Fractal Description of Dendrite Growing During Electrochemical Migration

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Abstract: *The electrochemical migration (ECM) is an important physical-chemical failure mechanism which limits the realization of fine pitch structures in the manufacturing technology of printed wiring boards (PWB). The cause of ECM is the material transport that leads to dendrite formation. Electrical shorts will grow between pads or leads in fine pitch applications. The mechanism of ECM can be described by electrochemical principles. Dendrites are treatable as a fractal phenomenon because these special formations are in accordance with the most significant criteria of the fractal theory. We have observed in pursuance of our experiment-series that there is relationship between the materials of selective surface finishes of printed wiring boards, mean time to failure (MTTF) done to the migration process and the shape and form of dendrites grown on the top of the substrates in lateral arrangement. If the result of failure analysis is shortage caused by ECM in form of dendrite structure then it is worth to examine the shape and form of dendrites. According to our conclusion the reason of failure can be found with simply and cheap methods and the most efficient protection can be applied if we apply the above-mentioned relationship.*

1. Introduction [1, 2, 3]

The ECM is such area of specialty, where the researcher must have sufficient practice, experience and has to fully know this special failure phenomenon. The material quality of dendrites growing in the course of electrochemical migration can be determined with adequate precision by the use of some good quality optical microscopic photographs, without using expensive examinations. Not only the substantial quality can be determined, the potential reason of failures and their simplest and most efficient mode of elimination can be established by the same way.

Unfortunately this examination method depends extremely on subjective factors such as practice and experience as I mentioned above. We have made attempts to work out an objective examination method what can be useful for engineers and scientists being engaged in this field. One potential method is the simple and brief description of dendrites' morphology and way of growing.

The efficiency of aforementioned method can be increased by the help of our new revelation. Fractal theory can be adapted for description of dendrites, grown from different materials [4]. Every criteria of fractal notion were examined and since dendrites fulfill them, fractal description of dendrites is an applicable idea. Dendrites, same as fractals, have diverse-way defined fractal dimensions whose values characteristically correlate with the substantial quality. These values are influenced aside from the material quality only by the operational principles of softwares which are used for the computation of fractal dimension.

The softwares, which use different algorithms, give implicitly various results in the case of one given material. However by the same program calculated fractal dimensions of various materials always representatively differ from each other and therefore the uniformly determined fractal dimensions can describe the substantial quality. Mostly the values of fractal dimensions correlated to each other will be similar according to our observations and experiences if we use other software.

2. BACKGROUND OF THE EXPERIMENT

2.1. Test specimens [5]

We needed good quality optical microscopic photographs made from dendrites to prove our hypothesis that the substantial quality and Mean Time to Failure (MTTF) correlate with fractal dimensions. Water Drop Test (WDT) is the easiest and simplest way to grow dendrites artificially. We have not taken care of WDT series' reproducibility (distance between electrodes, test voltage and volume of water drop) willfully because our exclusive and most important purpose was growing dendrites in good quality. The tests was carried out by partly repeatable process, with intent to justify that the conditions of dendrite growing do not influence the values of fractal dimensions which can be assigned to materials of dendrites. The two point of view of our examination were the substantial quality of the surface finishes, which cover the electrodes, and on the other hand the shape and form of the dendrites, which grow from these finishes.

The applied arrangement of the test specimens constituting electrodes can be seen in Figure 1. We have used FR4 (glass fiber – epoxy) substrate in our experiments.

Fig. 1. Arrangement of used test specimens.

We have observed the growing of dendrites by optical microscope and if it was necessary, the test voltage was adjusted. After shortage formation test potential was decreased and held on 0.5 V during evaporation of water drop. The time of shortage formation can be simply and precisely measured by a cascaded resistor. For the sake of segregation, dendrites of several metals grow on the top of the water drop and this is why low voltage was applied until its evaporation. If we turn out the power supply in these cases, the evolved structure will collapse. So the test specimens can be easily moved without damaging dendrite structures and beside with adequate storage they can be used for a long time. There is no need to take optical microscopic photographs immediately after WDT series thus the photos can be taken even in other room.

2.2. Taking optical microscopic photographs

Test specimens were lit on the bottom side while taking photographs because if precipitation arises then its effect can be eliminated. The values of magnification were not uniform advisedly, the reproducibility was not relevant. Photos were saved in color BMP format, and 1024 x 768 resolution was chosen for picture size. An example can be seen in Figure 2.

Fig. 2. Original image of a dendrite grown from immersion silver.

We have applied only two kinds of image processing such as decreasing color depth to 1 BPP (bit per pixel, black and white pictures) and 8 BPP (grayscale images). Resolution of images was not changed. Two examples can be seen in Figure 3 - 4.

Resizing, auto adjusting of colors, resampling, color inversion, sharpening, filtrating and edge detection were not applied, even if the evolved markings were not perfect. We have used a freeware picture imaging software which can be found on the WEB.

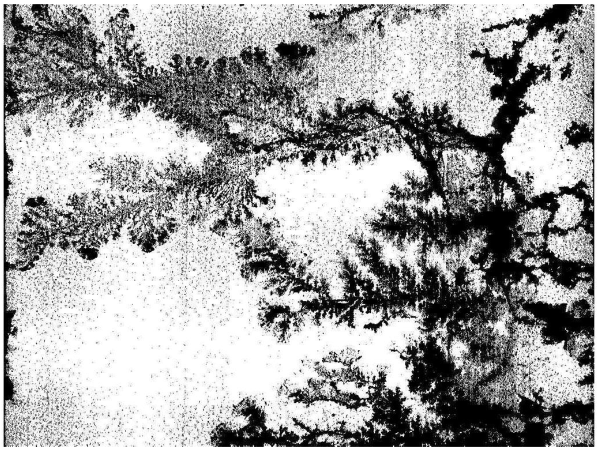


Fig. 3. Black and white image (1 BPP) of a dendrite grown from immersion silver.

After filtering images the file size was so small that the process time of our mathematical algorithms was quite fast.

Fig. 4. Grayscale image (8 BPP) of a dendrite grown from immersion silver.

2.3. The applied mathematical algorithms and softwares [6, 7]

Five different algorithms were used to determine the fractal dimensions of the images:

- Dff.m MATLAB file
- Dsz.m MATLAB file
- fft2d.m MATLAB file
- MATLAB – FracLab toolbox
- Schuszter.exe program

Dff.m and Dsz.m programs were written in text format by us on the basis of A. K. Demcu's Fraktdim.m MATLAB file. Practically functional principles were in both cases agreement with the original program but there were two important differences which must be brought to reader's notice. For the sake of algorithmical complexity's decreasing other functions and procedures were applied so the running time of softwares decreases in a great degree as well. This is not a negligible issue if the resolution of pictures is too large or the speed of our computer is relatively slow and it has not enough data memory.

The other difference is that Dff.m program calculates with black and white images but not this software decreases the color depth. The image (color) conversion (8 BPP → 1 BPP) was executed by using picture editor before running Dff.m file. Both Dsz.m and Fraktdim.m calculates the same type of fractal dimension of a grayscale image, both softwares give the same result but the computation of Dsz.m is essentially faster.

The fft2d.m file can be free downloaded from the public website of MathWorks Corporation. This is such a computational method which is applied in geodesy to analyze photos (images) taken from relief of an examined area using FFT algorithm. The fourth procedure is the freeware FracLab toolbox of MATLAB program package. The Schuszter.exe (the fifth program) is an executable file which does not need the installation of MATLAB. At first we have tested the usability of these softwares on a mathematical fractal, on the so-called Sierpinski Triangle which can be seen in Figure 5. Its theoretically fractal dimension is **1,5850**. Results of the five algorithms in the case of Sierpinski Triangle can be seen in Table 1.

Dff.m	Dsz.m	fft2d.m	FracLab	Schuszter.exe
1,5886	**1,5864**	**1,5993**	**1,5966**	**1,6024**

Tab. 1. Results of these five softwares in the case of Sierpinski Triangle.

Hence the computed and the theoretical fractal dimensions are just the same, these programs can be used for calculating the fractal dimensions calculating of our images.

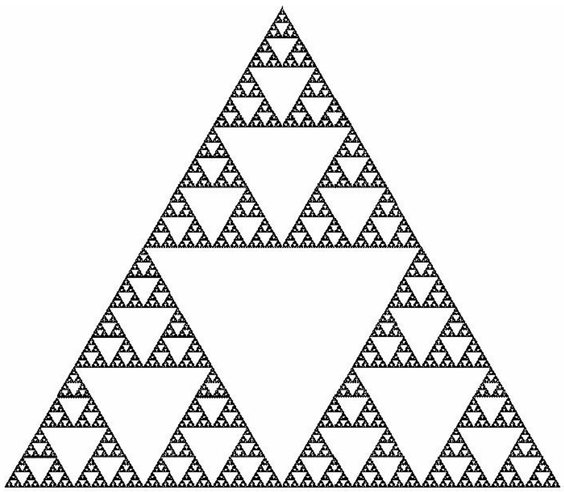


Fig. 5. The Sierpinski Triangle.

3. EXPERIMENT

Three experiment series were carried out in our research whose primary goals tended to the examination of dendrites' fractal dimensions grown from different kind of surface finishes using WDT. Preparation of test specimens was always made according to method introduced in chapter 2.

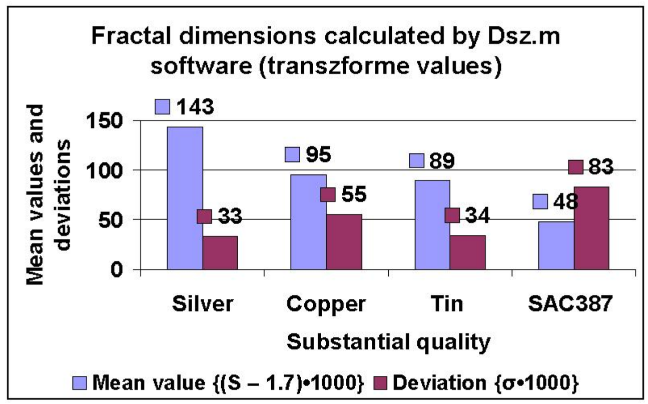
Fractal dimensions of four kinds of material were examined at the first experiment series. They were the followings: electroplated tin (Sn), immersion silver (Ag), pure copper (Cu) and SAC387 solder alloy. Abbreviation "SAC387" means that the compounds are 95,5 % tin, 3,8 % copper and 0,7 % silver.

Materials (surface finishes) examined at the second experiment series were pure lead (Pb), pure tin and eutectic tin-lead solder alloy (63 % Sn and 37 % Pb). In these cases the technology of metallization were not electroplating and immersion, but Hot Air Solder Leveling (HASL) were used. At the third experiment series the coatings were formed by pure lead, pure tin and tin-lead solders (Sn80 %Pb20 %, Sn63 %Pb37 % and Sn20 %Pb80 %) also by HASL technology.

4. RESULTS AND DISCUSSION

The five softwares, which were introduced in subsection 2.3, were applied to analyze the optical microscopic photographs taken from test specimens in case of every experiment series. The most important statistical parameters of fractal dimensions are mean value and deviation which were evaluated using tables and diagrams. It is difficult to draw distinctions between results because the difference of dimension values is not enough large.

In interest of more expressive representation the following solution was applied: not the mean values of fractal dimensions (S) and their deviation (σ) but the transformed values of these parameters are demonstrated on the diagrams. The transformations: $S^1 = (S - c)*1000$ and $\sigma^1 = \sigma*1000$ ($1 \leq c \leq 2$). By illustrating S^1 and σ^1 Instead of S and σ, it is easier to show difference between values, demonstrated on the diagrams, values visually too. The transformed results of the first experiment series can be seen in Diagram 1.



Diag. 1. Results of the first experiment series.

The results of second and third experiment series show the same tendency. By the same program calculated fractal dimensions of various materials or alloys in every case representatively differ from each other, thus the uniformly determined fractal dimensions can approximately well describe the substantial quality.

5. CONCLUSION

We have confirmed our hypothesis that there is relationship between the substantial quality and the fractal dimensions. The material of a dendrite can be characterized by the help of its fractal dimensions. Because the dendrite formation generates the failure in form of shortages the fractal dimensions can be applied in the failure analysis of PWBs.

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