What are Intermetallics and How Can We Overcome the Failures Associated with Them?

By: Aaron Olson, Lab Technician

Working in an analytical environment within the electronics industry, we see problems related to intermetallic growth and formation on a daily basis. Intermetallic formation is inevitable when attempting to solder and bond two metallic surfaces and once formed will continue to grow for the lifetime of the solder joint. This article will explain what intermetallics are, how they are formed and several methods to help reduce the number of failures caused by intermetallics.

Before we can talk about the failures associated with intermetallics, we must first discuss what intermetallics are and how they are formed. Intermetallics are formed by a process called dissolution or migration. Tin migration occurs when the solder alloy begins to liquefy or melt, and this tin migration will continue rapidly as long as the temperature is above the melting point of the solder alloy, and would continue until all tin has been depleted. However we want to control the time and temperature to cause the wetting of the tin to the conductor, this is when the intermetallic is formed. If one achieves wetting or bonding of the alloy to the surface material, an intermetallic compound is formed, this is the strength of the solder termination. Too much intermetallic and the termination is weak due to the loss of tin from the solder alloy leaving lead (Pb) nodules with no strength, (see fig. 4) also intermetallic compound is less ductile or a more brittle termination. If there is no intermetallic then there is no solder joint.

Intermetallic compound is necessary in every solder joint. The degree of wetting between two metal surfaces can be determined based on the amount of intermetallic that is formed. Take for instance tin and copper. We expect to see on average 1.0-2.5 microns of intermetallic formation. Any less than 1 micron means that the tin from the solder alloy is not wetting properly to the underlying base metal, which most likely means process not be followed, i.e., dwell time and temperature, or solderability problem with component lead or some type of board level problem. In cases where nickel was used as a barrier layer, 0.4-0.8 microns on average is to be expected if proper wetting of the two alloys is achieved.

The two most common types of intermetallics that are seen are tin/copper (SnCu) and tin/nickel (SnNi) intermetallics. Tin copper intermetallics will occur in 2 distinct phases. The first phase of CuSn intermetallic is formed nearest the copper interface and is designated as 'e-phase' Cu_3Sn intermetallic. A layer of 'n-phase' Cu_6Sn_5 will form on top of the initial layer of e-phase and is much thicker, comprising the bulk of the CuSn intermetallic layer. Many boards these days with the move to lead-free electronics use a surface finish known as ENIG, which uses electroless nickel plating as a barrier or diffusion layer between the solder alloy and the underlying copper. Nickel/tin intermetallics form at a much slower rate than that of CuSn intermetallics. The intermetallic formed between nickel and tin is known as $\underline{\delta}$-phase intermetallics, designated as Ni_3Sn_4. Below are some pictures of both e-phase and n-phase CuSn intermetallics and $\underline{\delta}$-phase SnNi intermetallics captured from the surface. The intermetallics were grown on a sample substrate from each plating type (i.e. copper and nickel) and where then chemically etched with nitric acid to remove the remaining solder alloy and expose the individual layers of intermetallic. The samples were then imaged at varying magnifications using a scanning electron microscope (SEM).

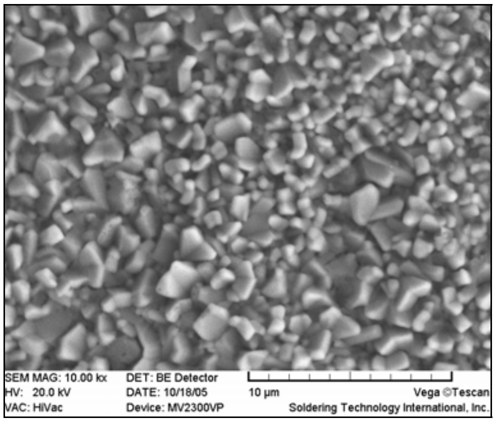

Figure 1. SnNi intermetallic formed on the nickel barrier layer

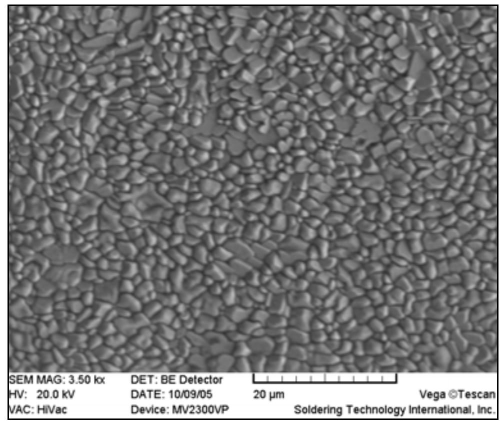

Figure 2. e-phase Cu_3Sn formed on the surface of copper pad

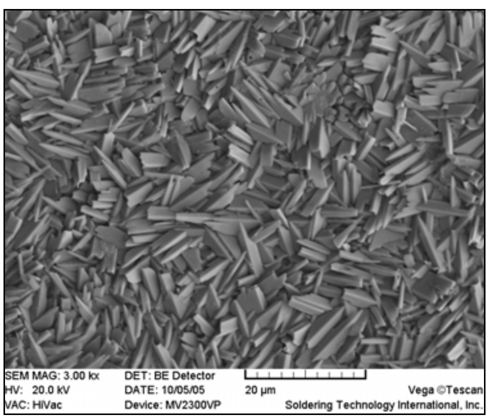

Figure 3. n-phase Cu_6Sn_5 formed on top of the e-phase Cu_3Sn intermetallic

It is a known fact that intermetallics are essential in any solder joint. Little to no intermetallic formation means poor wetting of the solder to either the board pad or the component lead. Since we know that intermetallic formation is vital to the strength and integrity of the solder joint, what are some of the potential problems we can encounter when dealing with intermetallics?

Intermetallics are inherently brittle material since they are predominately a crystalline structure as seen in the images above. The difference in ductility and density between the intermetallic formed and that of the solder alloy and metallization of the metallic surface being bonded can cause problems when the electronic hardware is subjected to harsh thermal or mechanical environments. When a more ductile material is adjacent to a less ductile material and is exposed to mechanical vibration/shock or thermal stress, fractures will begin to occur. This takes place predominately at the solder/intermetallic interface. It is vital to ensure that enough intermetallic is present to make the bond between the two metals but excessive amounts of intermetallic formation only open the door for more problems to occur.

The vast majority of problems that we see in the lab are related to the material set used for a particular application or improper reflow profiles causing excessive intermetallic growth. Below are some photos of fractures that are occurring along the solder to intermetallic interface after both mechanical and thermal shock testing.

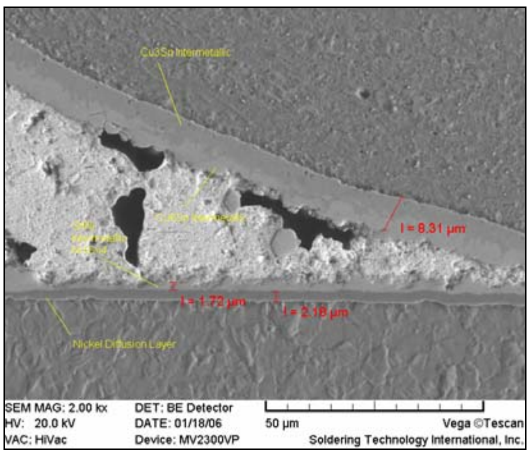

Figure 4. Image showing fractures between Cu/Sn intermetallics and solder alloy.

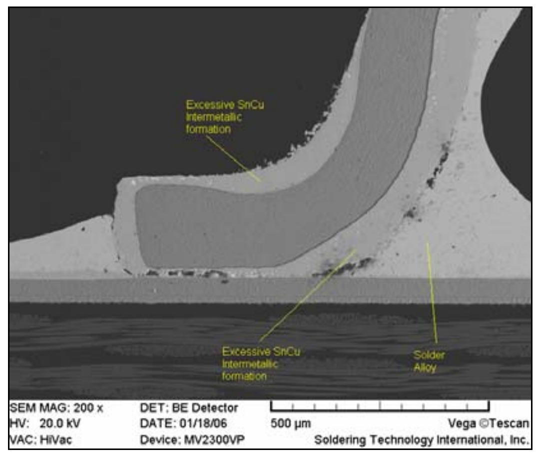

Figure 5. Excessive intermetallic growth and subsequent fracturing at the SnCu intemetallic solder alloy interface

Intermetallics, once formed will continue to grow over time. This growth is accelerated when exposed to high temperatures, especially where long dwell times at high temperatures take place. It is important to ensure that the reflow profile for a specific application is correct. In cases where high temperatures and dwell times are used to bond difficult to solder components, great care should be taken in regards to the surrounding components. If the remaining components on the board are seeing the same heat extreme, excessive intermetallic may be formed creating the potential for solder joint failures later in the life of the product.

In many cases, where the electronic hardware is exposed to harsh operating environments, especially where extreme temperatures are present, the use of a diffusion layer of nickel is often warranted. The growth rate of SnNi intermetallics is far less than that of SnCu intermetallics. If the hardware is intended to be subjected to extreme operating temperatures and high temperature environments, a nickel barrier layer is often a good choice. SnNi intermetallics are more brittle in nature than SnCu intermetallics so great care still needs to be taken during manufacturing of the board not create excessive amounts of intermetallic from the start.

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A good method to ensure that proper reflow temperatures are being achieved and adequate intermetallics are formed is to randomly cross-section and image via the SEM several solder joints from an assembly before and after thermal shock testing. This is especially true when dealing with assemblies that are being built for the first time or in situations where new manufacturing profiles and/or practices are in use. A good determination on the reliability of the solder joints can be made by analyzing the intermetallic formation and wetting angles of the solder to the lead and inspecting for any fractures that may be present. This is far less expensive than finding out later after many assemblies have been built.

For any questions or comments about this article, please email Aaron Olson at aolson@stielectronicsinc.com