

Electrical Characterization of Anisotropic Conductive Adhesive Based Flip Chip for a Direct Access Sensor

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Abstract

Anisotropic conductive adhesives (ACA) are ideal interconnect materials for flip chip assembly due to their low cost and low processing temperature. They also provide an advantage for fine pitch assemblies, high speed interconnection packages and sensor assemblies. They are often used as interconnect material in mainstream applications such as flat panel displays, camera modules, mobile phones, semiconductor packages and RFID tags.

In a direct access sensor the ACA seals the chip and substrate area and thus comes in direct contact with fluid environment. Moisture is known to affect the dielectric constant of the ACA.

The objective of this paper is to study the effect of moisture on the impedance parameter of ACA during a frequency sweep from 50Hz – 50MHz. In order to observe the effect of moisture on the ACA and thus its frequency response, a flip chip interconnect structure is made whereby the ACA is exposed to the fluid environment.

A HP4294A Impedance Analyzer was used to measure the impedance parameters of the samples before and after soak testing. The preliminary results after soak show that the real part and the imaginary part of the impedance have varied during the frequency sweep. The resistance increased from around 0.2Ω to around 6Ω while a small shift in resonant frequency was attributed to a slight increase in capacitance.

Introduction

Flip Chip (FC) interconnection involves attaching the bond pads of a chip face down on to a substrate directly through an interconnection material. This technology offers high input/output flexibility, miniaturization, low cost and short signal path – high electrical performance. The interconnection material ranges from solder to adhesives. FC technology and the advancement of thin flex used for electronic assemblies have opened up many new application opportunities. These smaller, lighter and more flexible assemblies for instance can be used for biomedical implants and other main stream electronics.

Electrically conductive adhesives come in two forms – Anisotropic conductive adhesive paste (ACAP), and Anisotropic conductive adhesive film (ACF). ACA's are generally composed of conductive particles dispersed in an epoxy based polymer matrix. The conductive particles are either metal or metal coated polymer particles. The electrical connection is achieved by trapping the conductive particles between the chip and substrate pad during the curing process

by applying heat and pressure. The electrical conduction is achieved in the direction of the applied pressure. More deformation of the conductive particles leads to improved electrical conduction along the Z-axis.

In the past ACA has been used for low frequency [1] interconnect but in recent years the use of ACA in FC applications has gained momentum and is used in many of these mainstream electronics such as flat panel displays, camera modules, mobile phones, semiconductor packages and RFID tags [2-4]. Due to the high frequency requirement in the FC semiconductor packages, numerous high frequency studies of ACA and mostly of ACF joints have been reported. Previous work by Xu Wang et al (2006) shows the effect of distribution of conductive particles in ACAs and the conductor overlap on RF performance. They concluded that the distribution and the distance between the particles had no effect on RF while the conductor overlap had significant effect on the RF properties. Myung-Jin Yim et al (2005) showed that a change in the ACF material dielectric property and the geometry of the bumps has an effect on the RF response. Work by Dernevik et al (2008) on ACA material concluded that it exhibits similar characteristics to that of solder. Dou et al (2006), Ahn et al (1999), Ryu et al (2000), and Myung-Jin et al (1999) have developed several high frequency models of ACF joints. The proposed equivalent circuit model for an ACA FC joint consists of resistors, inductors and capacitors. The extracted model agrees quite well with the measurements of the impedance parameters.

ACAP is a viable option for a sensor application as it provides an electrical connection while simultaneously sealing around the chip-substrate window perimeter area from any fluid environment [11]. ACA based flip chip for a direct access sensor involves attaching a chip's bond pads face down on to a substrate with an opening in it. This allows interaction between the surface of the die and the medium to be sensed. It is particularly suitable for low I/O count applications such as sensors. It is essential to have a good interconnection while sealing off the chip-substrate area to prevent any fluid from seeping in through the ACA. During the sensor application, ACA comes in contact with the fluidic environment which can lead to moisture penetration through the epoxy. The moisture penetration reduces the Young's modulus and tensile strength of the epoxy and thus weakens the strength of the epoxy [12]. The moisture also affects the dielectric constant of the epoxy [13].

This paper studies the effect of moisture on the frequency response of ACA for a direct access sensor. In the next section, a detailed review of the method used to perform the

frequency study is described. This is followed by the ACA frequency study in liquid environment with its results and discussion.

Experimental Method

Interconnection patterns

A single layer thin FR4 substrate with thickness of 0.25mm was used. The metallization scheme of the tracks on the FR4 substrate comprised of 64.8 μ m Cu, 5 μ m Ni and 0.2 μ m of electroplated flash gold. The tracks were 5.5mm long and 0.8mm wide with a pitch of 1. There are four tracks on the FR4 board and they are numbered from one to four, see figure1. From here on this notation will be carried all the way through during the assembly and the testing process.

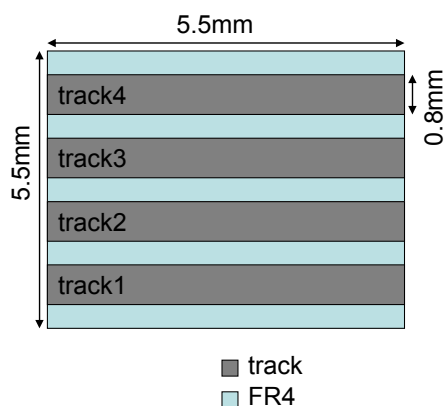
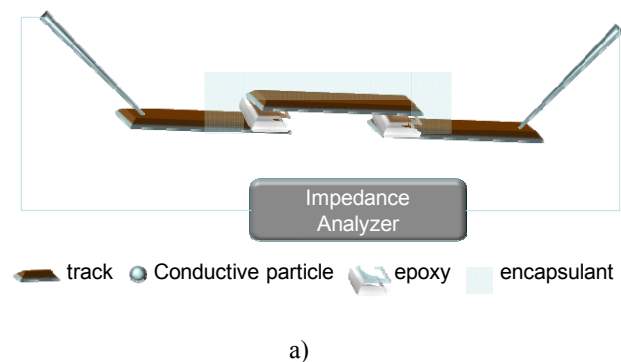


Fig 1. Schematic of the PCB board

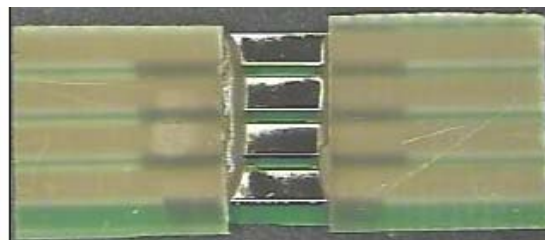
Direct access sensor is achieved by attaching a sensor face down to a substrate via ACA with a window on the substrate for sensor access. The sensor in this case has been represented by the 5.5 x 5.5 FR4 piece mounted on to two FR4 boards, as shown in figure 2a, 2b and 2c.



a)



b)



c)

Fig 2. Direct Access sensor structure achieved with FR4 substrate; a) 3D schematic view of the flip chip assembly of one of the test track connected via ACA with probe needles for Impedance parameter testing; b) Top view of the assembly; c) Back view;

Conductive Adhesive Material

ACAP is a thermosetting epoxy with conductive particles in its matrix. The conductive particles were Au coated Ni particles with an average particle size of 7 microns, as shown in 1000 fold magnification in the SEM image figure 3. Table 1 gives the specification of the material used in this research. To estimate the number of particles per bond pad, a bonded sample was separated from its bonded area and was magnified 90 times under Olympus SZX12. ImageJ particle count software was used to count the number of particles per bond pad, as shown in figure 4. ImageJ is a public domain, Java-based image processing program originally written at National Institute of Health. It is used to analyze/process all sorts of images in biology-related research. It is used to measure area, mean, standard deviation of an image. It also measures length angles and pixel value statistics depending on the user defined selection and intensity. The processed image (b) of the bonded area showed that there was an average of 833.75 particles per mm²

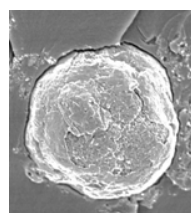


Fig 3. SEM image of 7 μ m Ni Ball

colour	CTE (μ m/m/K)	Resistivity (Ω .cm)	Modulus (GPa)	Tg($^{\circ}$ C)
Brown	47 pre Tg	0.1	5.9	126

Table 1. ACA Material Specification

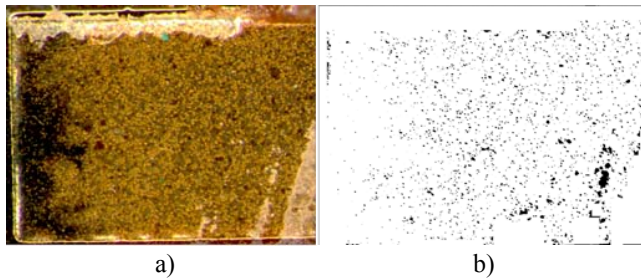


Fig 4. ACA particle count with ImageJ software. a) Epoxy with conductive particle; b) image processed via Image J showing just the conductive particles.

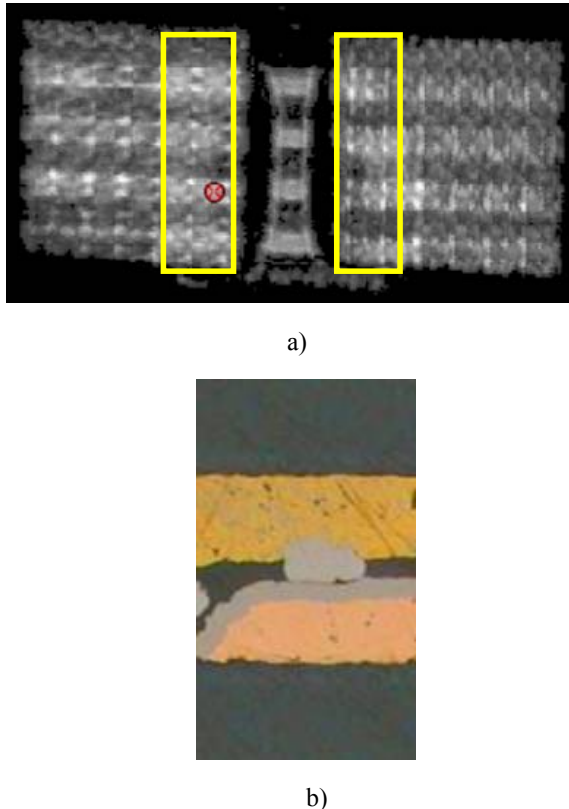


Fig 5. a) SAM image from the top view and; b) Cross sectional view of the particle.

Bonding Process

A pre-cleaning procedure was carried out separately on all the FR4 boards. This involved placing FR4 substrates into a barrel type chamber of a March Plasmod system and exposing them to an oxygen plasma for 40sec at 150 Watts. This was followed by IPA immersion in a bench top Ultraware ultrasonic precision cleaner for 5 min followed by a DI water rinse. The samples were then dried in a conventional Heraeus vacuum oven at 150°C for one hour.

Three boards – board I, II and III- were used to achieve the required flip chip structure. A line of 1mm wide ACA was dispensed across the 4 tracks on the edge of boards I and III using a CAM/ALOT 1414 liquid dispense system. Boards I and III were positioned at a distance of 3.5mm from one another, see figure 2a. The alignment of the board II to

boards I and III with ACAP was done using the Finetech Flip-Chip Bonder so that the overlap on the bond pads was 1mm, see figure 2a, 2b and 2c. Bonding was carried out at 180°C and a bonding pressure of 20N for 8 sec. As it can be seen in 2b, one sample has four test tracks connected via the third FR4 board and ACA. Scanning acoustic microscopy (SAM) was used to assess the sealing of the direct access sensor. As it can be seen from figure 5a, ACA has a good coverage and that there are no voids present in the setup. A cross-sectional image, figure 5b, showed that the Ni particle had deformed by around 10%. This shows that the bonding parameters produced a good metal contact between the pads.

Encapsulation Process

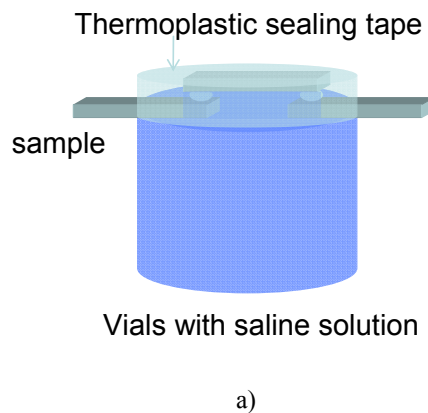
The encapsulation process consisted of applying silicone via a brush on the exposed tracks. This was cured for 24 hours at room temperature. As seen in figure 6, the silicone is applied to the top side of the test sample while a small area is left for the purpose of testing. This is carried out to protect the tracks from corroding during the soak testing. The bottom side as seen in figure 2c, is left without encapsulation so that the ACA will be exposed to the saline solution.

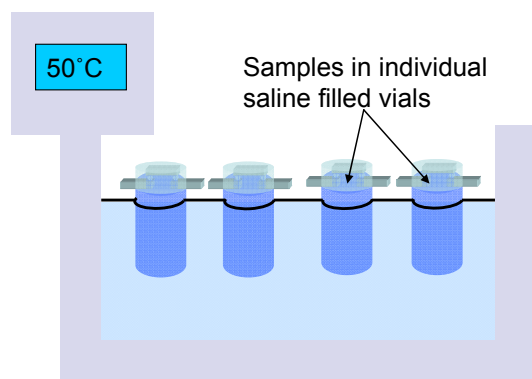


Fig 6. Encapsulated sample.

Soak Test

The encapsulated test samples were placed on the rim of the plastic vials filled with 10mM of phosphate buffer solution. A hermoplastic film – Parafilm- was used to seal the rim of the plastic vials. Care was taken to ensure that the ACA is in contact with the buffer saline solution, see figure 7a. These individual vials are placed in a temperature controlled circulating bath - Thermo Haake DC5 with temperature resolution of 0.01°C, figure 7b.





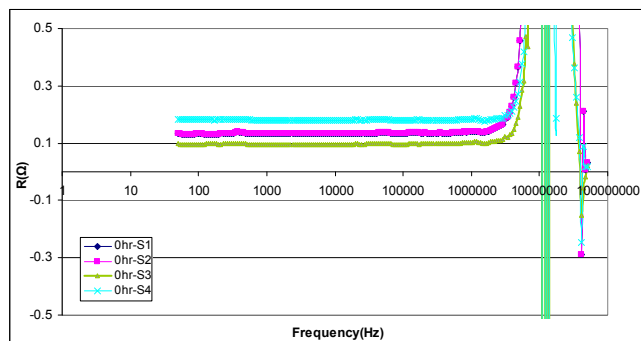
Temperature controlled
recirculating Bath

b)

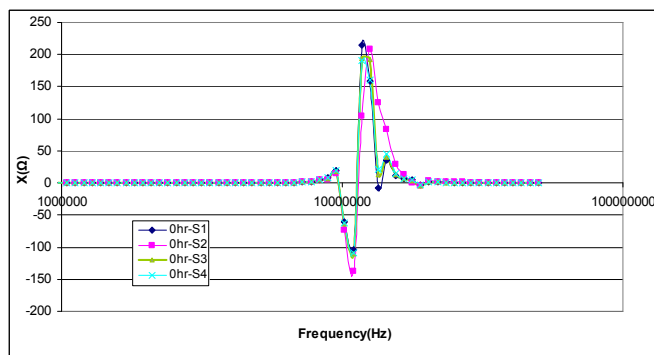
Fig 7.a) Schematic of the vial with sample; b) schematic of a temperature controlled recirculating bath.

Electrical Measurements

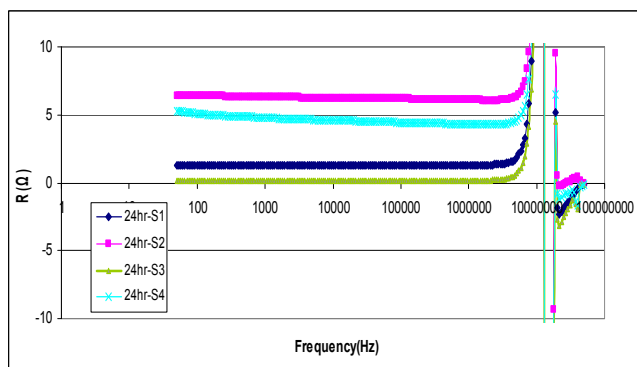
After calibrating the HP4294A Impedance Analyzer for an open and short circuits, the test samples were measured over a frequency range from 50Hz to 50MHz. A Batch of 4 samples was fabricated. Each test sample contained four test tracks. As shown in figure 2a, probing needles were placed on each test tracks and the measurement was carried out using impedance Analyzer. The first measurements were carried out on all the four samples of the batch in a dry environment as a reference point. After the dry environment measurements the test samples were soaked in a temperature controlled circulating water bath at 50°C. Subsequently all the samples were taken out after 24hrs and 48hrs and the measurements were repeated in the same environment for the same range of frequency.



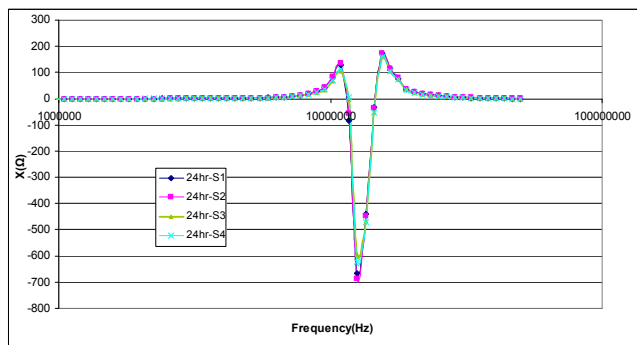
a)



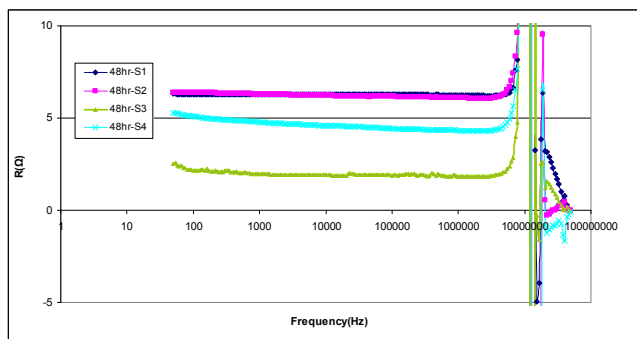
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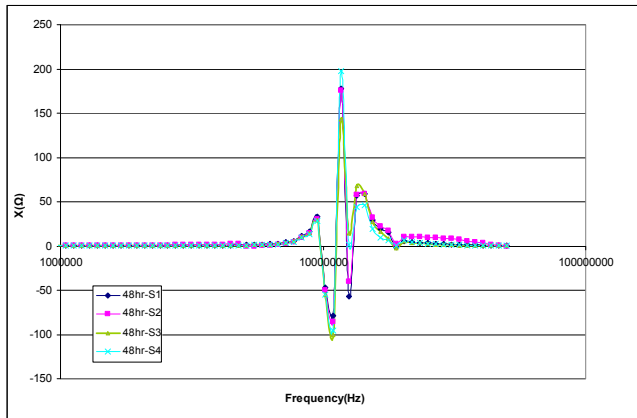
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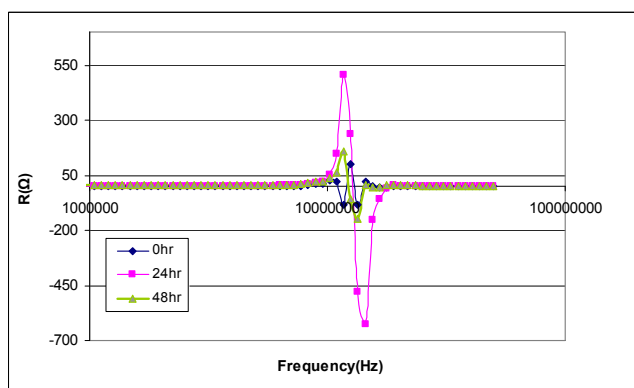
e)



f)

Fig 8. a) comparison of resistance for track1 on all four samples before soak; b) comparison of reactance for track1 on all four samples before soak; c) comparison of resistance for track1 on all four samples after 24hr soak; d) comparison of reactance for track1 on all four samples after 24hr soak; e) comparison of resistance for track1 on all four samples after 48hr soak; f) comparison of reactance for track1 on all four samples after 48hr soak

Figure 8a to 8f shows the variation of the real and the imaginary part of the impedance parameter before and after soak of the track1 between four samples. It can be seen that before soak that there is a small variation in resistance of the track 1 between samples. This could be attributed to the number of particles making contact. The resistance starts to increase after 24 hrs for sample 2 and 4 from 0.2Ω to around 6Ω . This could be attributed to the hygroscopic swelling of the ACA. It takes another 24hrs to see the increases in resistance in sample 1 and 3. It also shows that the reactance is similar for the four samples before and after soak.



a)

Fig 9. Comparison of resonant frequency for track1 on the same sample before and after soak;

Figure 9 shows the comparison of the resonant frequency impedance parameters between the dry test samples and the

soaked samples of track 1 before and after soak. It can be seen that after soak there is a small shift in the resonance frequency. As mentioned before ACA is prone to moisture absorption. This hygroscopic swelling increased the dielectric constant and the distance between the bond pads. This could be seen as a small shift in capacitance which is reflected in the small shift in the resonant value

Conclusions

These preliminary results show that ACA can be used for direct-access sensor packaging. Furthermore ACA can be used as a suitable material for applications with few relatively large bond pads and particularly in relation to measurements in the fluidic environment when the sensing area needs to be sealed off from the electronics.

Electrical measurements of dry and soaked samples show that the moisture does influence the impedance parameters during a frequency sweep. The resistance is increased from around 0.2Ω to around 6Ω while there is a small shift in the resonant frequency which could be attributed to the small change in capacitance.

Future work will continue this preliminary work and also look into the resonant frequency. This study will be complemented by the study of leakage of the encapsulated assembly.

Acknowledgments

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References

- [1] S. Ahn, W. Ryu, M. Yim, J. Lee, Y. Jeon, W. Kim, K. Paik, and J. Kim, "Over 10 GHz equivalent circuit model of ACF flip-chip interconnecting Ni-filled ball and Au-coated polymer balls," *IEEE/CPMT Int'l Electronics Manufacturing Symposium*, 1999, pp. 421-425.
- [2] B. Xia, J. Shah, and W. O'Hara, "Corrosion-Resistant Anisotropic Conductive Adhesive for Consumer Electronic Applications," *IMAPS Conference*, November 2008.
- [3] K. Gilleo, B. Boyes, S. Corbett, G. Larson, and D. Price, "High volume, low cost flip chip assembly on polyester flex," *Circuit World*, vol. 25, pp. 11-17, 1999.
- [4] H. Kristiansen and J. Liu, "Overview of conductive adhesive interconnection technologies for LCDs," *IEEE Transactions on Components, Packaging, and Manufacturing Technology, Part A*, vol. 21, pp. 208-214, 1998.
- [5] X. Wang, Z. Cheng, and J. Liu, "RF characterization of flip-chip anisotropic conductive adhesives joints," *High Density Microsystem Design and Packaging and Component Failure Analysis*, 2006, pp. 213-217.
- [6] M. Yim, I. Jeong, H. Choi, J. Hwang, J. Ahn, W. Kwon, and K. Paik, "Flip Chip Interconnection with Anisotropic Conductive Adhesives for RF and High Frequency Applications," *IEEE Transactions on Components and Packaging Technologies*, vol. 28, pp. 789-796, 2005.

- [7] M. Dernevik, R. Sihlbom, K. Axelsson, L. Zonghe, L. Johan, and P. Starski, "Electrically conductive adhesives at microwave frequencies," in *48th IEEE Electronic Components and Technology Conference* 1998, pp. 1026-1030.
- [8] G. Dou, Y. Chan, J. Morris, and D. Whalley, "RLC effects in fine pitch anisotropic conductive film connections," *Soldering and Surface Mount Technology*, vol. 18, p. 3, 2006.
- [9] W. Ryu, M. Yim, S. Ahn, J. Lee, W. Kim, K. Paik, and J. Kim, "High-frequency SPICE model of anisotropic conductive film flip-chip interconnections based on a genetic algorithm," *IEEE Transactions on Components and Packaging Technologies*, vol. 23, pp. 542-545, 2000.
- [10] Y. Myung-Jin, R. Woonghwan, J. Young-Doo, L. Junho, A. Seungyoung, K. Joungho, and P. Kyung-Wook, "Microwave model of anisotropic conductive film flip-chip interconnections for high frequency applications," *IEEE Transactions on Components and Packaging Technologies*, vol. 22, pp. 575-581, 1999.
- [11] R. Briegel, M. Ashauer, H. Ashauer, H. Sandmaier, and W. Lang, "Anisotropic conductive adhesion of microsensors applied in the instance of a low pressure sensor," *Sensors and Actuators A: Physical*, vol. 97-98, pp. 323-328, 2002.
- [12] Y. Lin, X. Chen, H. Zhang, and Z. Wang, "Effects of hygrothermal aging on epoxy-based anisotropic conductive film," *Materials Letters*, vol. 60, pp. 2958-2963, 2006.
- [13] C. Zou, J. Fothergill, and S. Rowe, "The effect of water absorption on the dielectric properties of epoxy nanocomposites," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 15, pp. 106-117, 2008.