

# The CAF Mechanism

The course team are grateful to Alan Brewin of NPL for permission to adapt his explanation of CAF.

The five stages in the formation of a conductive anodic filament are described below.

## 1. Initiation

For CAF to occur there must be a source of copper, a electrical bias and a glass reinforcement fibre in the same locality. In dense multi-layer PCBs this can often occur at the PTH wall where the plating has ingressed into the glass bundle, although fibres protruding through the surface of PCBs to the locality of surface tracks has also been reported.

## 2. Separation of glass and epoxy

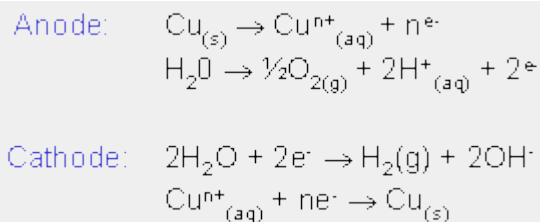
In order to facilitate good wetting of the epoxy resin into the glass fibre weave during manufacture, the glass surfaces are prepared prior to impregnation. If this preparation is of poor quality, separation of the epoxy resin and glass fibres can be more likely. Bonding can also be lost due to hydrolysis of the glass finish, or even due to residual stress in the glass fabric weave being relieved, and the hollow glass fibres themselves can become CAF growth routes.

The absorption of moisture into the laminate accelerates these processes and the delamination can then provide a pathway for CAF growth.

## 3. Electrochemical reaction

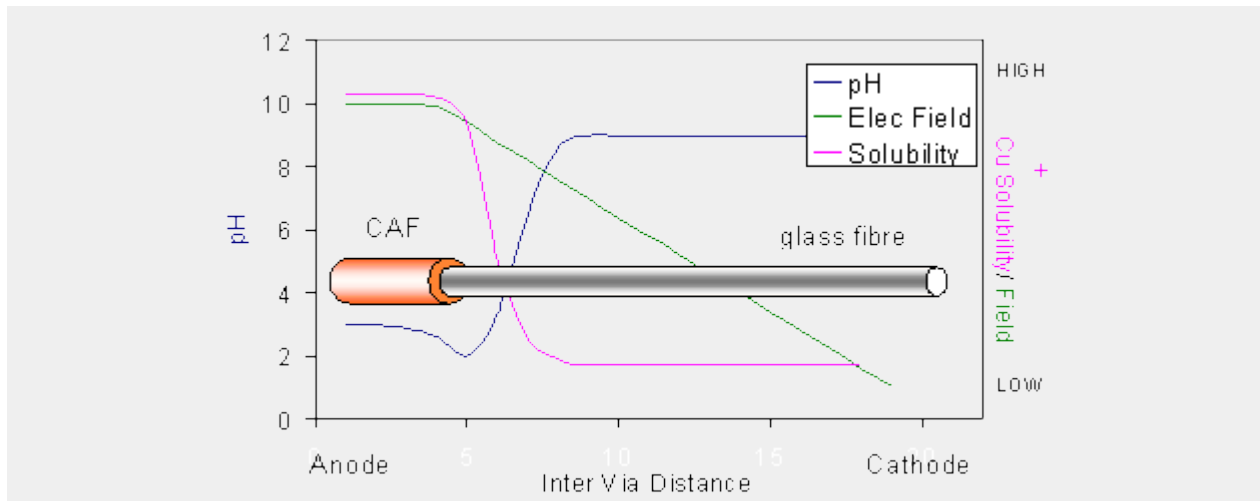
With moisture present an electrolyte can form and a pathway established for current flow that allows an electrochemical process with bias applied on the PCB. The mechanism involves oxidation and dissolution of copper at the anode; if copper anions reach the cathode they are reduced back to copper metal (Equation 1).

### Equation 1: Electrochemical equation for CAF formation



The process shown here is ideal; in reality this process is solubility-dependent. The formation of Cu(s) at the cathode doesn't readily happen since the copper deposits as an insoluble salt due to high pH. This solubility effect is responsible for the CAF deposits growing from the anode, a low pH environment towards the cathode and is illustrated in Figure 1.

**Figure 1: Schematic of pH, and electric field conditions during CAF growth**

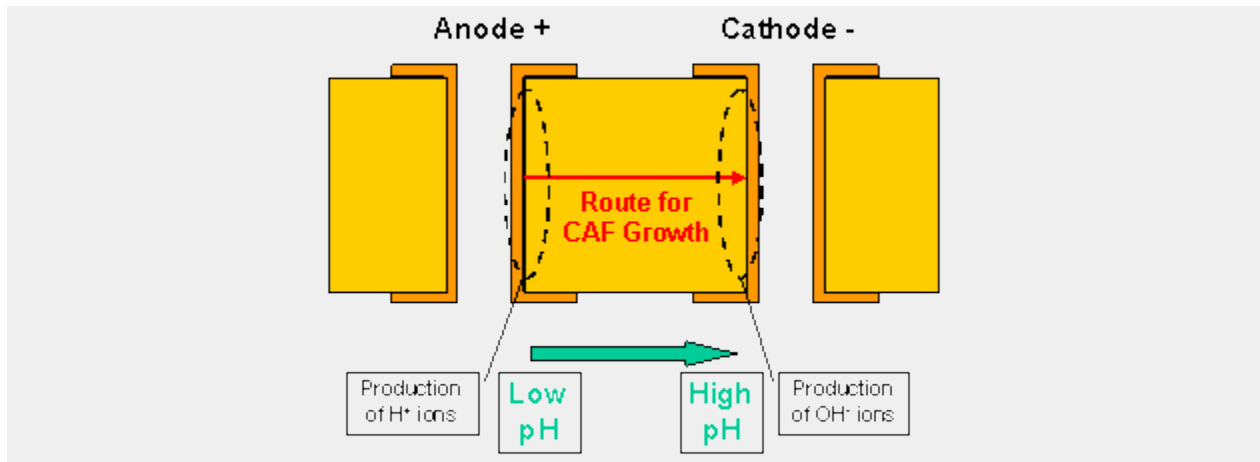


Other ions present from processing, or materials, such as chloride, sulphur or other metals may also take part in this process.

#### 4. Salt deposition

As the electrochemical dissolution of copper continues, a pH gradient is produced due to the hydroxonium ions produced at the anode and hydroxide ions at the cathode. In Figure 2 this is represented by a schematic of two through-hole vias, where the anode via wall is the initiation site.

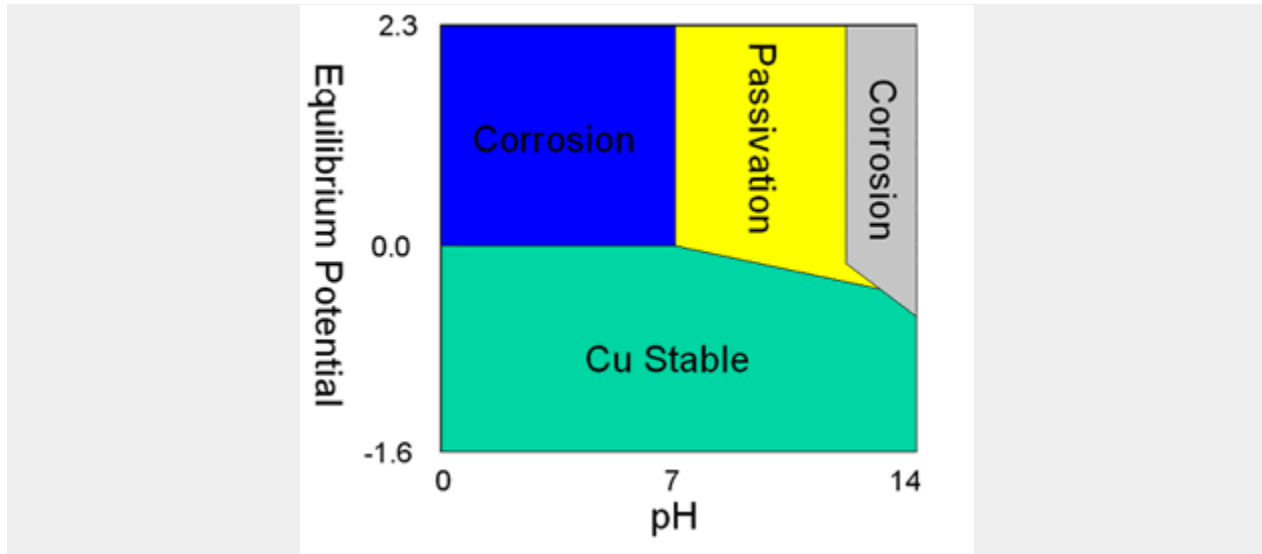
**Figure 2: Schematic of CAF growth between two vias**



The formation of this pH gradient is key to the mechanism of CAF growth. The solubility of copper salts is dependant on pH and the electrical potential applied, as shown by a simplified Pourbaix diagram<sup>1</sup> (Figure 3). At the cathode, Cu metal remains stable (green area, negative potential). However at the anode, a positive potential environment with an acidic pH, the copper is mobile in solution as copper cations  $\text{Cu}^{2+}$  (blue region).

1. For an explanation, see <http://www.wou.edu/las/physci/ch462/redox.htm>

Figure 3: Simplified Pourbaix diagram for copper



As the CAF filament grows (Cu ions migrate) along the glass fibre/epoxy interface towards the cathode, quickly an environment of neutral pH is reached. Thus copper precipitates as an insoluble copper salt (left-hand edge white region in Pourbaix diagram), and it is this build-up of copper salts that constitute a conductive anodic filament.

The electrochemical reactions described in Stage 3 then continue with current flowing along the CAF, and H<sup>+</sup> ions being produced at the CAF. In this way the localised pH gradient moves forward with the CAF growth front.

## 5 Completion of conductive pathway

The steps above can all initiate without any serious effect to circuit functionality. Catastrophic electrical failure only occurs when the filament of copper salts bridge the anode and cathode in question. Under humid conditions the salts are conductive and will allow a massive increase in current flow between the previously well-isolated copper areas and consequently circuit failure occurs.

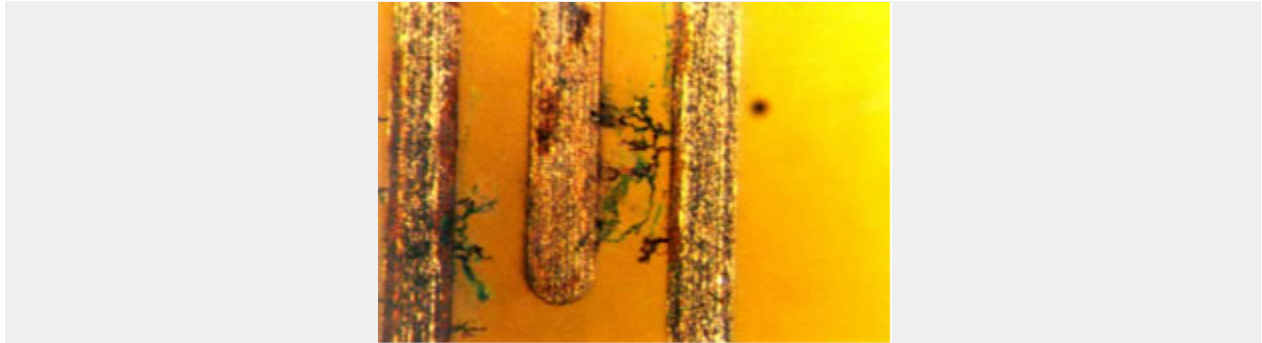
## Dendritic growth

Dendritic growth is an electrochemical process associated with electromigration on the surface of a PCB, the dendrite grows from the cathode to anode as copper builds up. An image of such a dendrite is shown in Figure 4, and it is important to note this is distinct and different from CAF for the reasons described below.

- A dendrite can be seen on the surface of a PCB, a CAF is sub-surface.
- A CAF is associated with glass filaments, a dendrite is not.
- A CAF will grow from an anode to a cathode, a dendrite will grow from a cathode to an anode.
- A CAF is made from copper salts, a dendrite is metallic e.g. copper; nickel.

It is not possible to see a CAF with the naked eye (even with backlighting), as you can for a surface dendrite, although you may see carbonisation as a result of a complete failure if high currents have flowed.

**Figure 4: Surface PCA dendrites as a result of flux contamination**



Source : [http://www.ami.ac.uk/courses/topics/0152\\_caf/index.html](http://www.ami.ac.uk/courses/topics/0152_caf/index.html)