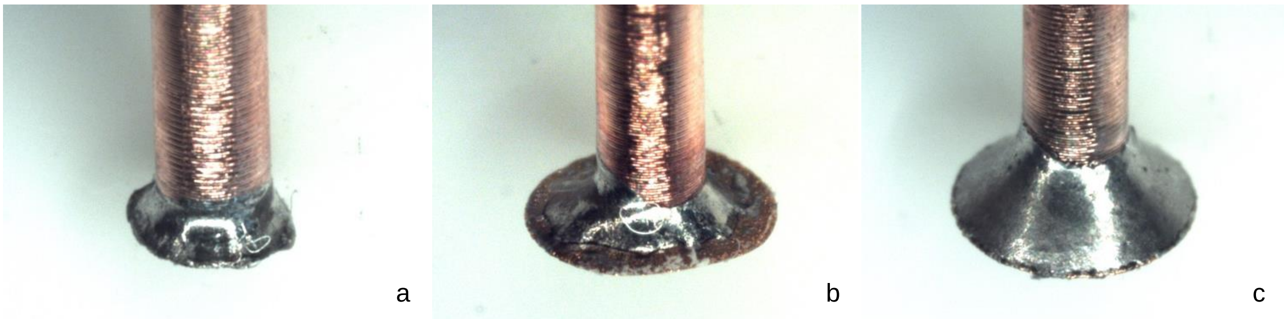

Fig. 6: Released test pads after the hot pin pull test with different solder wetting

Integration into series production. One important topic is the integration of the test method into series production. This means that the series product parts can be used without any further modification of the layout and without any additional test structures.

Ideally, there is an insulated pad as shown in Fig. 7, a. Then, the wetted area and thus the size of the removed metallization are defined – in this case the area of the pad is 3.06 mm^2 (corresponding to a circle with a diameter of approximately 2 mm). Even if the test area is not a circle or a rectangle, the whole metallization was removed in 100 % of the tested pads (Fig. 7, a, b, c). For this test series (20 values) with the material Vectra E840i LDS, the mean was 4.86 N/mm^2 with a minimum of 3.90 N/mm^2 and a standard deviation below 10 % (based on the mean value). Fig. 7, b clearly shows that material was released with the metallization.

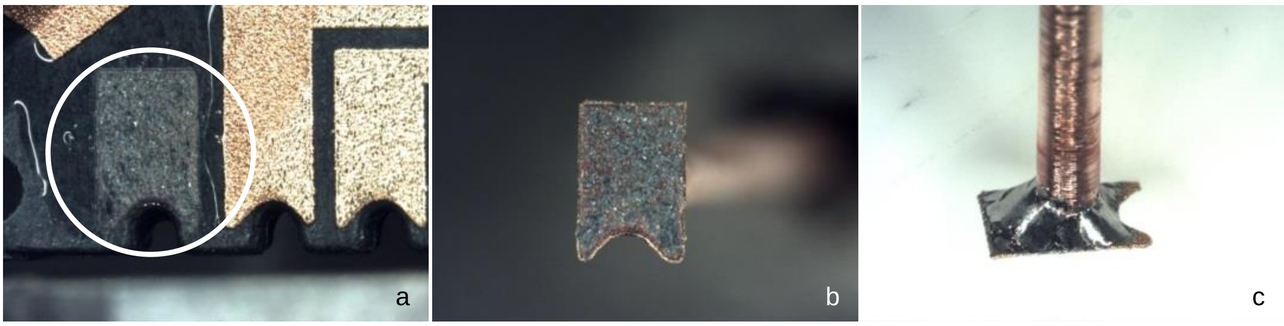

Fig. 7: Exemplarily illustration of pin and pad after the hot pin pull test

In case an insulated pad is not available, it is also possible to use a conductor track or a solder pad. To avoid undefined wetting the soldered area can be limited e.g. by solder resist.

Summary and Outlook

Focus of this paper is to present fundamental topics of the hot pin pull method with the focus on the test itself. The investigations confirm that the hot pin pull method is an easy test procedure to determine the adhesion of metal coatings on thermoplastic materials.

For all investigated test configurations the whole metallization was released. The test results show a low standard deviation below 10 %. Areas from 0.6 mm to 3.0 mm were examined. Different pad sizes are possible, but the adhesion decreases with increasing pad diameter. The current recommendation for a test geometry is a circle with a diameter of 1.0 mm because of the necessary temperature and relation pin to pad size. The temperature profile should basically be defined as low as possible, because increasing peak temperatures show a negative impact on the adhesion strength. For reproducible test conditions and thus reliable results the test should be proceeded with completely wetted structures.

For most MID users and also for manufactures it is an important issue to use parts out of serial production. The hot pin pull test allows the direct use of serial parts without layout modification or additional test areas.

To establish the hot pin pull method as a standard testing method for 3D-MID with the possibility to compare results of different products, different test batches or even different materials standards are necessary, e.g.:

- using defined machine parameters (e. g. take-off speed)
- using defined test geometries (e.g. 1.0 mm circles)
- define the amount of solder paste (related to the test pad)
- define the temperature profile for the test (also related to the test pad and amount of solder paste)

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