Elektronikus készülékek megbízhatóságának vizsgálata gyorsított élettartam tesztekkel

Kutatási jelentés

Introduction

Electronic components are undergoing increasing miniaturization and ongoing integration to higher density. Printed circuit boards (PCBs) have ever smaller pitches between the leads and are more vulnerable to insulation failure. The component leads are likely to be electrochemically unstable during operation under certain environmental conditions such as high humidity [1]. Under these circumstances, electronic components respond to the applied voltages by electrochemical dissolution of metals and form dendrites between the anode and cathode across the nonmetallic medium. This effect causes short-circuit failures of the electronic circuits, which is known as electrochemical migration (ECM). The common characteristics of the ECM phenomena include the presence of moisture between two electrodes under bias voltage, the electrochemical process and the metallic dendrite growth. This process is driven by an applied electric field from the anode to the cathode. Dendrite growth occurs as a result of metal ions being dissolved into a solution from the anode and deposited at the cathode, thereby growing in needle-or tree-like formations.

There are two main methods for obtaining information about the migration behavior of the samples. The water drop (WD) test that is performed by placing a drop of distilled water or other well defined electrolytes (e.g.: NaCl solution) between adjacent metallization strips under bias voltage. The other methods are the environmental tests, such as the Thermal Humidity Bias (THB) test, which is performed on the samples at high humidity levels and high temperatures under bias voltage [2, 3]. In the latest publications, most of the investigations were carried out with WD tests [4-6], and only in some cases was the ECM behavior studied by THB tests. The main reason is that the WD tests can be performed much faster than THB tests. However, the WD tests are qualitative investigations while the THB tests are more realistic, and simulate the various environmental effects such as water condensation. During the environmental tests, the common way to bring out information about the ECM is done by a continuous measurement of electrical parameters, such as insulation resistance, leakage current or voltage change in appropriately built up circuitries.

In a previous paper, we have presented a novel measuring method, which is applicable for in situ and real time optical observation of water condensation and dendrite growth formation during THB tests [7]. We have found the followings: firstly small droplets of the dew condensation were occurred on the conductor lines and the substrate probably was covered by a thin water film or small water cores (start of condensation period). Than the size of the water droplets were become bigger and the formation of water islands was started on the conductor lines, while on the insulation layer very rarely moisture volume could be seen. Finally the start of the water bridging on the insulation layer between the conductor lines was recorded (end of condensation period). Shortly afterwards the start of the dendrite growth could be observed (start of electrochemical migration period) and finally the short formation was measured and seen (end of electrochemical migration period).

Insulating materials with water-attracting polar groups could begin to adsorb water as invisible films at much lower relative humidity (RH) values, the extent of the adsorption increasing with rising RH. In the same way, capillary condensation can occur in scratches, pits, and other high surface-energy areas, the net effect being the lowering of the minimum ambient RH required for adsorption, even on otherwise water-repellent materials [8]. This capillary effect was recognized during an extensive experimental program on silver migration on FR4 substrates [9]. Supposedly the condensation time strongly depends on the capillary effect and on other physical, chemical properties of the substrate such as wettability, water adsorption, heat conductivity, etc. In other words the velocity of the condensation time could be mainly determined by the type of the insulation material.

The reports above [7-9] were delighted the importance of the condensation effect before starting dendrite growth caused by ECM. Therefore it can be supposed that in some cases the condensation time (referred as Mean Time To Condensation: MTTC) have huge relevance relating the total failure time, which will referred as Mean Time To Failure (MTTF) in this paper. If the hypothesis will be true, than some current accelerating migration models [10] have to be modified with the MTTC.

Experimental

In order to verify the above mentioned assumption WD tests (without condensation) and THB tests (with condensation) were carried out and results were compared. Only one parameter was changed between the samples, the type of the insulation layer which was FR4 and Kapton™ polyimide (PI). The Kapton polyimide is also widely used for electrical applications [11,12]. The applied interdigital comb patterns were designed and prepared according to IPC-B-25-A type standard. The patterns were made from copper and by conventional photolithography – wet etching processes. The copper patterns were coated by immersion silver (iAg) surface finishes. The gap size between the conductor lines on the test board was 0.2 mm with the line width of 0.4 mm in all cases. The sizes of the test panels were: 39 mm x 44 mm x 0.2 mm.

The test platform of WD tests can be seen in Fig.1. Before starting the WD tests, droplets of 15 µl high purity water (0.055 µS/cm) were placed by a pipette onto the comb patterns and then 10 VDC was applied. During the WD tests, the short circuit formation (the time to failure) was detected by voltage step measures on a resistor connected in series to the interdigital comb pattern. The failure criterion was experimentally determined at 0.1 V due to the fact that over this value dendrite growth can be observed and the value of the resistor (R) was 1 kOhm. From the measured failure times the Mean Time To Dendrite (MTTD) was calculated as an average value. So, in this case MTTD=MTTF.

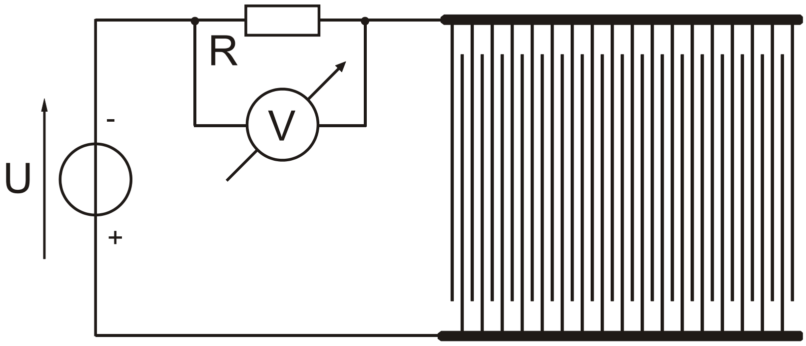

Figure 1. Schematic of the WD test platform.

In the case of THB test, the optical measurement system contents a charge coupled device (CCD) monochrome camera (Imagingsource, type DMK41AF02.AS) and a rigid borescope (Olympus, type R060-047-000-50), which are connected to each other with an optical adapter device (Olympus, type MC-R44). The borescope is a kind of fiberglass image transmitter device in a stainless steel protection tube for in situ measurements. Only the tube part of the borescope was lead into the Thermal-Humidity (TH) chamber, so the variation of the different measuring TH parameters depends on the resistivity of the stainless steel tube of borescope.

The optical inspection is verified with real time voltage change measurement. During the THB tests, 10 VDC was also applied in each case. The voltage changes were monitored by two NOVUS MyPCLab data logger units. The schematic of the measuring system can be seen in Fig. 2. The failure criterion was also 0.1 V and R = 1 kOhm. Finally the MTTF was calculated as an average value. During the investigations (WD and THB tests) 32 measurements were carried out pro samples.

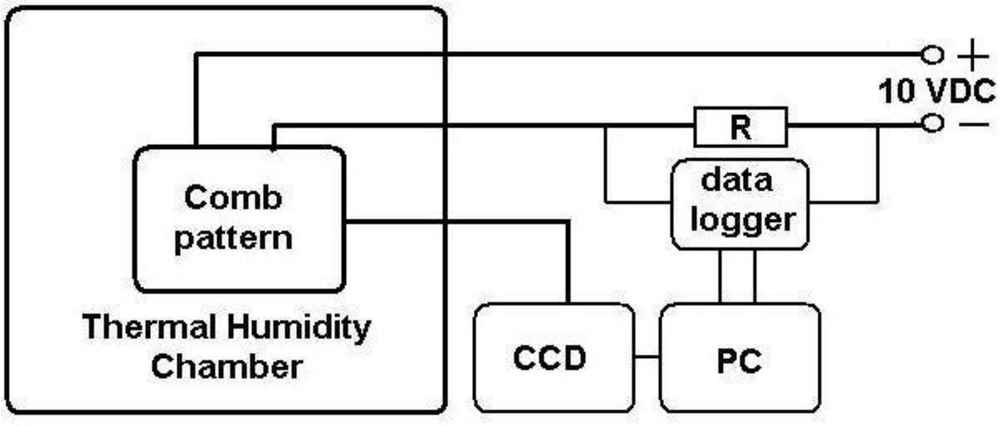

Figure 2. The schematic of the in situ optical and voltage measuring system.

The experiments were carried out especially for investigating the water condensation and dendrite growth simultaneously, therefore a special THB test was applied, which was practically a dew point test with the followings: 40°C/95RH% was fixed for 1 hour. After 45 minutes the samples were cooled by a peltier element to produce dew condensation on the surfaces. The applied voltage of the peltier element was 3 VDC in all cases. The samples and the peltier element were fixed by a thermally conductive adhesive transfer tape (3M™ 8805). In order to increase the efficiency of the peltier, the warm size was contacted to a heatsink by the tape. The measurement number of THB tests was 32 in every case.

Results and Discussion

The results from WD test are 3.5 ± 0.707 in case of FR4 and 3.9 ± 0.509 for PI. So, there are no significant differences between iAg on FR4 substrate and iAg on PI substrate.

Figs. 3-7, the results of THB test are presented parallel on the two samples (iAg on FR4 and iAg on PI). In Fig. 3 the dry iAg comb pattern on the FR4 (left) and on PI (right) substrate can be seen at the start of monitoring (optical and electrical inspection) during the dew point condensation test (t=0 sec). The FR4 and PI substrates are separated by a white broken line in fig 3-7 and the bright areas are the insulation layers, while the dark fields are iAg.

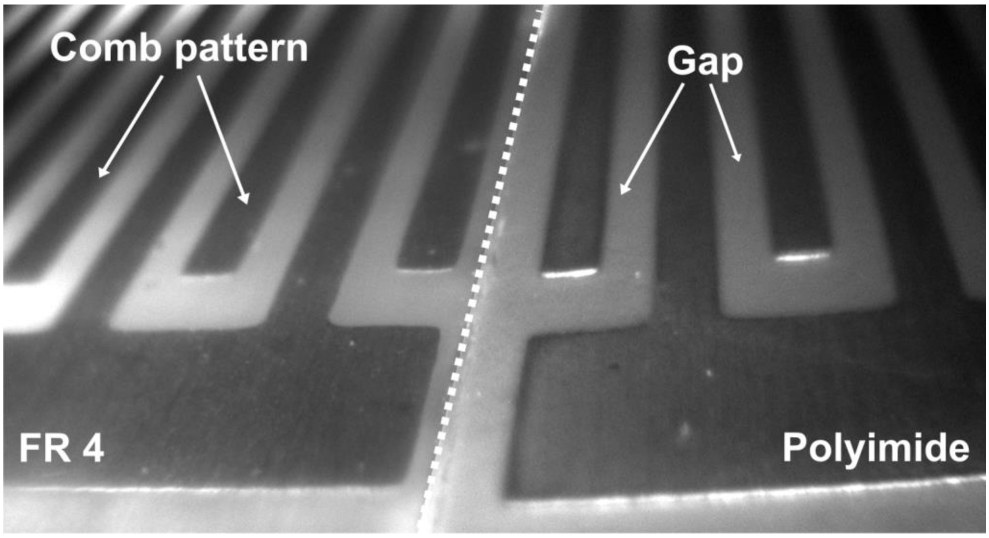

Figure 3. Start of dew condensation (t = 0 sec).

In Fig. 4, small water droplets can be seen on the FR4 surface, while on the PI substrate no condensed water can be seen after 5 seconds.

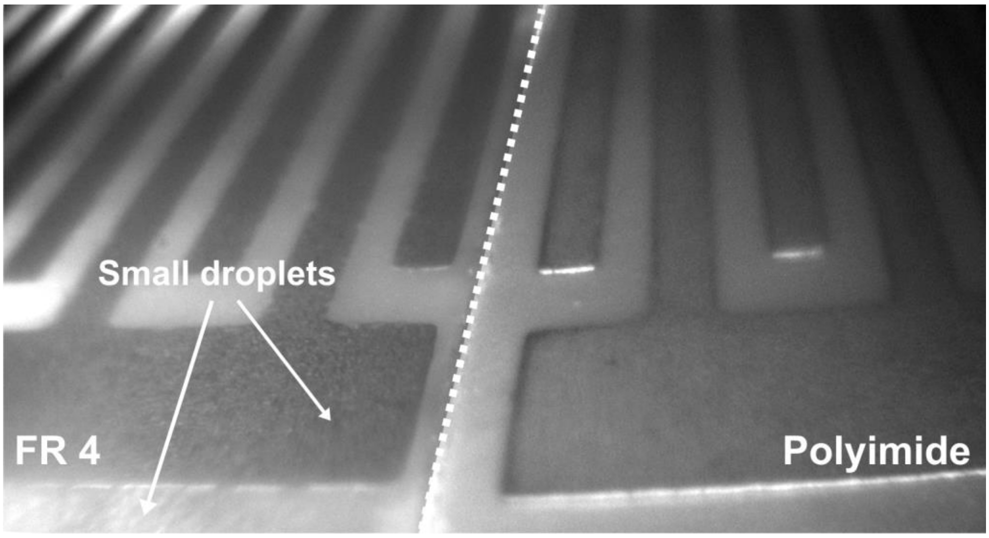

Figure 4. Small droplets on the metal, even smaller droplets on the insulation layers (t = 5 sec).

After 10 seconds different sizes of droplets can be observed between on FR4 and PI surfaces (Fig. 5.). It can be seen that the droplets becomes thicker on FR4 gaps, while relative smaller droplets can be observed on PI.

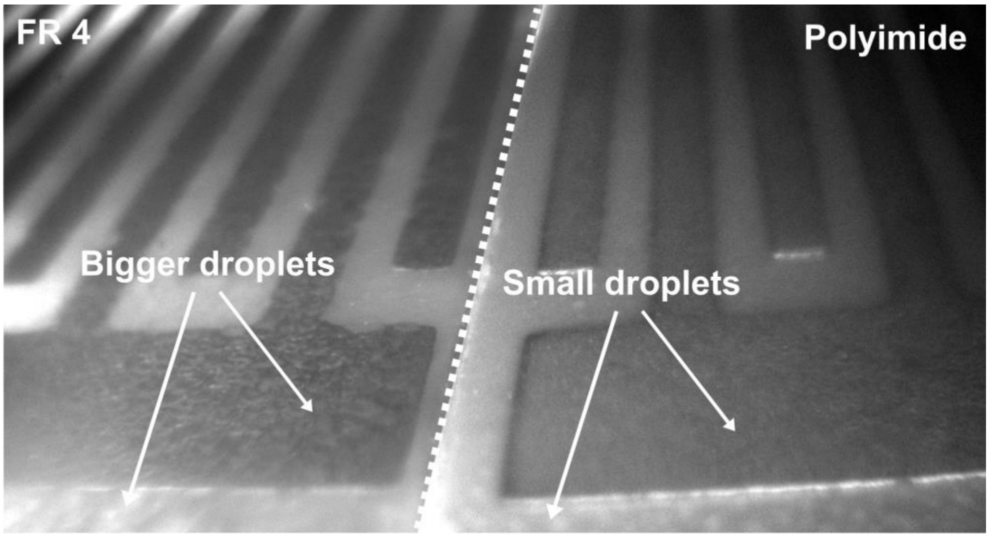

Figure 5. Different size of droplets were formed after 10 seconds.

The bigger droplets on FR4 surface were accumulated into water bridges between the iAg lines. This is the stage (t = 13 sec), where the ECM process and dendrite formation were started (end of condensation period), while in that moment the condensation period was still run on PI substrate. Dendrite formation can be seen only on FR4 substrate at after 13 seconds (Fig. 6.).

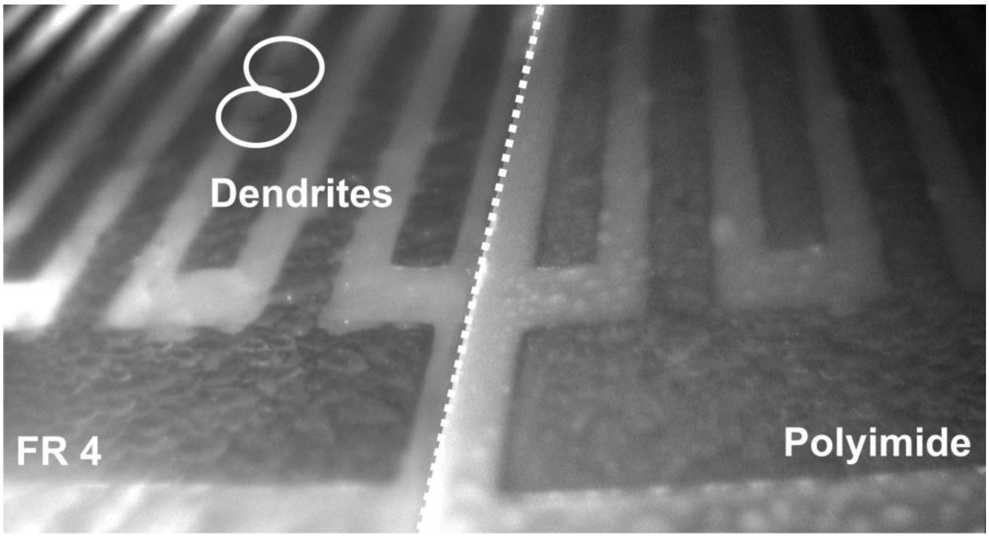

Figure 6. Dendrite formation started first on FR4 after 13 seconds.

Finally dendrite growth can be detected on PI as well, and even more dendrites and relative bigger droplets can be observed on the FR4 substrate after 23 seconds (Fig 7.).

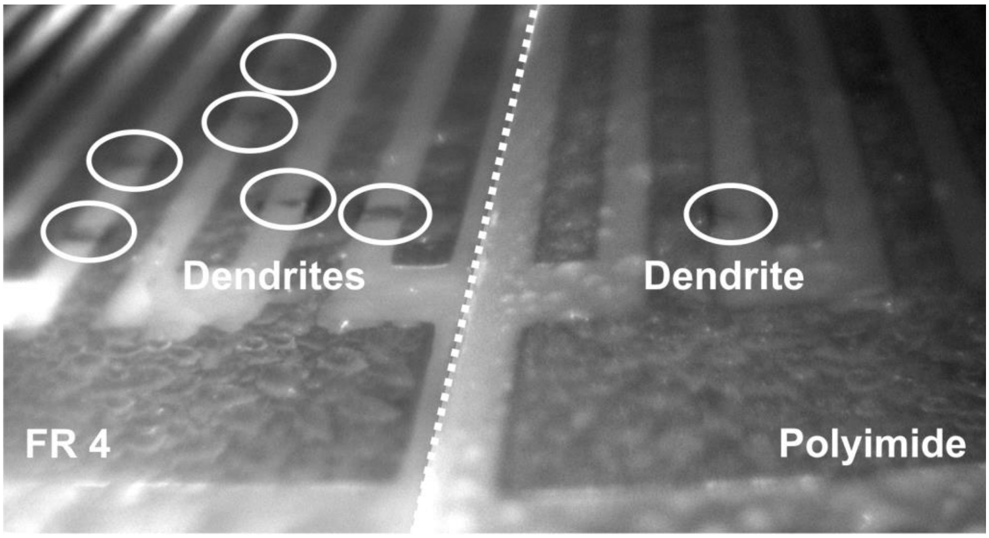

Figure 7. Dendrite formation in both cases (t = 23).

In order to validate the effect of water condensation and dendrite growth, a voltage change monitoring was carried out simultaneously during Dew Point THB test according to Fig. 2. In Fig. 8, the voltage changes can be seen as a function of time. The end of the condensation period and the start of the electrochemical migration period were separated by the line of failure criterion (in Fig. 8). The time difference between end of condensation periods in the case of FR4 and PI is about 10 seconds. Furthermore the MTTF difference between FR4 and PI are also significantly high comparing to the WD test results (see Fig. 9)

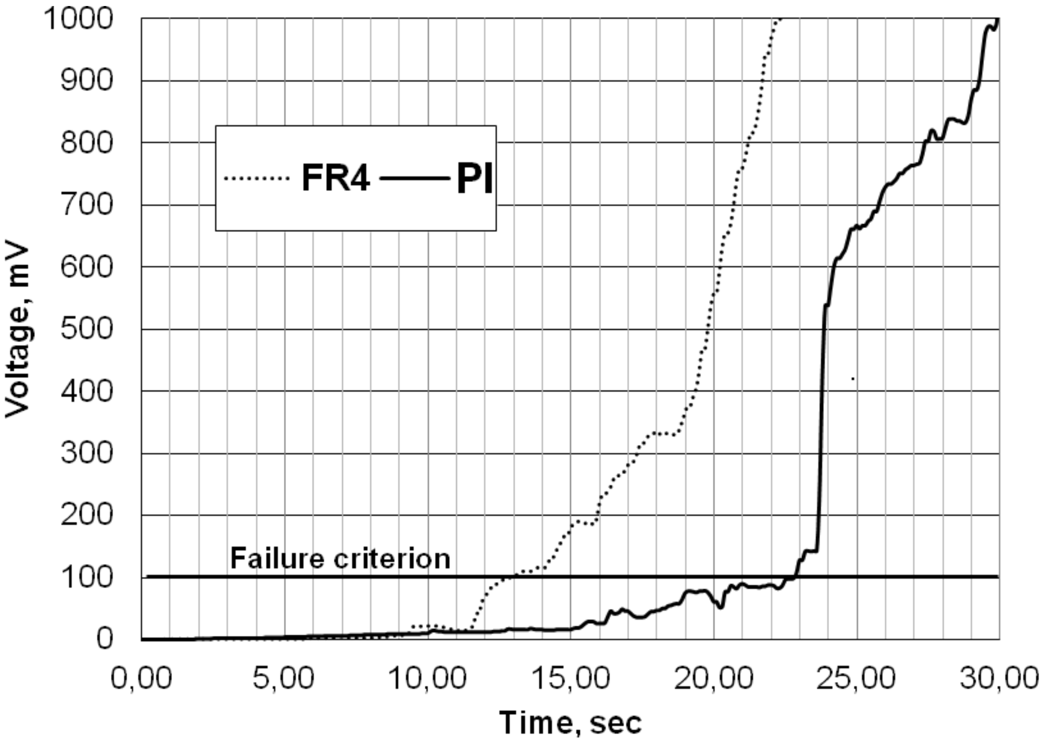

Figure 8. The total Time To Failure difference taking account of the condensation time.

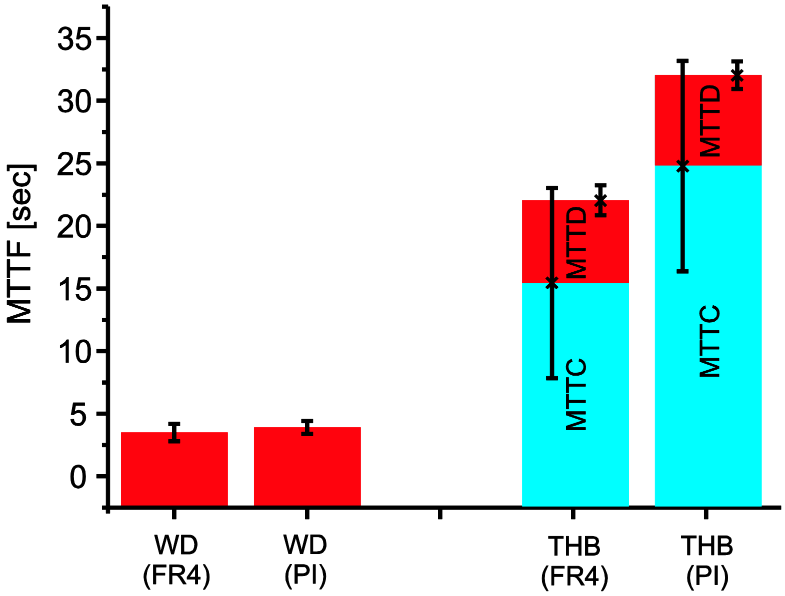

Figure 9. MTTF difference between WD and THB tests, due to the condensation effect.

According to the results of WD and THB tests, the water condensation has had a significant impact on the MTTF relating ECM phenomenon, if the only difference is the insulation material (iAg on FR4 versus iAg on PI).

The different mechanism of the water condensation between the FR4 substrate and PI substrates could be explained with the different surface roughness and therefore their different hydroscopic nature caused by the so called capillary condensation [12], hence the more porous surface has a relative larger effective surface and therefore it has more condensation cores. Furthermore the substrates have also a significant difference relating heat conductivity (FR4: 0.25 W/mK and PI: 0.12 W/mK according to the suppliers), hence the better heat condensation behavior resulted in more intense water condensation. So, manly the effective surface roughness and heat conductivity determines the volume and the intensity of water condensation. In order to validate the assumptions, surface roughness comparison between FR4 and PI was carried out as well. Scanning electron microscopy (SEM) pictures were taken under the same magnification (Fig 10.). Furthermore the effective roughness of the FR4 and PI surfaces were also measured with a Surface profiler (Tencor, Alpha Step 500). Ten roughness scans were made in both cases. The FR4 average and deviation values were 2.56 ±0.5 µm, while these were 1.69 ±0.3 µm on PI surfaces.

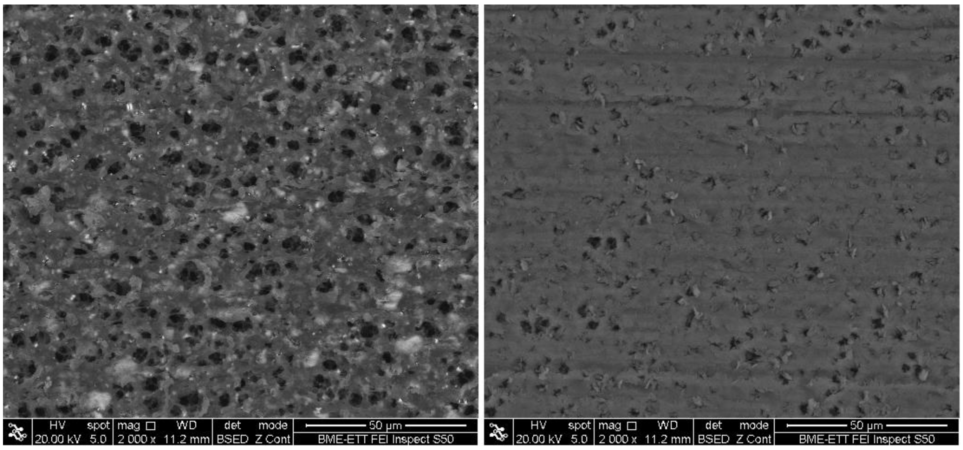

Figure 10. The roughness difference between FR4 (left) and PI (right).

In Fig 10. a huge surfaces roughness difference can be seen, which is in good agreement with the capillary condensation theory.

It was shown and proved that the water condensation has a significant impact relating the total failure mechanism. The MTTC between FR4 and PI substrates showed significant differences, due to the various surface roughness and heat conductivity values. Therefore the existing classical ECM model, have to be modified:

$$\mathbf{MTTF = MTTC + MTTD}$$

Conclusions

In order to investigate the effect of water condensation relating ECM failure mechanism, WD and THB tests were carried out and the results were compared. From the samples of view, only one parameter was changed between them, the type of the insulation layer which was FR4 and Kapton™ polyimide (PI). The MTTF THB values of FR4 and PI were significantly high comparing to the WD test results, hence the condensation effect has a high relevance relating the total failure mechanism in both cases. Furthermore, it was shown, there is a significant MTTC difference between FR4 and PI samples after THB test. This MTTC difference between FR4 and PI samples was explained by the capillary condensation, which is mainly determined by the various surface roughness and heat conductivity parameters. So, it was proven that the condensation effect (MTTC) has a significant impact on the total failure mechanism (MTTF), in the case of iAg on FR4 substrate as well as on iAg on PI. Therefore the existing classical ECM model, have to be extended from the viewpoint of the condensation effect depending on the applied substrate.

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Készítette: Dr. Harsányi Gábor
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