Interconnection Technology based on combination of Isotropic Conductive Adhesive filled by Metal-Coated Polymer Spheres with Compliant Ball Greed Array

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ABSTRACT

Interconnection technology based on combination of isotropic conductive adhesives (ICA) filled by metal - coated polymer spheres (MPS) with Compliant - Ball Grid Array (C-BGA) has been introduced and discussed as an alternative to technology featuring a combination of ICA with brittle solder BGA.

As an MPS for ICA and C-BGA two types of MPS equal in production technology but different in size were used. The first type is an MPS for ICA with a diameter of 10 µm and 30 µm and for a second type MPS for C-BGA - 380 µm and 720 µm diameter. From this there are four combinations of different size MPS which will be examined.

Since both types of MPS have the polymer core there would not be any mismatch of the thermal expansion coefficient and thereby it can potentially improve the mechanical properties. Moreover, different metal coatings of MPS and different sizes of MPS in combinations may affect electrical properties and reliability of the interconnection.

Four types of samples, one for each of four types of combinations of MPS, were manufactured. They were electrically and mechanically tested; several effects were detected and characterized. However, the alternative idea of replacement of brittle solder by C-BGA in combination with ICA filled by MPS for interconnections requires a further in-depth study in order to be implemented.

CONTENTS

LIST OF ABBREVIATIONS

ECA – Electrically Conductive Adhesive

ICA – Isotropic Conductive Adhesive

MPS – Metal-coated Polymer Spheres

PSB – Printed Circuit Board

MEMS – Micro-Electro-Mechanical System

BGA – Ball Grid Array

C-BGA – Compliant Ball Grid Array

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1 INTRODUCTION

1.1. Background and Motivation

The interconnection technologies using tin/lead (Sn/Pb) based materials were widely used in microelectronics, semiconductors, radio and etc. technologies, but they have been restricted because of their toxicity [1]. The implementation and use of lead-free materials that fit for environment protection is extremely important. One type of this material is lead – free solder. In order to replace Lead other metals were used in alloys with Tin, such as copper, silver, bismuth, indium, zinc, gold and etc.

Also, the reasons for the transition to a new type solders (in addition to environmental security) are some of its operational characteristics of such alloys. However, there are a number of causes why the industrial application of this type of alloys is still limited. The fact that lead-free type solders have higher melting point range than lead based solder, affects the complexity of solder process and is not acceptable for some applications of the interconnection technologies. Also, lead-free solder has a higher Young's modulus thus making it more brittle under mechanical stress, which influences the reliability of interconnection used lead-free solder.

1.2. Isotropically Conductive Adhesive (ICA)

The other alternative of the Sn/Pb based materials is Isotropically Conductive Adhesive (ICA), a type of Electrically Conductive Adhesive (ECA). ICA have been developed as possible candidate for replacement of traditional tin/lead (Sn/Pb) solder for electronic interconnection applications and technologies, such as: a surface mount technology (SMT), flip chip, chip scale package (CSP) and ball grid array (BGA) applications [2]. Isotropically conductive adhesive (ICA) - it is electrically conductive adhesive which conductive properties are equal in all directions. These adhesives are composites of polymer resins and conductive fillers [3]. Conductive fillers may include silver (Ag), gold (Au), nickel (Ni), copper (Cu) particles in various sizes and shapes. Ag is the most common conductive filler for an ICA due to its high conductivity even as Ag oxide [2] [4]. Optimal combination of filler particle's geometry, size and concentration provide minimum resistance, the best contact between neighboring metallic particles, and strongest adhesion to the polymer matrix [4] [5]. Electrical Properties of ICA is an important parameter based on Percolation threshold theory. The Percolation threshold is a mathematical concept related to percolation theory. It describes the behavior of connected clusters in a random graph. In the case of an electrical percolation, conductivity increases sharply (by several orders of magnitude) when the concentration of inclusions or filler exceeds a critical value[6] [7].

1.3. Metal-coated Polymer Spheres (MPS)

MPS is a type of filler in the adhesive matrix for ICA. It is made from polymer spheres coated by metal. Metals can be different, usually, nickel, silver, gold and copper. Silver is a noble metal and its oxide is highly conductive, which is a clear advantage for the electrical performance of interconnections. The presence of the polymer core substantially reduces the consumption of metal and the cost of this type of technology. The employment of MPS as polymer core solder balls (Compliant Ball Greed Array (C-BGA)) instead of solder ball in ball greed array (BGA) applications is another method of MPS use [8].

2. MATERIALS, TECHNIQUES AND SAMPLES MANUFACTURING

2.1 Materials

In this master thesis, Metal Polymer Spheres (MPS) - based ICAs were prepared by using an adhesive matrix filled with MPS. Tested cards "substrate" and "component" provided by Conpart Company.

2.1.1. Adhesive

A commercially available two-component epoxy system was used as the adhesive matrix - premix for all self-made prepared adhesive pastes in this master thesis.

According to the specification from the supplier, part A - non-crystallizing bisphenol-A/F based liquid epoxy resin blend of Araldite® PY 302-2 [9], while the part B - the hardener epoxy curing agent of The JEFFAMINE® Polyetheramines [10]. Mixing ratio by weight of part A and part B was 100 : 35 and densities 1.17 g/cm^3 and 0.948 g/cm^3, accordingly.

2.1.2. MPS Types of metal-coating for polymer spheres

Silver Ag and copper Cu were applied as a coating material for polymer spheres, which are the most common metals for conductive particles. Ag has good chemical stability and good high electrical conductivity, compared to other metals. Another advantage is that Ag oxide is also electrically conductive, compared to the most other metals.

2.1.3. MPS Sizes of metal coating polymer spheres for ICA

Two different sizes of MPS for ICA were provided by the Conpart Company. In the first instance, it is 30 µm diameter MPS, which were investigated and proved its suitability in many previous research. Furthermore, 10 µm diameter MPS were included in purpose to look at the effect of filler size on the conduction of this new type of an interconnection. Herein, spheres of 30 µm and 10 µm MPS size are referred as type A.

As it was proved in previous research, for the same filler volume fracture, ICA filled by 4.8 µm Ag-MPS has a lower resistivity than ICA filled by 30 µm Ag-MPS. Thus, the smaller particle size spheres will show low electrical percolation threshold and compare, at the same volume fraction with bigger spheres, small spheres have better electrical conduction [7].

2.1.4. MPS. A particle loading of adhesive matrix

A particle loading of 40 vol% for both types ICA, 10 µm and 30 µm, was selected based on the electrical conductivity and rheological results from previous researches and trial tests stencil printing [11]. In that research, it has been determined the electrical percolation threshold (lie around 24 vol % for particle sizes 4.8 µm and 33 vol% for 30 µm.) It means that after these values of volume fraction the conductivity increases rapidly. Moreover, until particle fraction of 55 vol%, the ICA pastes are in uniform suspension, with sufficient viscosity at which the printing process can still be done [7].

Several experiments were performed in order to demonstrate that the most satisfying printing results with good shape and fluidity of the adhesive on pads. The experiments were made at 24 vol%, 33 vol%, 40 vol%, 45 vol% and 55 vol% for both sizes of MPS type A.

Trial stencil printing demonstrated that the most satisfying printing results with good shape and fluidity of the adhesive on pads were at the 40 vol% of particle fraction for both ICAs. Several results from this trial printing are presented in a Tables 1 and 2, below.

Table 1. Examples of printing of 10 µm ICA

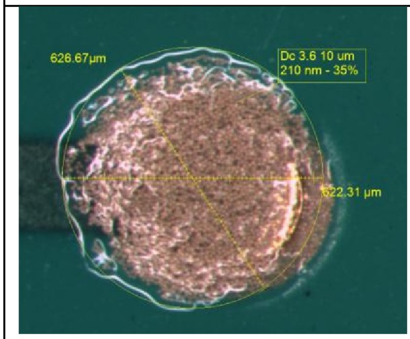
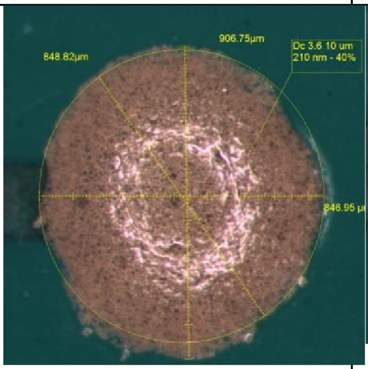
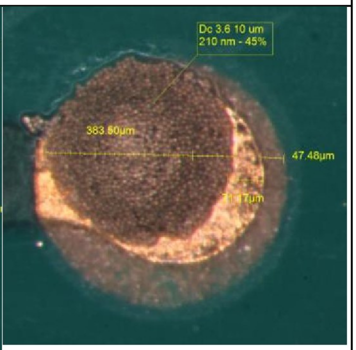
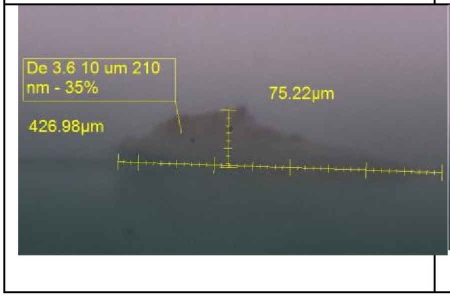
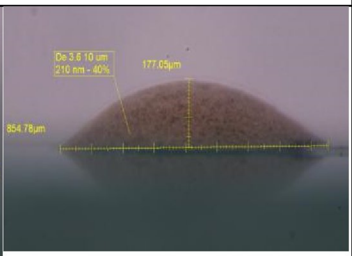
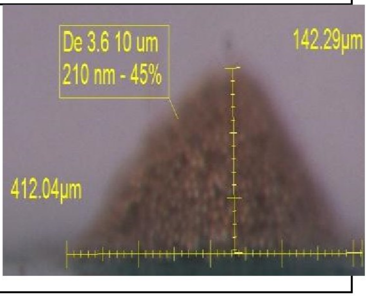
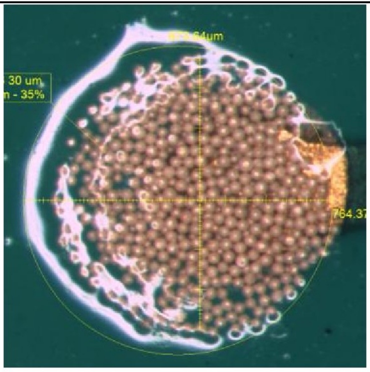
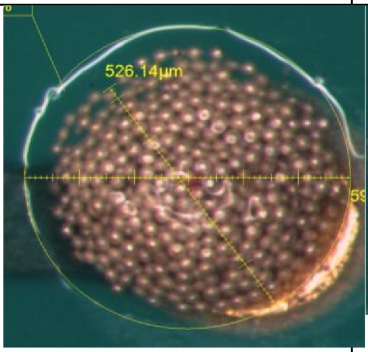
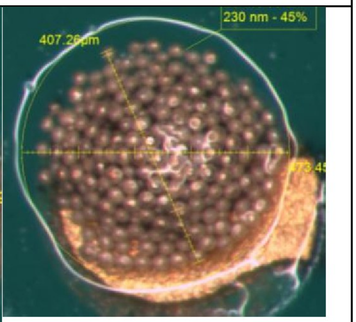
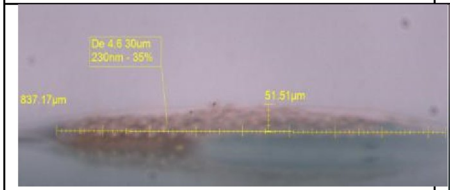
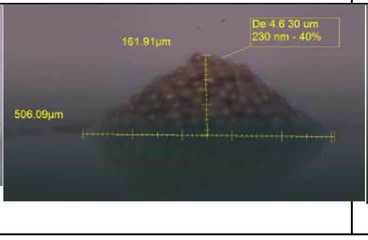
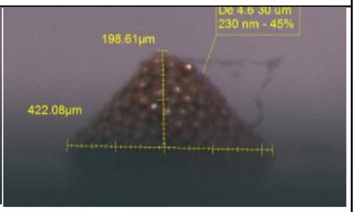
33 vol% ICA with MPS Size – 10 µm	40 vol% ICA with MPS Size – 10 µm	45 vol% ICA with MPS Size – 10 µm
		
		

Table 2. Examples of printing 30 µm ICA

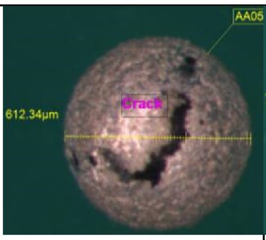
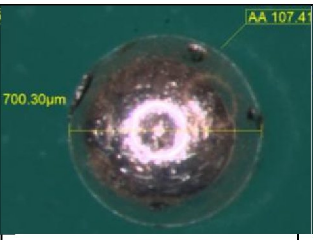
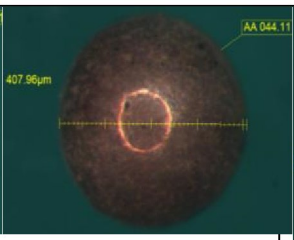
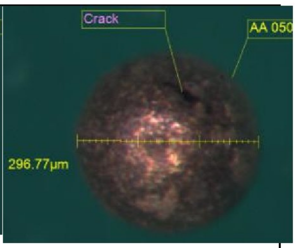
33 vol% ICA with MPS Size – 30 µm	40 vol% ICA with MPS Size – 30 µm	45 vol% ICA with MPS Size – 30 µm
		
		

From the results have shown in the tables 1 and 2, it can be seen, clearly, that different ICAs with 40 vol% have a similar shape of printing pattern, which is adequate for further experimental work.

2.1.5. Metal coated polymer spheres for a Ball Greed Array

Instead of conventional solder balls, to apply a compliant BGA on a substrate, MPS were also used. A set of different MPS were provided by the Conpart Company. These BGA were produced using the same coating technology as for a conductive filler to create an ICA, but with another range of the diameters and coating material. From the several types of MPS two types were selected, this choice was based on important parameters. First of all, the quality of the MPS coating. By optical inspection using an optical microscope The Leica DM4000 M it was figured out the types of balls with the best coating quality that are uniform, without cracks and not porous. Some of the results of this optical inspection can be seen in the Table 3, below.

Table 3. Results from the optical microscope inspection

Picture				
BGA	AA051.2	AA107.4.1.4	AA044.11	AA050.2

According to the results shown in the Table X, it can be seen clearly, that some types of spheres have significant drawbacks, such as cracks in MPS AA051.2 and porous in MPS AA050.2, which in turn could impact performance of the whole interconnection. Second, according the JEDEC standards for the Solder BGA size [12], one size, 720 µm diameter was chosen, which was close to conventional one, and another one, 380 µm diameter to compare BGA size effect on the performance of this type of interconnection. Herein, both, 720 µm and 380 µm, are referred as MPS type B. Besides, choice of the BGA with a coating material - Ag, was due to the same reasons as for MPS type A. Second type of the BGA (380 µm) was coated by a layer of copper underneath a layer of silver. Details of all MPS used in this Master thesis are presented in Table 4.

Table 4. Specifications of all MPS

Company code	Diameter	Polymer	Coating	Density
Dc 3.6 (Type A)	10 µm	resorcinol - formaldehyde	210 nm Ag	2.25 g/cm^3
Dc 4.6 (Type A)	30 µm	resorcinol - formaldehyde	230 nm Ag	1.58 g/cm^3
AA107.4.14 (Type B)	720 µm	resorcinol - formaldehyde	20 µm Cu + 0.2 µm Ag	
AA044.11 (Type B)	380 µm	resorcinol - formaldehyde	0.5 µm Ag	

The table 4, shows that both types A and B MPS have the same type of the core polymer, thus matching in thermal expansion coefficient and making it impossible for this induced stress and lead to further cracks and failures, so thermal conducting experiments is not required.

2.1.6. Printed circuit boards

Test card "substrate" and "component" were provided by Conpart Company. They are made from FR4, with 17 µm thick Cu and ENIG (electroless nickel and gold) Au - flash. [13] FR4 is the most common and high-quality material used for the manufacture of printed circuit boards, it is good and high quality. It has good physical properties, stable size characteristics, and high resistance to adverse climatic conditions. Good physical and chemical characteristics make this material the most demanded.

Geometry and characteristics of substrate and component:

Substrate with Cu pads diameter - 0.38 mm and pitch 2 mm, thickness – 1,7 mm and size: 25 x 75 mm. Number of pads along each side are 19, that forms the longest daisy chain with 38 interconnections. Component 3 with length - 38 mm has the same amount, material and same size of the pads. The image of the substrate and the components are shown in the Figure 2-1, below.

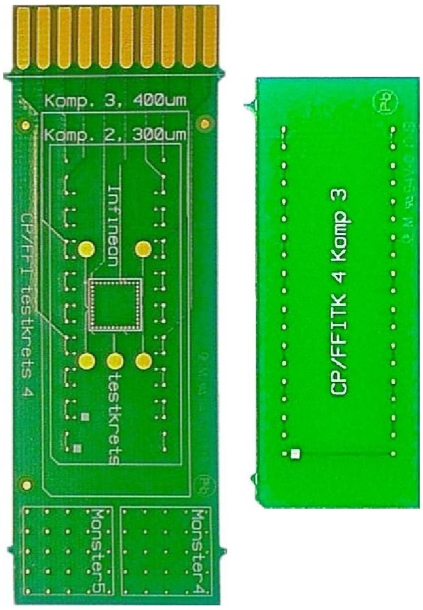


Figure 2-1. Substrate and component

2.2. Equipment

2.2.1. Stencils for printing

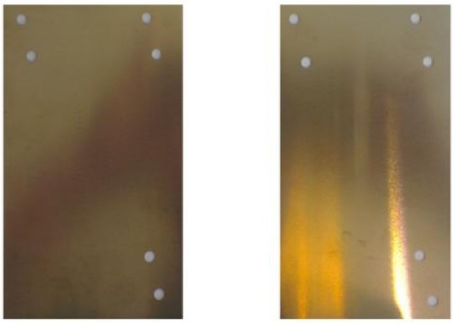


Figure 2-2. Stencils

The ICA pastes were applied to the metal pads on the PCB by screen printing. The volume of the printed ICA paste is determined by the stencil aperture and the stencil thickness. A stencil from stainless steel with thickness of 0.2 mm and size 120x70 mm, produced by HP-Etch AB Company [14] were used for a screen printing. The stencil apertures were circular with a diameter of 0.4 mm. Picture of the stencils are present on Figure 2-2.

2.2.2. Printing equipment. Design and manufacturing.

For the successful stencil printing ICAs on the PCBs special equipment were designed and manufactured. It is a set of three aluminum bars of different sizes with determined size cavities inside, which are matching to the dimension of the "substrate" and "component". The first bar - the base or frame, it is the basis in which are inserted two other bars, alternately. The two next bars, respectively, serve as supports for the substrate and components, the size of the cavities correspond to the size of the substrate and the component. Besides the base - bar has some special holes for the alignment of the stencil relative to the PCBs before printing of ICA. Furthermore, all bars are equipped with special notches for a comfortable introduction and removal of component of the system.

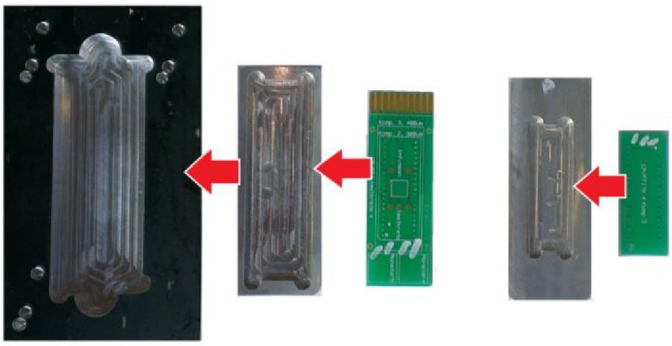


Figure 2-3. Printing equipment

For a modeling of this printing equipment, it has been installed and used free software SketchUp. [15]. Using this software were created 2D and 3D models and drawings. The drawings have been constructed on the basis of given sizes of printed circuits and stencil.

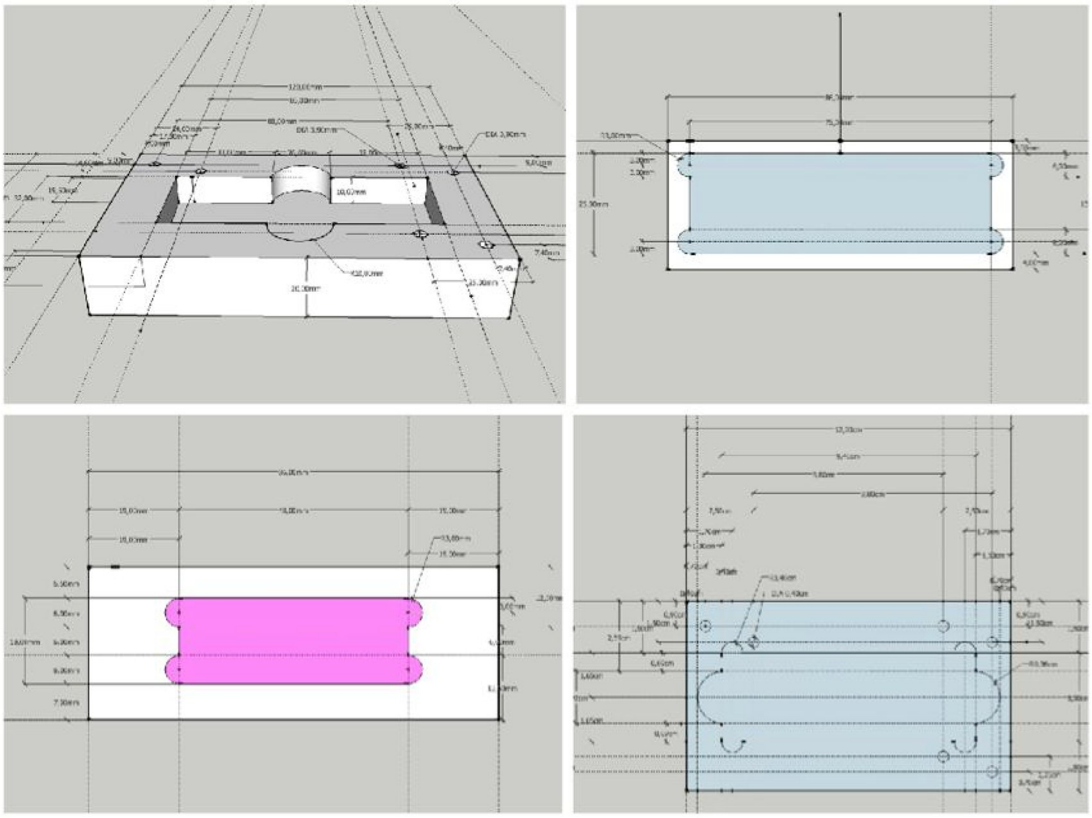


Figure 2-4. Drawings from SketchUP

2.3. Sample preparation and manufacturing

A. PCBs preparation.

PCB and components have been extracted from the frame holder, their edges were polished for easy use of printing equipment. On the back side of the components, at the center a special mark was placed, to optimize the bonding process.

B. ICA preparation

The ICA was supplied as a two-part epoxy system that can be stored at room temperature in its un-mixed state. After mixing the adhesive, it has a shelf life of 16 hours but this can be extended by storing it at - 40°C.

C. Printing

Pattern of the formulated adhesives were manually printed onto the PCB boards using a laser cut stainless steel stencil and a razor blade.

D. Manual process of pick and place BGA on a PCB

After that BGAs were picked and placed manually on each pad covered by ICA on a substrate.

E. Manual alignment of the BGA

For each substrate with the BGA placed on it, it was carried out optical inspection and alignment with an optical microscope The Leica DM4000 M and special small hook.

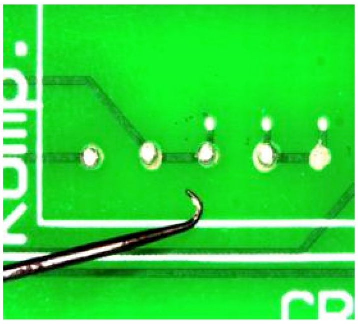


Figure 2-5. Ilignment of the BGA

F. Bonding

The connection process was carried out with the help of FINEPLACER® PICO AMA Automated Flip Chip Bonder[16]. It is a cost effective, fully-automated bonder, offering a high level of application flexibility. It was used «Flip Chip» installation method. Alignment of the substrates and components relative to each other were manually performed. For bonding, firstly, it was used a force of 5 N and 10 N; however, the bonding was not successful. Therefore, a force of 15 N was used for bonding of all samples. Pictures from the bonding process are presented on Figure 2-6 below.

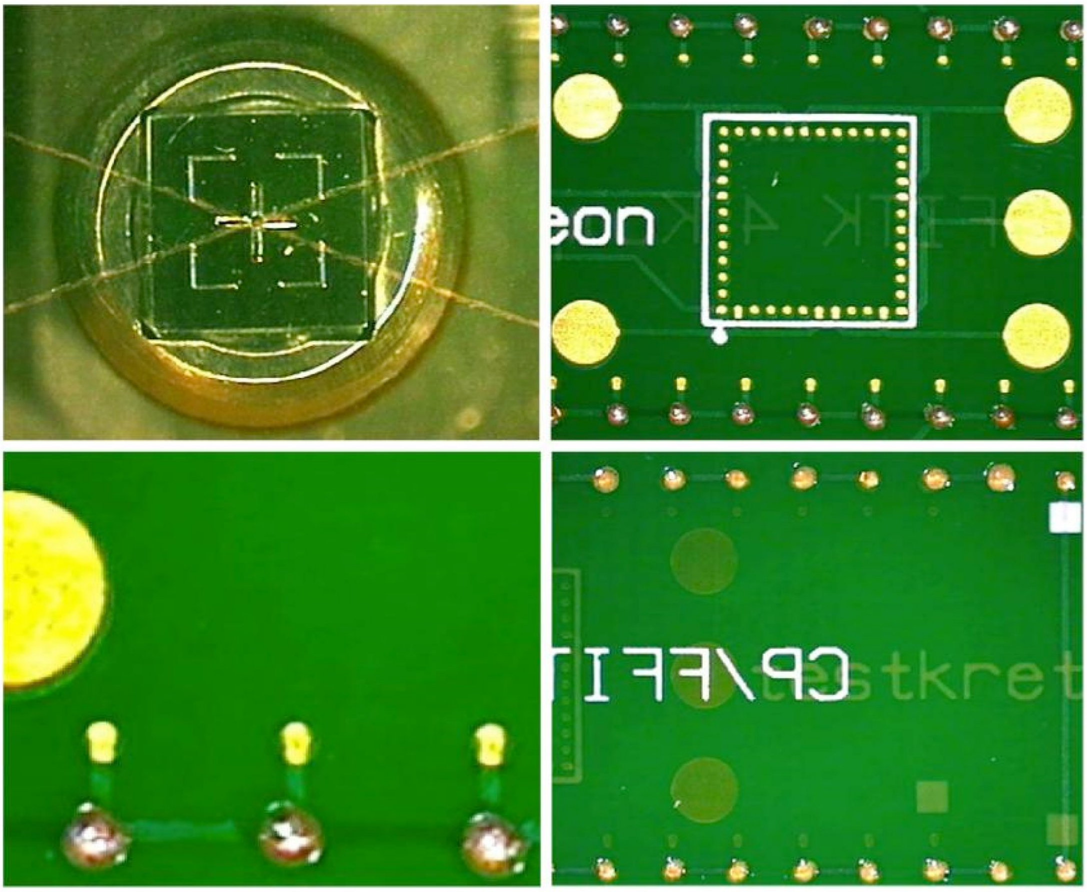


Figure 2-5. Bonding process.

G. Curing

The system - the substrate and component bonded together by ICA and BGA was cured in a Thermal Chamber Thermax TS4115 at 150°C for 20 minutes following the manufacturer's recommendations. Thereafter, finished systems were cooled down and tested for operability.

Eventually around 55 samples were made, but 40 operable samples were characterized and tested for further research, 10 for each combination of ICA and BGA.

Table 5. ICA and BGA combinations for samples and Figure 2-7 shows sets of operable samples

No. of combination	ICA	BGA
1	10 µm	AA107.4.14
2	30 µm	AA107.4.14
3	10 µm	AA044.11
4	30 µm	AA044.11

Table 5. ICA and BGA combinations for samples.

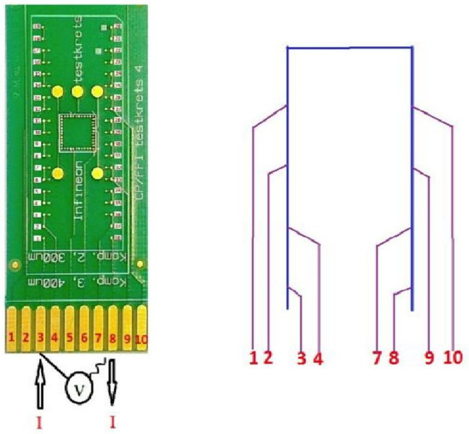
Figure 2-6. Manufactured samples

3. CHARACTERIZATION METHODS

3.1. Electrical measurements

In this master thesis, the electrical properties of new interconnection based on ICA filled by MPS and compliant BGA and their performance were investigated. Electrical conductivity of ICA filled by MPS and compliant BAG relies on several factors such as concentration, individual conductivity of individual particles and etc, that has been explored in several studies before. In this thesis the task is to look at the viability of a new connection, in search of replacement of the conventional solder balls in BGA by complainant BGA. This replacement and effect of the various MPS sizes in ICA and BGA for this type of interconnection would impact the electrical performance. Ten samples for each configuration of ICE and BGA were tested. Each sample consisted of several daisy chains of different length and number of interconnections. A resistance was calculated from four point probe measurements by Probe Station PWS Probe II (The semi-automatic probe tester, with the microscope) on nine different daisy chain for each sample. Constant current I = 10 mA was applied to pads number 3 and 8, detected voltages were measured from pad number 1 till pad 10. Figure 3-1 presents measurements configuration.

Figure 3-1. Measurements configuration



Resistance was measured for several configurations, which have been described before. Average resistance of longest daisy chain per one interconnection for the was calculated and recorded in the table 7 of results. With one refinement, this resistance is an overall resistance which also included the resistance of all the pads and tracks.

Based on the results of the above mentioned test several properties of this type of interconnection would be investigated. Those properties' influence on the electrical performance of this type of interconnection is to be investigated.

3.1.1. Size effect of MPS type A on the resistance of interconnections

As the filler volume fraction has been higher than percolation threshold, both ICAs are supposed to show good and predictable electrical performance.

Moreover, from the same filler volume fracture for both types of ICAs filled with 10 µm and 30 µm the ICA with 10 µm MPS is to have a lower resistance than ICA with 30 µm. This is due to the surface to volume ratio, 10 µm MPS have it larger than 30 µm size spheres. Thus, more opportunities to create contacts appear. Hereby in 10 µm ICA resistance will be lower, as it has been proved in previous research [7]. This property cannot be clearly seen from the electrical measurements results, because the combinations of MPS type A with type B may have an impact.

3.1.2. Effect of different types of MPS (type A and type B) combinations on the resistance of interconnections

In order to understand and describe the different types of MPS combinations effect, the following approach has been used. In this approach each connection in between two surfaces of sphere type A and sphere type B is considered as a separate contact. It is clear that the larger amount of contacts exist the better electrical conductivity will appear. The maximum number of contacts appears when entire surface area of sphere type B is covered by spheres type A.

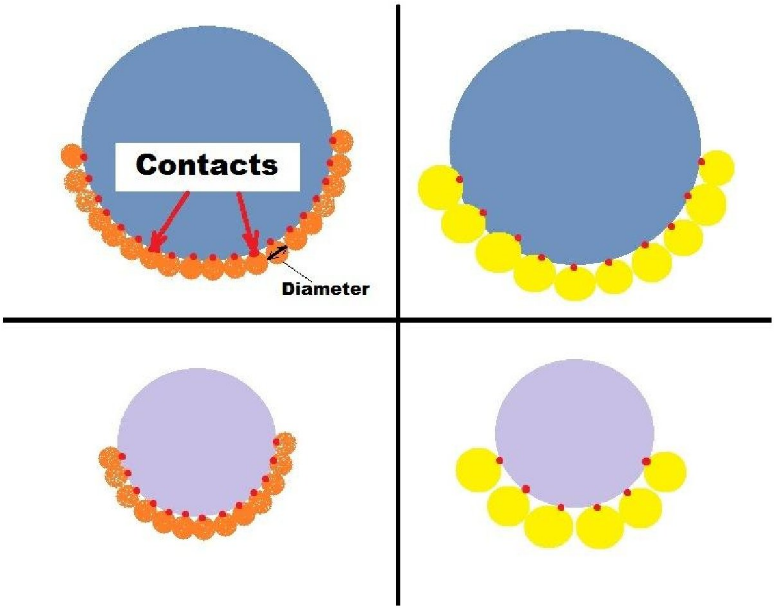


Figure 3-2. Illustration of the approach

Logically it turns out that a sphere with a large surface area type B covered by maximum amount of the small spheres type A will create a large number of contacts. But if the size of large sphere type B will reduce or the size of small spheres type A will increase, the number of contacts will reduce. Figure 3-2 presents schematic illustration of this approach. Taking into account the dimensions of the two types of MPS type A and two types of MPS type B, it was theoretically estimated the probable number of contacts for each combination of spheres. Comparing the theoretically calculated number of contacts with an electrical resistance for the all four combinations, the examination of the working principle of this approach poses an interest. The number of contacts for each of 4 combinations were calculated by dividing surface area of a single sphere type B by the meridional plane section area of a single sphere type A, as illustrated in Equation 1.

$$N = \frac{s_{sp\,h}}{S_{mp}} = \frac{4\pi R^2}{\pi R^2} \quad \text{- Equation (1)}$$

where

N – number of contacts for a single sphere type B in contact with maximum number of spheres type A.

$s_{sp\,h}$ −single surface area sphere type B

S_{mp} − meridional plane section area of a single sphere type A

The results of this calculation are presented in Table 6 below.

No. of combination	Combination	Number of contacts
1	S720/S10	20000
2	S720/S30	2300
3	S380/S10	5700
4	S380/S30	640

Table 6. Number of contacts for each combination of MPS type B with MPS type A

It is important to note that the table shows the result calculated for the combination of one sphere type B and maximum number of spheres type A around. A number of interconnections consisting of MPS type B in each sample is 38 and is equal for all combinations.

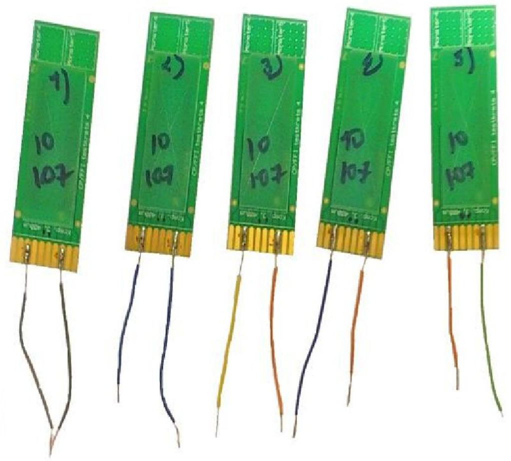
3.2. Mechanical characterization. Three point flexural test.

For high quality and reliable electronic components and materials flexural tests are an important method in both the manufacturing process and research and development, used to define a material's ability to resist deformation under load. A component's and/or material's flexural strength provides critical insight into the modulus of elasticity in bending, flexural stress, flexural strain and effective stiffness. It has several advantages: it does not need complex sample preparation and it is fast. However, this method has an disadvantages: the results of this testing method are sensitive to sample and loading geometry and it is a destructive test [17].

Flexural tests simulate stresses on samples. The physical response behavior of the sample is then monitored.

In this master thesis Universal Material Testing Machine LLOYD Instruments LR 50K equipment was used. Tested samples were placed on two parallel supporting pins with a settled distance apart. The loading force is applied in the middle by means of loading pin at a constant rate until sample failure. This configuration provides uniform loading of the samples and prevents friction between the samples and the supporting pins.

Figure 3-3. Soldered wires on samples



To determine the maximum load and maximum extension at failure the components are electrically monitored during the tests. For this purpose a multimeter have been used in R measurement mode. The device was connected through the terminals to the pre-soldered wires on the sample. Pre-soldered wires on the samples are shown on Figure 3-3 above. To determine the force and extension for all samples, it has been given a constant speed of 5 mm/min and the limited distance. Those parameters were kept equal for all samples to keep uniform mode of testing. On Figures 3-4, 3-5 schematic drawing and real pictures of the three point flexural test are shown.

Figure 3-4. Schematic drawing of the three point flexural test

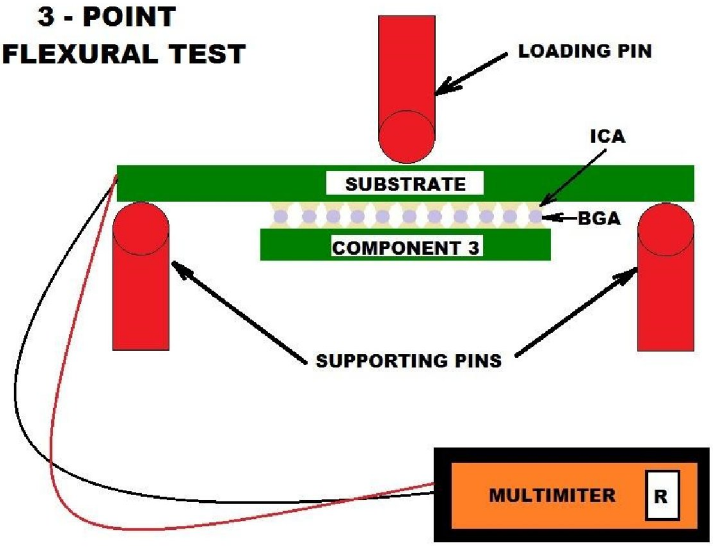
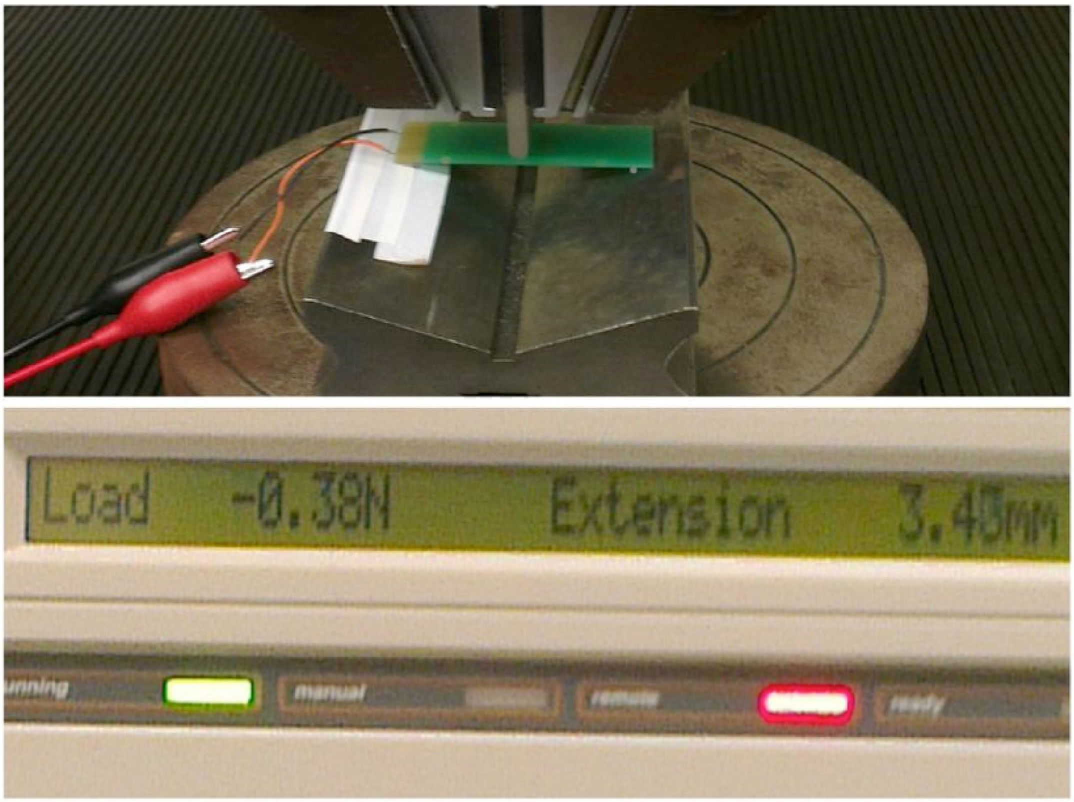


Figure 3-5. A three point flexural test



As soon as a stable resistance is followed by a dramatic increase of its value, the destruction of the sample is detected. An effective stiffness is defined as a relation of the load to the expansion at the moment of failure. Since the core of all types of MPSs is made from the same polymer material but coating material for some of them is different, the effect of different type of metal coatings and effect of different sizes of MPS could influence the samples' effective stiffness and strength.

The strength of a material is defined as the maximum stress that the material can sustain under a loading before the failure. Strength of this interconnection will depends on several different properties, individual strength of epoxy matrix, strength of metal coated polymer spheres filler, strength of individual large spheres, it is also depends on transfer stress in-between the particles and the matrix and particles to particles and etc. It is difficult to analyze the impact of all of these parameters in this study will be investigated several effects, which may have an impact.

3.2.1. Effect of different type of metal coatings

Due to the fact that core materials for all types B of MPS are identical, the metal coating materials of these spheres can affect their strength and stiffness. For spheres of size 380 µm coating was made only of silver with thickness of 0.5µm, and for spheres of size 720µm it was 20µm Cu + 0.2µm Ag coating. Layer of copper have thickness of 20 µm what is much larger than thickness of silver layer. Furthermore, copper has a higher Young's modulus than silver: 110 - 128 GPa compared to 83 GPa. Therefore, sphere type B coated by both copper and silver is assumed to be more resistant to deformation and be able to withstand a larger load.

In considering the effect of different type of metal coatings of MPS type B on the mechanical properties, we disregard the effect of the particle size on its strength.

In previous studies it has been proven that in composite materials such as resin reinforced by different types of particles the Young's modulus of the particles in resin is insensitive to the particle size. Only when the particles are reduced to a critical size, such as 30 nm, there will be obvious effect of particle size on Young's modulus. Since in this master study MPS sizes of 380 nm and 720 nm are examined, the effect of particle size on Young's modulus will not be significant [18] [19].

3.2.2. Effect of the MPS size of ICA on the strength of interconnection

Due to assumed structural similarities between interconnection based on ICA filled by MPS with compliant BGA and particulate-reinforced polymer composite materials, the structural model of the latter is employed.

Based on the results of the previous research on composite materials, particle size has a significant effect on the strength of particulate-filled polymer composite. It has been proven that smaller particles have a higher total surface area for a given particle loading. This indicates that the strength and overall ductility of the material increases with increasing surface area of the filled particles through a more efficient stress transfer mechanism [18].

4. RESULTS AND DISCUSSION

4.1 Electrical characterization

The Table 7 below shows the results of testing of all types of samples for electrical property. Resistance was measured for several configurations, which have been described before. Average resistance from 10 samples of 4 combinations each for the longest daisy chain per number of interconnections was calculated and recorded in the table of results. From the resulting data a number of properties of this type of interconnection are indicated and discussed below.

4.1.1 Size effect of MPS type A on the resistance of interconnections

It could be seen from the table 3 that in spite of the presence of the MPS type B in this type of interconnection the effect of smaller particle size in ICA on resistance is still registered. Both combinations consisting of 10 µm MPS, combination 1 and 3 have a lower resistance than combinations consisting of 30 µm MPS. And the lowest resistance and best electrical performance had samples with ICA filled by 10 µm size MPS type A combined with MPS type B for BGA size 720 µm - combination No. 1 in Table 7.

Table 7. Results from the electrical measurements

No. of combination	ICA	BGA	Size of BGA (diameter)	R average of longest daisy chain per one interconnection ($Ohm \cdot 10^{-2}$)
1	10 µm	AA107.4.14	720 µm	5,87
2	30 µm	AA107.4.14	720 µm	20,42
3	10 µm	AA044.11	380 µm	18,21
4	30 µm	AA044.11	380 µm	32,10

4.1.2 Effect of combinations with different types of MPS, type A and type B on the resistance of interconnections

The table 4 clearly shows that the theoretical approach discussed in 3.1.2 works. We can see that for combinations with a large number of theoretically estimated contacts, resistances are lower. It is combinations number 1 and 3 with ICA filled by 10 µm size MPS.

Table 8. The maximum theoretical number of contacts and average resistance

No. of combination	Combination	Number of contacts	R average of longest daisy chain per one interconnection (Ohm$\cdot 10^{-2}$)
1	S720/S10	20000	5,87
2	S720/S30	2300	20,42
3	S380/S10	5700	18,21
4	S380/S30	640	32,10

You can also see that the resistance value for combinations 2 and 3 are very close and the sizes of combined MPSs vary. The ratio between sphere diameters is assumed to affect resistance. That suggests the idea that the variations in different sizes of MPSs have an impact on the obtaining close results for different sizes of MPSs combinations. And it can be assumed that with a good selection of sizes of spheres these two types A and B can achieve the smallest value of electrical resistance.

Based on the results from the electrical tests, the combination No -1 ICA filled by 10 µm size MPS (type A) in combination with MPS (type B) for BGA size 720 µm - shows the best electrical properties in this particular approach also in the overall electrical test results.

The possible inaccuracy in the values of the resistance should be taken into account, due to different factors. Since the openings of the stencils and pads area were very small, it was very challenging to perform good quality printing with specified and identical quality and quantity for each sample. An accuracy of printing and amount of printed ICA on each pad influenced the electrical performance of interconnections. This can be seen in the figures from the optical analysis below (see 4.3.).

4.2. Mechanical three point flexural test characterization.

A maximum load, extension and effective stiffness are presented as average values for a each of 4 types of samples, in Table 9.

Table 9. Results from the Three point flexural test

No of combination	ICA	Size of BGA (diameter)	F max load (N)	Max extension (mm)	Effective stiffness (N/mm)
1	10 µm	720 µm	12,40	0,40	31,00
2	30 µm	720 µm	13,78	0,37	37,24
3	10 µm	380 µm	7,30	0,46	15,87
4	30 µm	380 µm	7,98	0,18	44,33

4.2.1. Effect of coating material on the strength of the interconnection.

It is a well illustrated by the results presented in the table 9, that the combinations number 1 and 3 which include a large sphere of the size of 720 µm can withstand a greater load than a sphere from combinations 2 and 4 of the size 380 µm. Due to the fact that core materials for both of large spheres types type B are identical, it can be concluded that the metal coating of these spheres can affect their strength. As a result, the interconnection consisting of a 720 µm size silver and copper coated MPS shows ability to withstand higher applied load.

4.2.2. Effect of the filler MPS size on the strength of interconnection.

According to the study possible to tell that the systems consisting of 10 µm MPS shows ability for a larger extension – ductile behavior, than interconnection system with a particle size of 30 µm. Assumed that ICA is a composite material containing adhesive matrix and filler inside, such factors as particle size, particle/matrix interfacial strength and particle loading have significant effect on the composite material strength and ductility.

Based on the results of mechanical tests, the combination of the 10 µm ICA and 720 µm large spheres shows the best mechanical properties: 1) the ability to withstand the highest loads 2) the large deflection under this load.

4.3. Failure analysis by optical microscope

It can be noted that a lot of different factors have affected the electrical and mechanical performances of this type of interconnections. Those factors are the causes of defects. From the optical failure analysis several defects are presented on Figures 4-1, 4-2, 4-3, 4-4. A further research and a deep understanding of the causes of these defects can lead to an improvement in the electrical and mechanical the properties of this type of interconnection.

Types of defects:

1. From figures 4-1 and 4-3 it is clearly seen that sphere size 380 µm more fragile and susceptible to crack initiation compare to sphere 720 µm.
2. In combinations where the sphere size 720 um involved, figures 4-2 and 4-4, there is the effect of delamination of its own coating metal of the sphere and a formation of large cracks between this sphere and ICA.

Figure 4-1. Defects of 10 µm ICA with 380 µm BGA

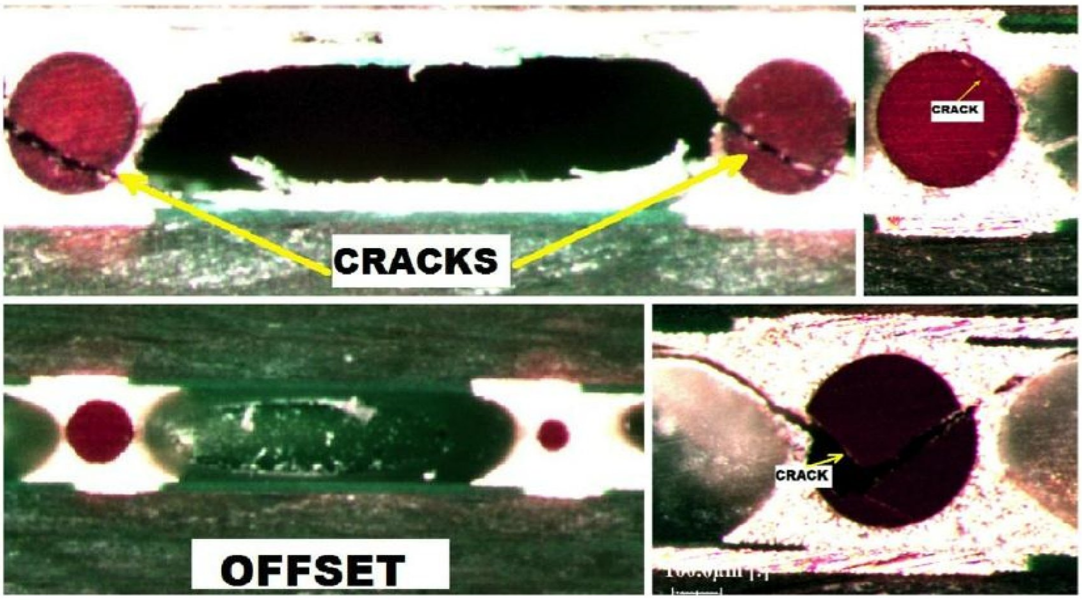


Figure 4-2. Defects of 10 µm ICA with 720 µm BGA

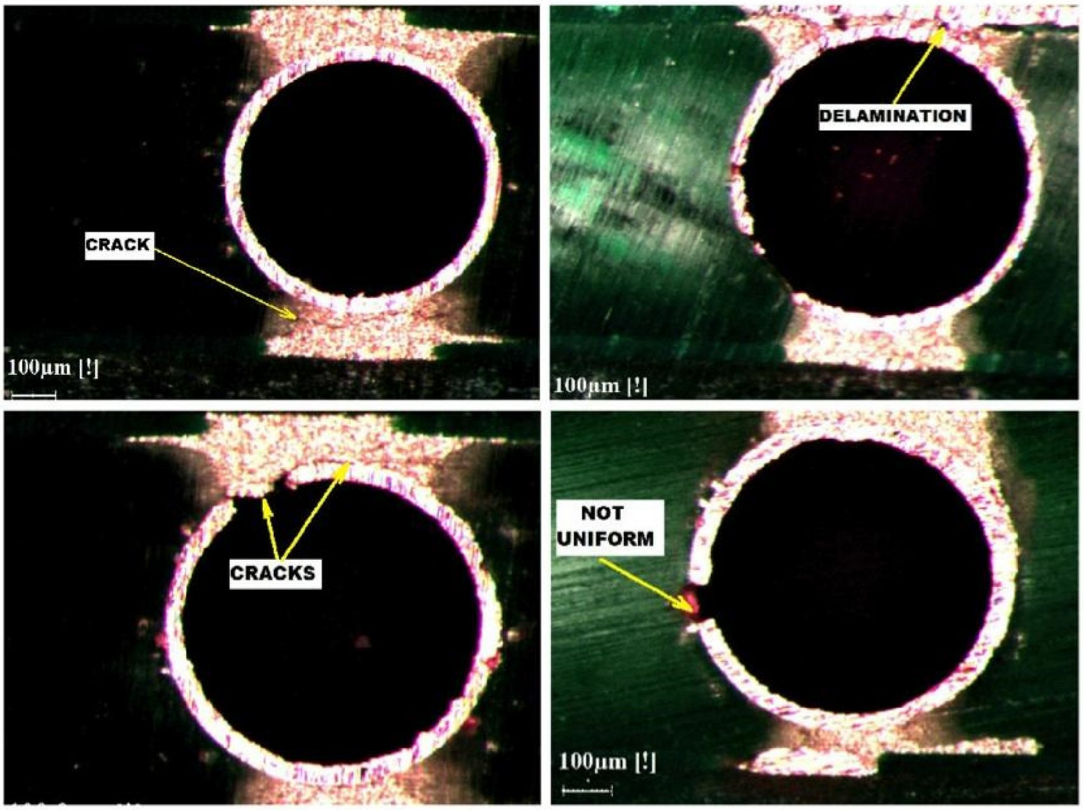


Figure 4-3 Defects of 30 µm ICA with 380 µm BGA

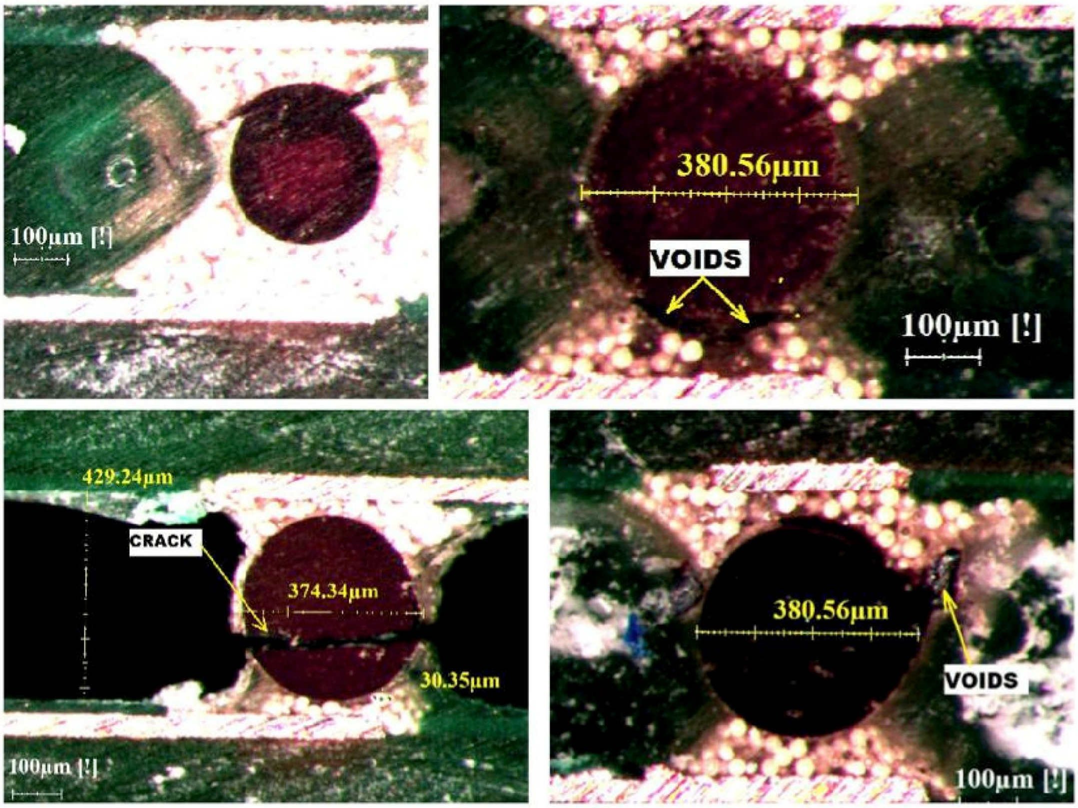
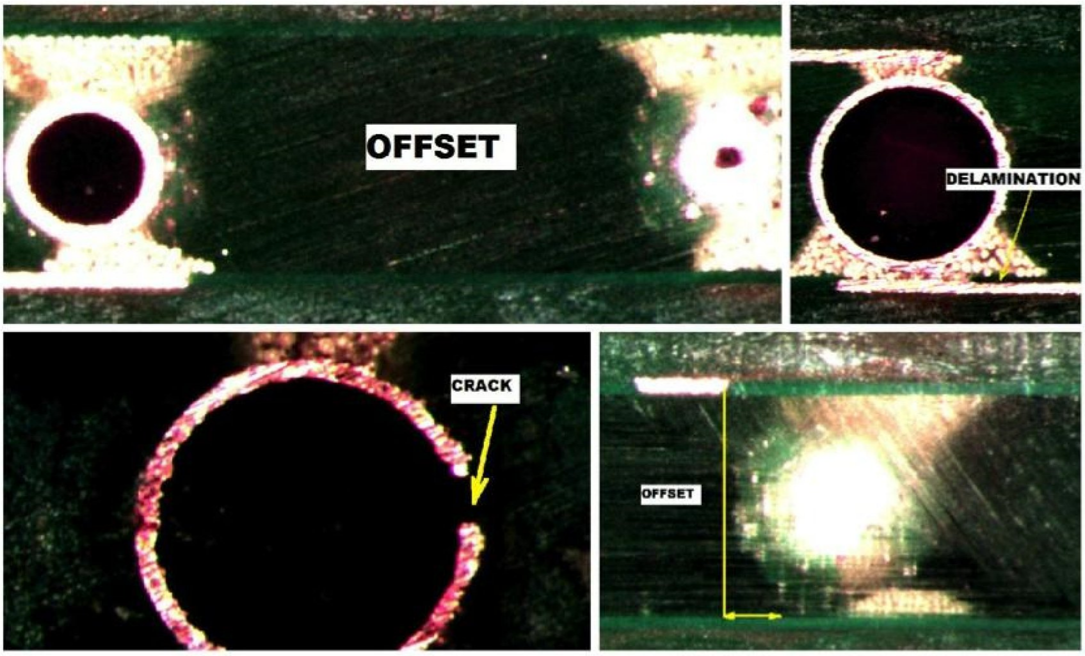


Figure 4-4. Defects of 30 µm ICA with 7200 µm BGA



3. From figures 4-1 and 4-4 can be detected the imperfection of printing process which represents offsets and dislocation of printed ICA and in turn the wrong position of BGA spheres.
4. Formation of voids in printed ICAs can be seen on figures 4-3.
5. Uneven of printed ICAs can be seen on figures 4-2.

5. CONCLUSION

In this master thesis the possibility of existence of a new type of interconnection, its electrical and mechanical properties were studied. For this purpose four types of samples were manufactured and tested.

As a result of the electrical testing and further characterization the following conclusions were made:

1. Size effect of MPS type A on the resistance of interconnections.

In spite of the presence of the MPS type B in this type of interconnection the effect of particle size type A in ICA on resistance is still registered. Both combinations consisting of 10 μm MPS (combinations 1 and 3) have a lower resistance than combinations consisting of 30 μm MPS. The lowest resistance and the best electrical performance are attributed to samples with ICA filled by 10 μm size MPS type A combined with MPS type B for BGA size 720 μm - combination number 1.

2. Effect of combinations with different types of MPS, type A and type B on the resistance of interconnections.

For the investigation of this effect the particular approach was used, utilizing a mechanism of electrical conductivity based on creating electrical contacts between the metal surface area of sphere type B and the surrounding spheres type A. The effect of conductivity between MPS in different ICA already has been investigated in previous studies and has not been emphasized in this approach.

The results have shown that for combinations with a large number of theoretically estimated contacts resistances is lower. It is combinations number 1 and 3 with ICA filled by 10 μm size MPS. And the combination number 1 ICA filled by 10 μm size MPS type A in combination with size 720 μm MPS type B shows the best electrical properties in both this particular approach and in the overall electrical test results.

Several conclusions from mechanical test results and characterization were made:

1. The effect of different type of metal coating.

The interconnection consisting of a 720 μm size silver and copper coated MPS shows an ability to be more resistant to deformation and withstand higher applied load. This is attributed to presence of 20 µm thick underneath layer of Cu which has a higher Young's modulus than silver layer.

2. Effect of the filler MPS size on the strength of interconnection.

According to the study it is possible to tell that the systems consisting of 10 µm ICA shows ability for a larger extension, i.e. ductile behavior, than interconnection system with 30 µm ICA. Therefore, the relevance of composite materials approach to this type of interconnection is corroborated.

Based on the results of mechanical tests, the combination of the 10 µm ICA and 720 µm MPS type B shows the best mechanical properties: 1) the ability to withstand the highest load; 2) the large deflection under this load.

Summing up the results from all of the tests for all samples we can say that the combination No. 1, i.e. ICA filled by 10 µm MPS with 720 µm C-BGA, has shown the best mechanical and electrical properties.

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