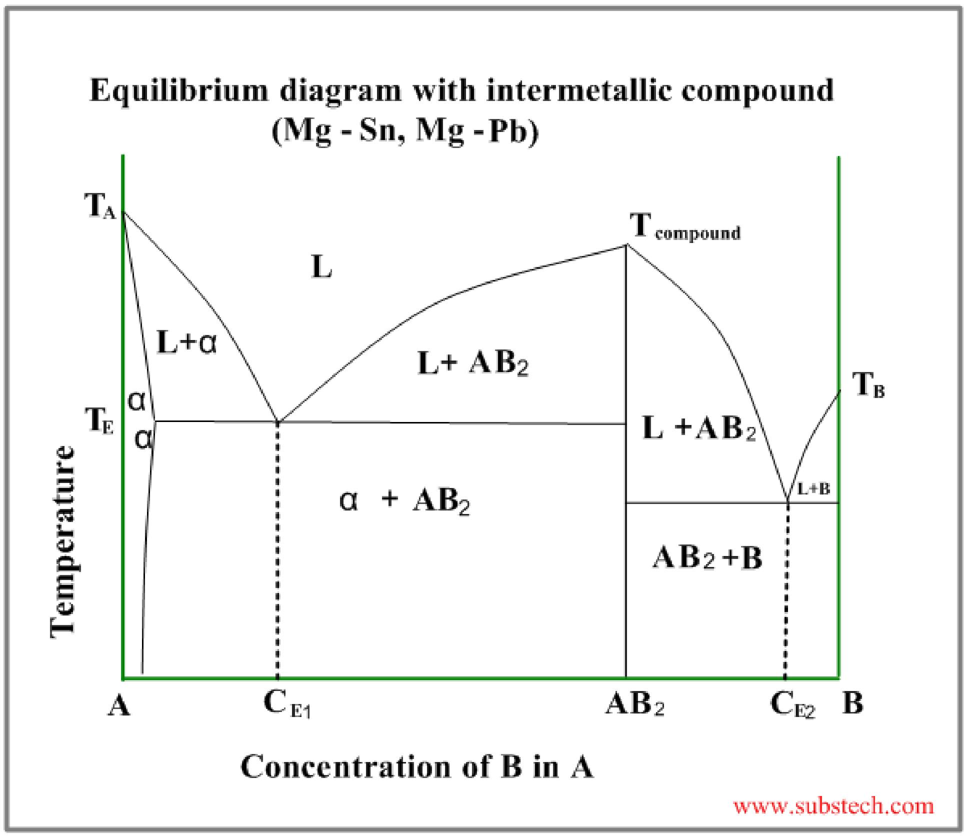
Intermetallics: Friend or Foe

The term 'Intermetallics' appears frequently in technical papers discussing novel solder alloy formulations and applications. Because of the frequency of inclusion in these papers the term obviously relates to a critical aspect of the subject matter. Either the presence of intermetallics is critical to the success of the subject matter, or the presence is detrimental to the success and needs to be prevented, or at a minimum controlled to a certain level. The questions become - what exactly are intermetallics, and why is understanding the role they play in solders so important? In other words - are they **Friend or Foe**?

Background

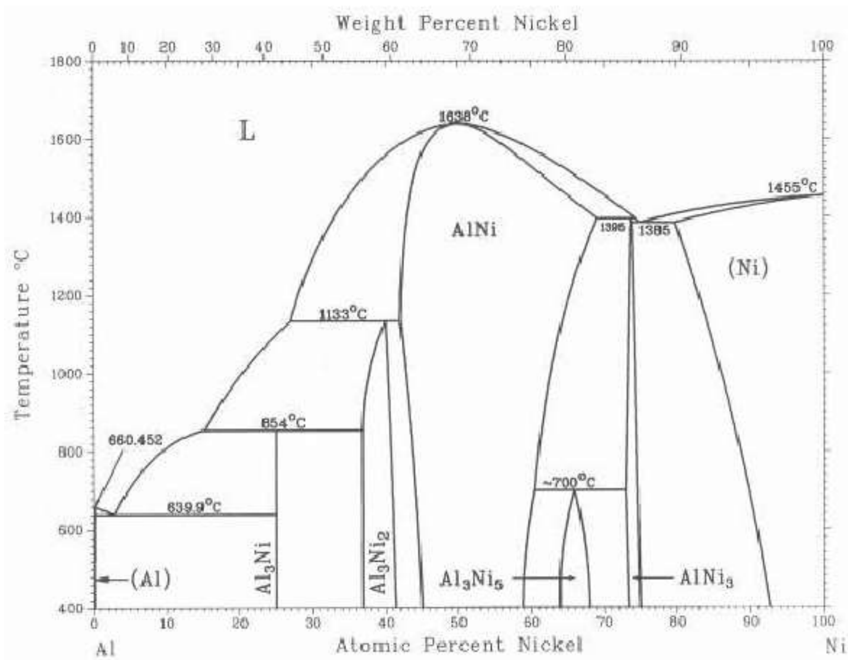
By definition, intermetallics are specific phases that have stoichiometric chemical compositions, like CuZn, Cu_3Sn, or Mg_2Pb. These compositions exist over a very narrow band. Many binary alloy systems contain intermetallic compositions. The generic binary phase diagram below has composition AB_2. This composition, 33.33% A and 66.67% B, would be defined as an intermetallic.



The nature of composition does not, in and of itself, have bearing on the performance-affecting nature of the intermetallic. Metallurgically, intermetallic compositions tend to have ordered structures. Ordered structures exhibit high thermodynamic stability over extended temperature ranges and possess excellent resistance to mechanical deformation under extreme conditions. Or put another way, ordered structures exhibit high hardness values, relative to the alloy matrix around them. High hardness, in certain applications, equates to brittleness. And manufacturers and end users of solder joints agree that brittleness in solder joints reduces long term reliability.

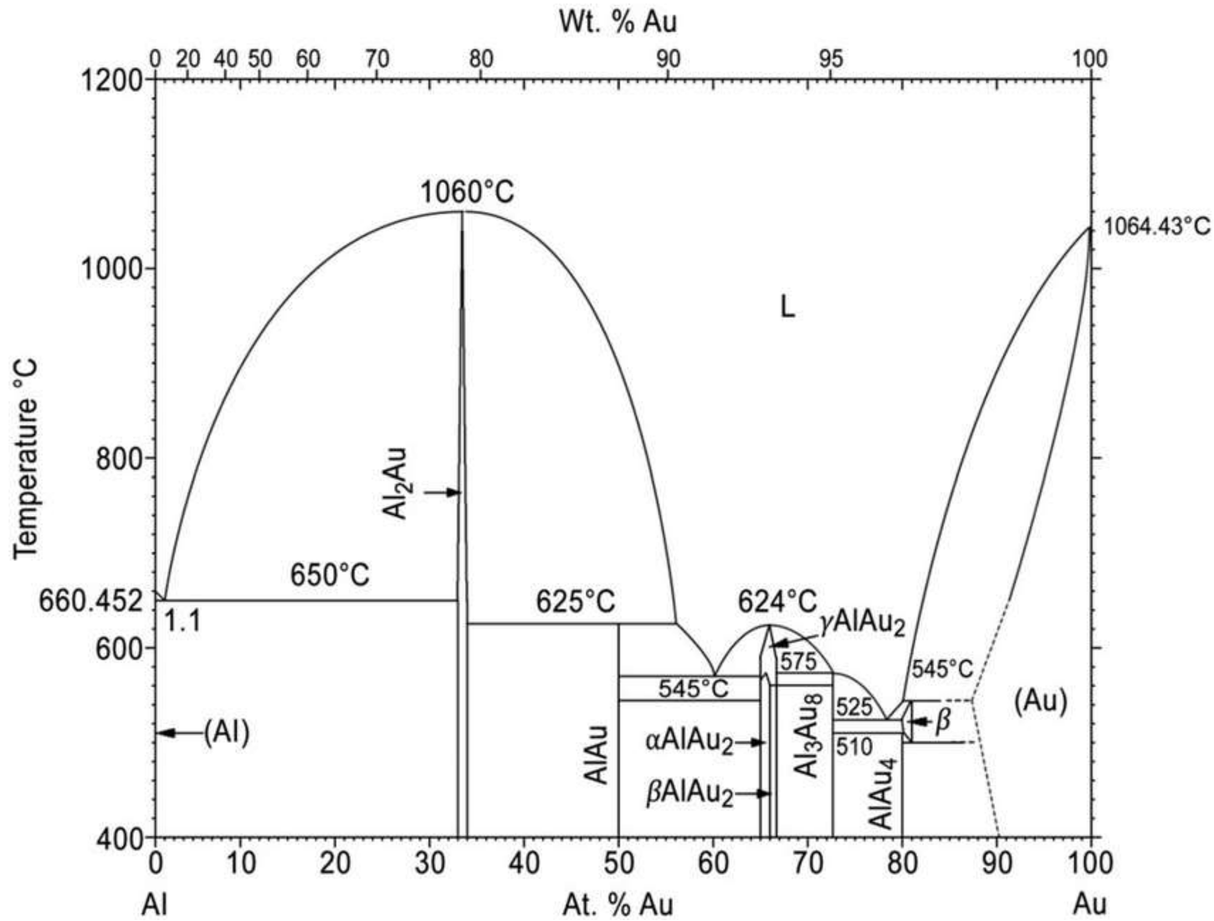
Commercial Applications

Intermetallics, with the mechanical properties they possess, easily fit the definition of the expression "Friend or Foe"? In many commercial applications, success is predicated on intermetallics and the properties they possess. A noteworthy example comes from the Ni-Al alloy system.



Nickel-based superalloys find unparalleled success in aerospace applications like gas turbines and rocket motors. The metallurgy behind their success is extensive, but one contributor to this is the formation of a very specific intermetallic - γ′, called gamma prime. This intermetallic has the composition $AlNi_3$ and is the principal strengthening phase in many of these alloys. This intermetallic imparts the requisite high temperature operating strength needed to prevent mechanical failure. With a melting point of almost 1400°C, the intermetallic retains its strength properties at the extreme temperature limits of the aircraft engines. In this application the intermetallic would be considered a **Friend.**

With every successful intermetallic application comes a catastrophe. A well-documented example comes from the Al-Au binary system.



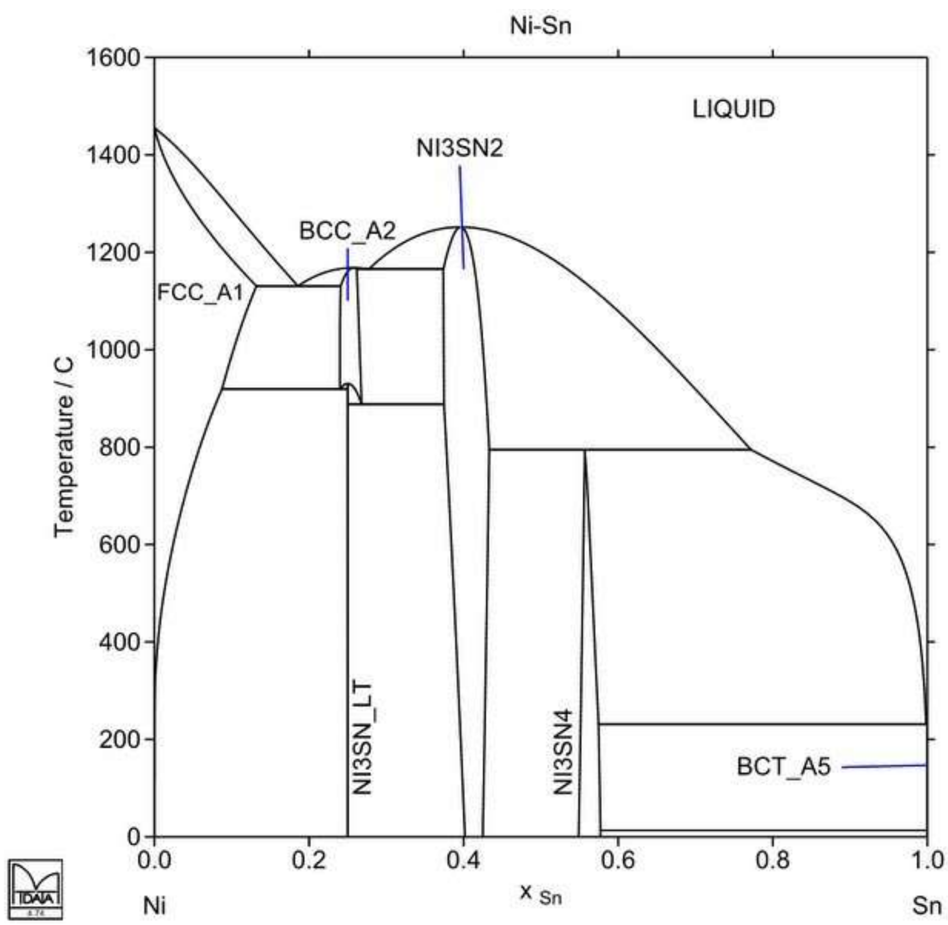
Both Au and Al have found extensive use in microelectronics manufacturing for decades. They both get used as substrate coatings, wire for bonding wire applications, and other applications. Invariably both were metallurgically joined together - Au wire bonded to an Al substrate - probably to take advantage of the better electrical conductivity of Au. The success was short lived. This combination produced the intermetallic composition $AuAl_2$, a heretofore unrecognized biproduct of this metallurgical bonding. The formation of $AuAl_2$ caused substantial wire bond failures by the following mechanism: growth of the intermetallic layers caused a reduction in volume, and hence created cavities in the metal near the interface between gold and aluminum, leading to reduced bond strength. This led to subsequent device failure in untold numbers of microelectronic devices before the root cause was fully investigated, understood, and documented. Later, this intermetallic came to be termed 'Purple Plague' because of its bright purple color and ability for causing disaster. Purple Plague and has since become a standard term in the microelectronics manufacturing dictionary. In this application the intermetallic would be considered a **Foe.**

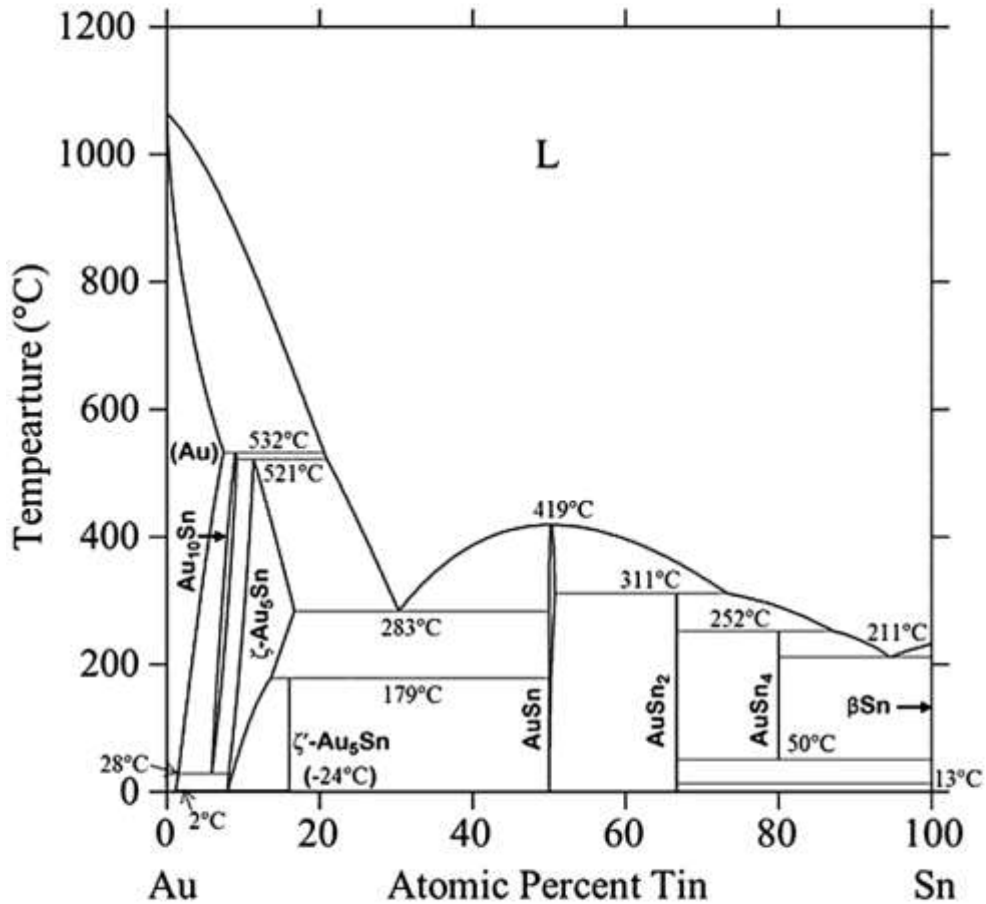
Solder-Specific Applications

The microelectronics manufacturing industry relies heavily on solder reflow for a huge percentage of its processes: BGA, SMT reflow, wave soldering, solder preforms, solder wire, solder paste, etc. Success of these devices, in applications ranging from military to aerospace to medical to automotive, relies on reliable solder joints. Within this subset of manufacturing, intermetallics can be defined as either **Friend or Foe**.

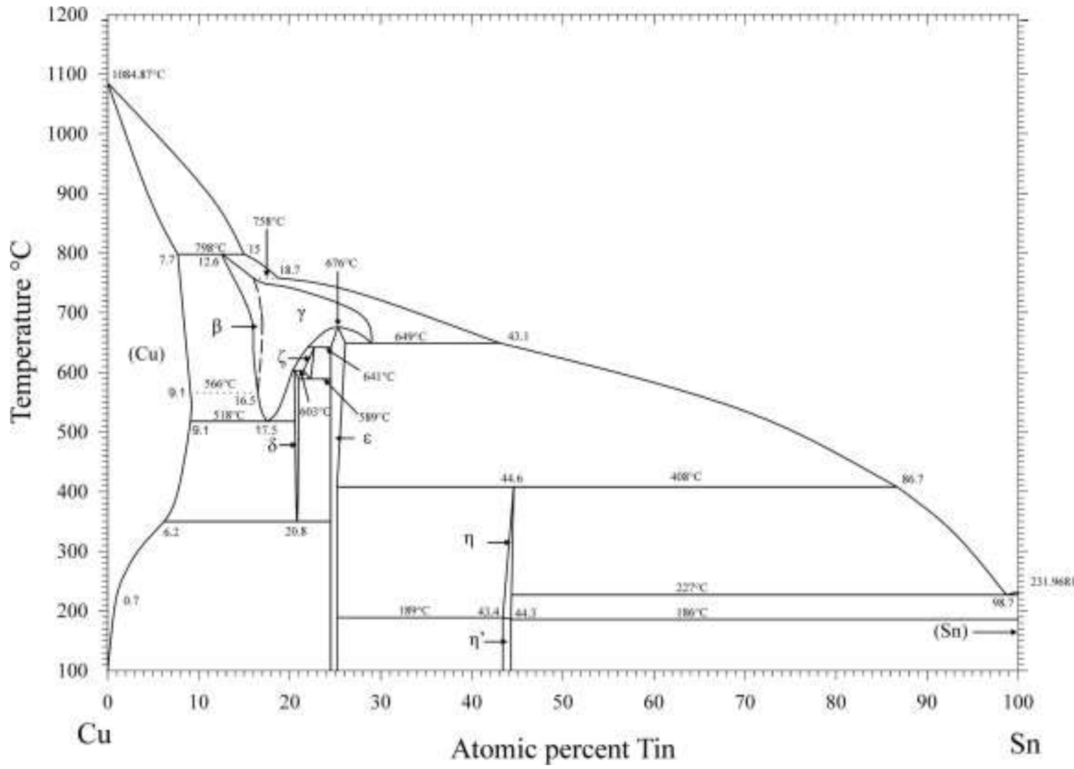
Solder alloys work by melting at a specified temperature, then bonding to the metallization layers of the mating substrates. The bonding mechanism is intermetallic formation between the solder alloy and the metallization layers. A review of solder alloy compositions reveals that these alloys predominantly contain Tin (Sn). The Sn percentage in alloys ranges from as low 1% by weight up to as high as 99%. This is by design as the Sn acts as the primary bonding element in solder alloys. It achieves this by its propensity to form intermetallics with substrate materials most frequently used in the industry - Gold, Copper, Silver, Nickel. Proper bonding through intermetallic formation would be, in this case, be considered a **Friend**.

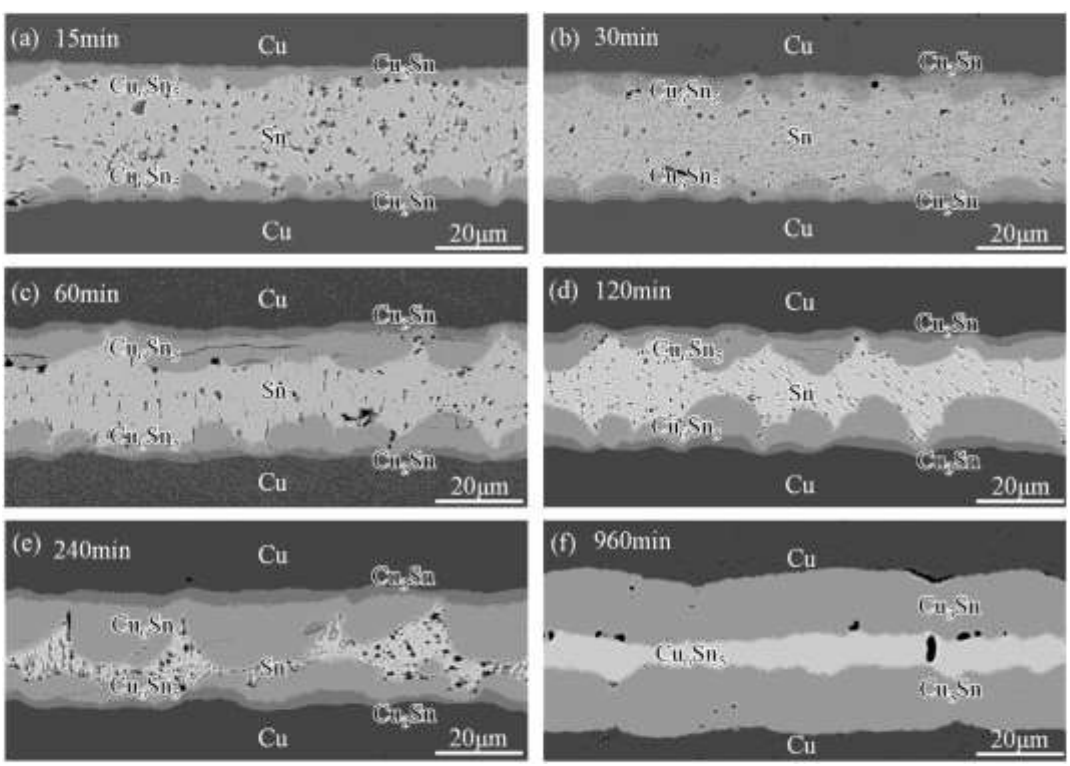
Two examples are the Ni-Sn and Au-Sn binary alloy systems, shown below.





Often the field applications for solder connections require operating at elevated temperatures. The elevated temperature increases the diffusion rate of the mating metals, leading to increased volume fraction of the intermetallic relative to the matrix. An example of this growth comes from the Cu-Sn alloy system on the following page.





Morphology evolution in Cu-Sn intermetallic joints at 260 °C for various times: (**a**) 15 min, (**b**) 30 min, (**c**) 60 min, (**d**) 120 min, (**e**) 240 min, (**f**) 960 min.

From: [Growth kinetics of Cu6Sn5 intermetallic compound in Cu-liquid Sn interfacial reaction enhanced by electric current]

The extent of intermetallic growth may potentially be catastrophic for the application. High temperature applications would be candidates where the intermetallic growth be kept to a reasonable minimum. Here the intermetallic could be considered a **Foe**.

As discussed above, intermetallics play an integral role in the functionality and reliability of mechanical and electronic assemblies. Intermetallics can have tremendous advantages to the performance of an application, but one needs to be careful to avoid the potential pitfalls. Designed properly intermetallics improve reliability. Designed improperly they reduce reliability.

The question remains: Intermetallics - Are they **Friend** or **Foe**? History will decide.

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