

What is Electrochemical Migration – Dendrite Shorting of Electronic Circuits?

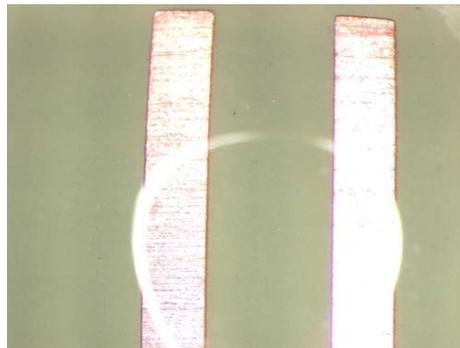
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Dendrite shorting of electrical circuits are metal ions plating in a linear plating cell creating a metal crystalline structure. Metal ions (commonly copper, tin, and silver, but any metal even gold and nickel under the right conditions) are dissolved by corrosive residues (chloride, acetate, sulfate, WOA (succinic, adipic and malic to name a few) and ammonium ions that are found in an acid solution) in a fluid media (typically water, (moisture in the form of relative humidity) but can be any fluid media) under a voltage potential difference of 1.0-1.5 or greater volts.

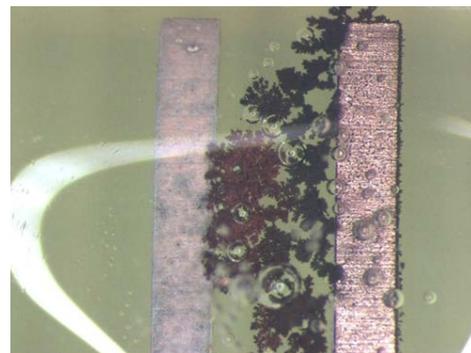
What did we just say?

1. A metal short created by a chemical reaction and voltage is called a dendrite because of its tree like appearance under magnification.
2. A dendrite is grown! Ok I'll say that again
"A Dendrite is Grown", using what available metal is present on the surface. It is not zinc (metal) that is in solution causing the short but the electroplated copper causing the short.
3. How is a dendrite grown? Three things are required to grow a dendrite as seen in the photo. In the defined space of where a short will grow (top a capacitor or on a PCB gap) between power and ground.
 - a. Voltage (1-1.5 or greater voltage difference)
 - b. Fluid Media to create a metal rich solution of dissolved available metal.
 - c. Corrosive ions to dissolve

Dendrite short on top of Capacitor



Fluid Bridging Gap (DI water + Cl⁻)



After powered - Dry Dendrite

Note – A DI water droplet under power will cause a dendrite to grow very slowly because it is not able to dissolve metal as quickly and it dries out typically before it causes a hard failure.

Now with these three conditions a dendrite forms under the following sequence.

- Fluid bridges a gap (power to ground location) typically humidity absorbed over time will create a micro droplet.
- Corrosive residue is dissolved by the fluid, creating an acid rich micro environment that will dissolve the available metal.
- In the micro droplet of fluid and metal salts (dissolved metal such as CuCl_2) a reaction occurs to dissolve more metal under the bias voltage. This bias will drive the plating of the copper (metal) salts from the anode (powered side) to the cathode (ground side) until a bridge (short) occurs (metal plating in a linear direction causing a metal bridge between anode and cathode).

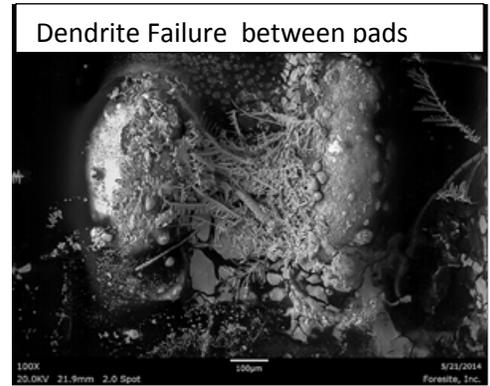


Diagram of Electroplating Copper

Electroplating of copper is a timed event to establish plating thickness and if the anode and cathode are close together they will short out due to thick copper plating bridging the two poles.

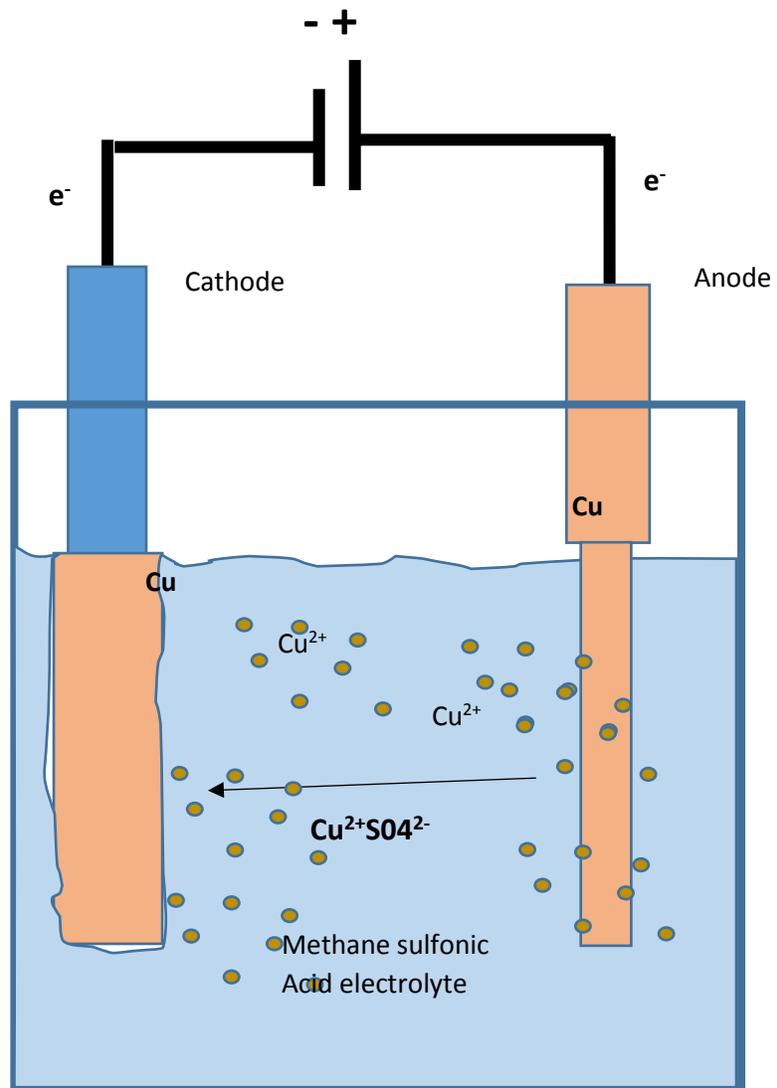
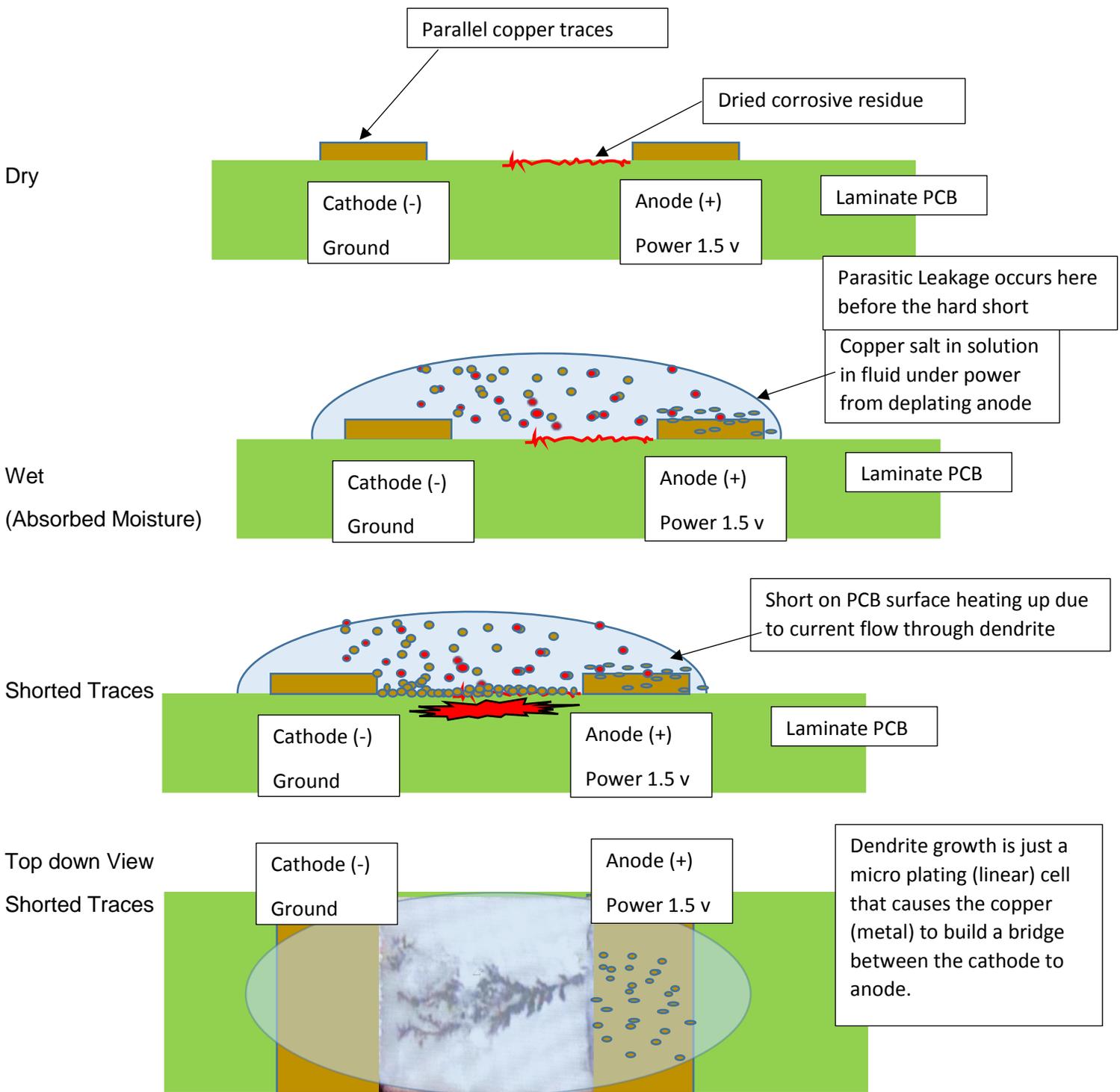


Diagram of Dendrite Shorting

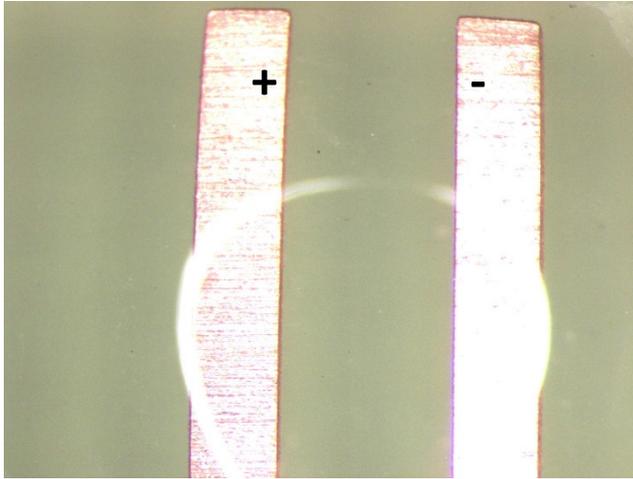
Cross sectional view



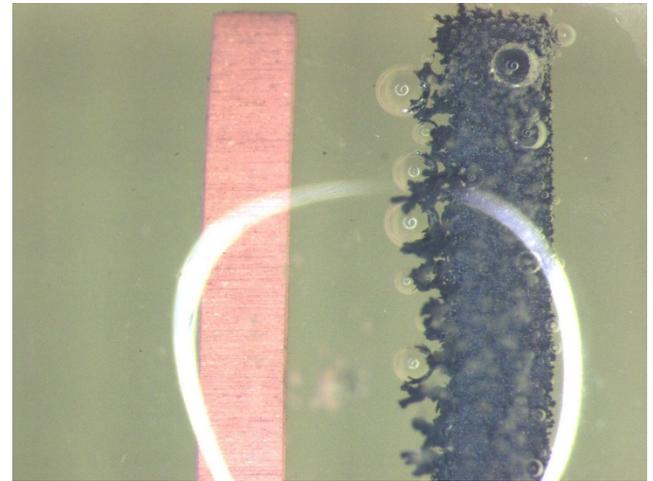
What Happens When a Dendrites Grows?

1. The area of the dendrites heats up!!!
 - a. How hot depends on the source of fluid, if it is absorbed moisture then it is defined by how hygroscopic (moisture absorbing) the residue is, or is it a condensing environment.
 - b. This is due to the current flowing through the plated metal short. As more current attempts to flow the hotter the area becomes. At colder operating temperatures the localized heating allows the rate reactions of moisture being absorbed and solubilizing the corrosive residues to become much quicker in cold operating environments. The corrosive flux residue found in cold conditions is a very slow reaction due to slower atomic movement reducing the ability to absorb moisture even in high humidity conditions of a winter morning with 60% RH at -15C. The air is at 60%RH but the surface of the powered electronics still has a high surface insulation resistance till it warms up to 7-15C (this typically is done by the defrost blower in a vehicle)
 - c. This current flow through the crystal of metal is restricted and causes localized heating of the dendrite and surrounding area. During the heating it typically will dry out the fluid and stop the reaction.
 - d. Each dendrite is a fragile crystal structure initial and the heating occurs when the voltage/current are trying to pass through it and initially it will blow the connection away because it will not be able to carry the current and will carbonize (break the short) and blow like a fuse.
 - e. With very corrosive residues they are able to hold large amounts of fluid from the humidity and form a dendrite reaction quickly with a much thicker dendrite that is able to carry the full current /voltage flowing from the power supply causing a thermal event to cause the PCBA laminate to catch on fire and even vaporize the copper trace.
2. What accelerates dendrite growth???
 - a. Continuous moisture available (inside a humidity chamber at a constant humidity) even at 30% RH doped samples failed in 2-3 minutes because they had enough moisture to mix with a very corrosive flux residue (that absorbs large amounts of moisture).
 - b. The greater the concentration of corrosive residue the more moisture it will absorb and cause failures to occur quickly.
 - c. The more acidic a corrosive residue is the more aggressive the chemical reaction is to grow the thicker dendrite to grow and cause the thermal event and blow the copper traces and catch the board on fire.

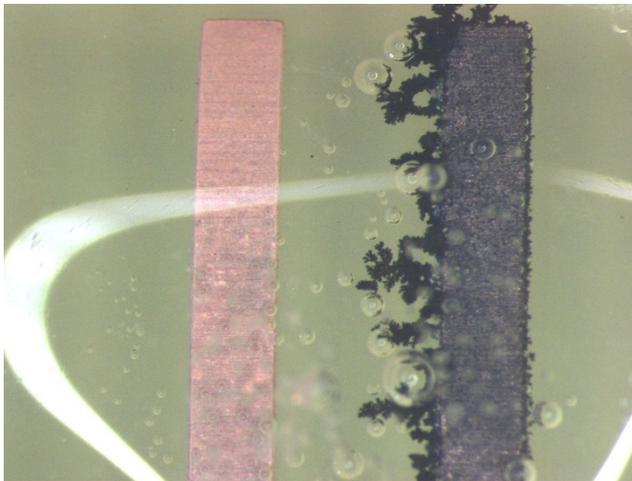
Images of a dendrite growth with a 13 volt bias in dried $ZnCl_2$ flux (Run time of 1.11 minutes)



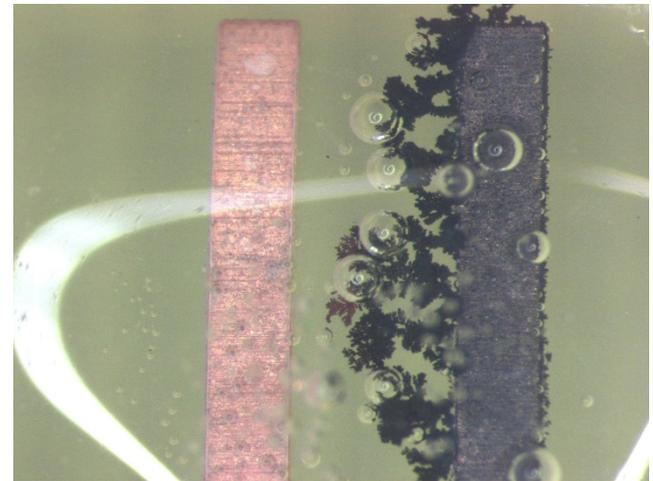
Water and Corrosive Residue between traces



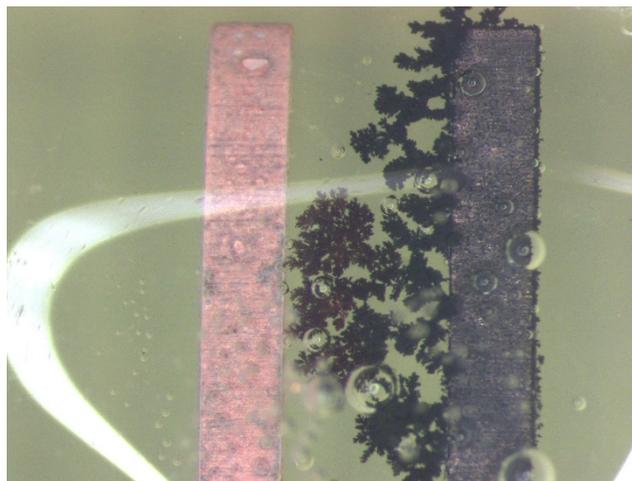
Biased voltage 15 seconds



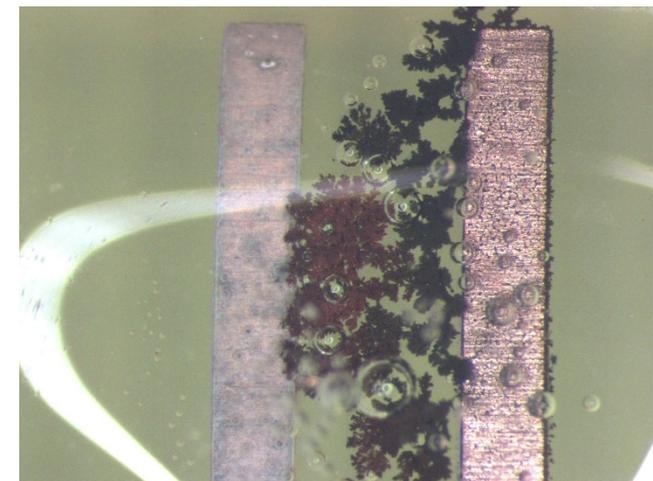
Biased sample for 39 seconds



Biased sample for 51 seconds



Dendrite short at 1 min 11 seconds



Continued growth at 1 min 30 seconds