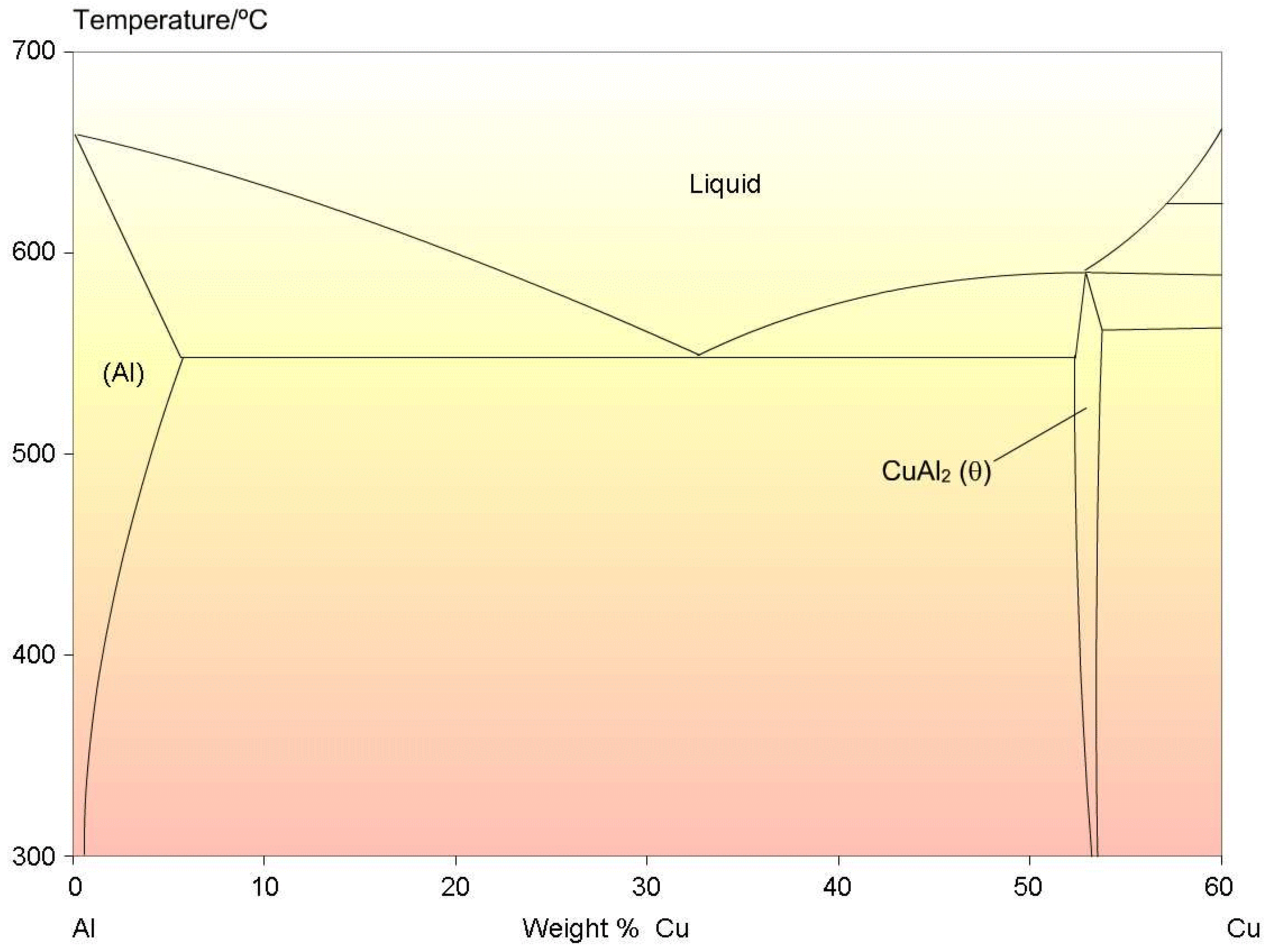
Copper Aluminum Alloys

This Al-Cu phase diagram shown only goes up to ca 60%, by weight, of Copper. and is “split” at around 54wt%Cu by a particular phase.

This "split" means that the two parts of the diagram must be considered separately. The diagram up to the 54% point is very similar to the "standard" phase diagram.

Intermetallic phases are not named α or β, but are assigned other Greek letters (though there is no strict convention for this). Here the phase on the right is named θ, but other than its name it is dealt with in exactly the same way as a beta phase.

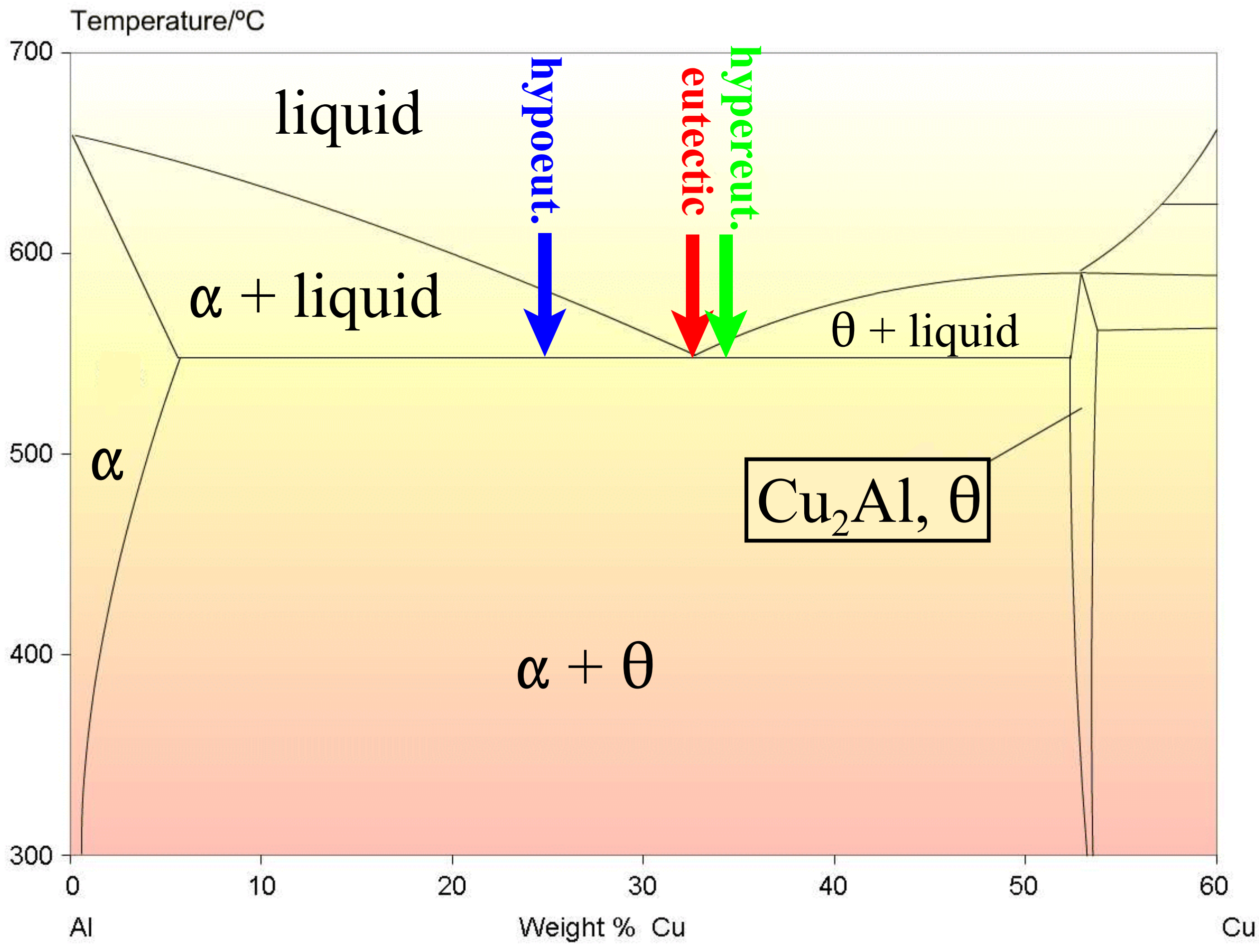


Cu-Al Phase Diagram

The **eutectic composition** is at 33%Cu/67%Al, and the T_e is ca. 550 K.

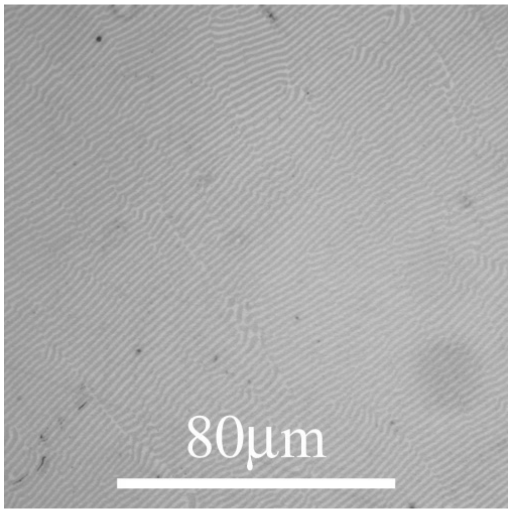
A 25%Cu/75%Al composition is known as a **hypoeutectic** alloy

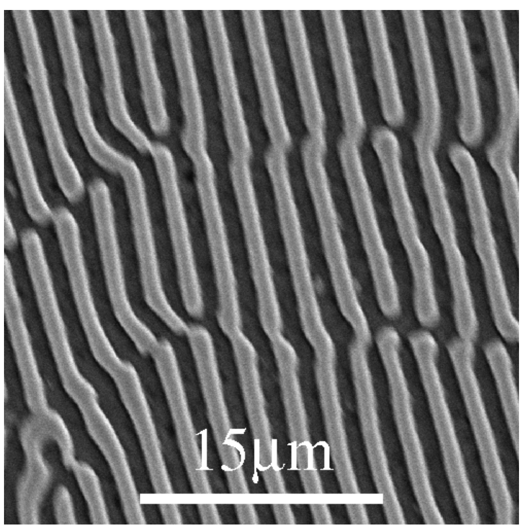
A 36%Cu/64%Al composition is correspondingly called **hypereutectic**



Micrographs: Eutectic Alloy

Micrographs are high-resolution microscope pictures which may be produced by techniques such as reflect light microscopy (RLM, top), scanning electron microscopy (SEM, bottom) or scanning transmission microscopy (STM).





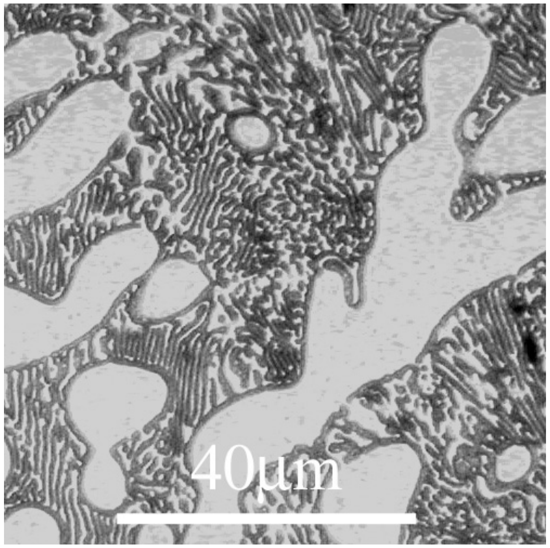
As a liquid is cooled at the eutectic composition, the two phases grow simultaneously as an interconnected structure which forms the solid eutectic phase. The phase has a **lamellar** structure, which consists of many thin alternating layers of the two components.

The lamellar structure ensures that there are very small **diffusion fields** head of the solid-liquid interface, meaning that atoms do not travel over very significant distances for the two phases to simultaneously form.

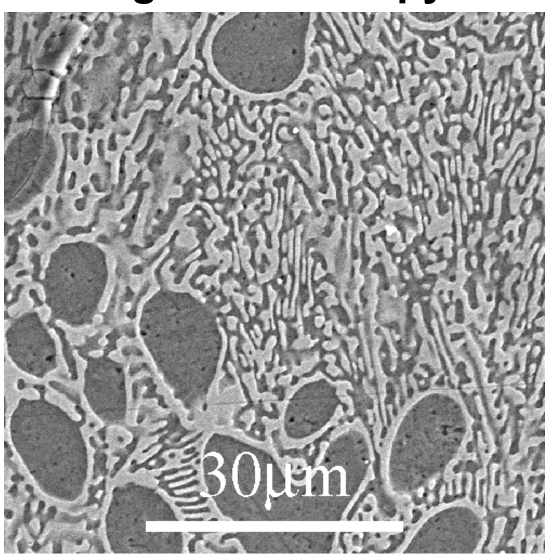
The RLM picture shows the co-operative formation of θ and Al phases which form the eutectic lamellae. The SEM picture shows an interlamellar spacing of about 1 μm, as well as some imperfections which form from irregularities and disturbances during growth.

This specimen was made by unidirectional cooling and was metallographically prepared (mounted, ground and polished) and etched in dilute NaOH which stains the surface of the θ phase brown/black while leaving the α phase unattacked (appearing white).

Micrographs: Hypoeutectic

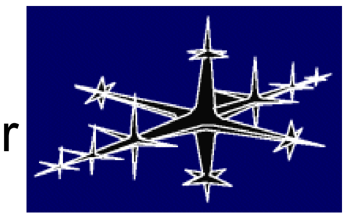


Light Microscopy



SEM

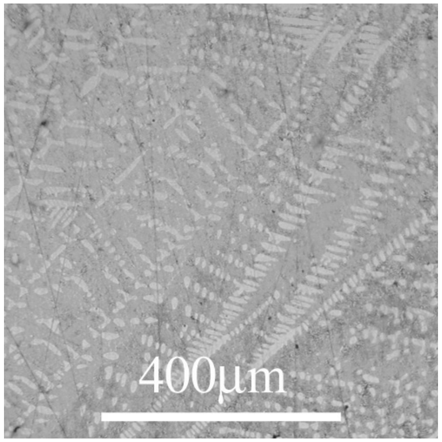
The RLM micrograph (top) of the 25%Cu/75%Al sample shows primary Al **dendrite** arms (white). The dendrite trunk has been intersected at an angle by the plane of polishing to give the observed morphology.



Primary phases often form as dendrites. These are solid structures forming from a liquid, which solidify in a branched manner because it is energetically favourable.
A dendrite will rarely form in a completely regular manner. A diagram of such an idealised regular dendrite is pictured above and to the right.

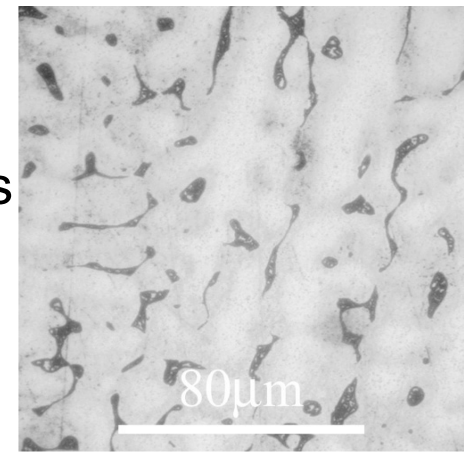
Between the dendrites is the Al - CuAl2 eutectic. Initially dendrites would have formed from the liquid, the regions between the dendrite arms known as the **mushy zone** transforming to a eutectic solid (L to Al + CuAl2). These two phases form cooperatively as neighbouring lamellae with the lateral diffusion of material across the growing interface. The relative amounts of the two phases (Al and θ) in the eutectic are determined by applying the Lever Rule at the eutectic temperature.

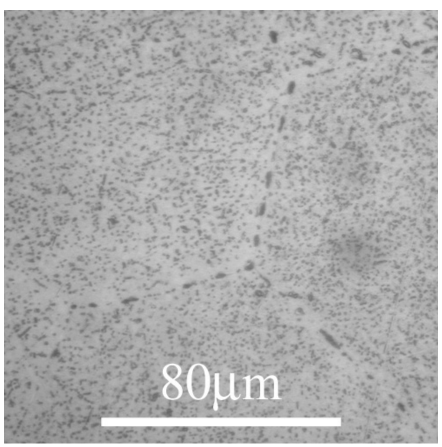
More Cu/Al Micrographs



The RLM micrograph (left) of the 36%Cu/64%Al sample, just to the right of the eutectic (known as the **hyper-eutectic**) shows primary **dendrite** formation from the θ ($CuAl_2$) phase. The remaining liquid transforms to the eutectic at the eutectic temperature.

The RLM micrograph (right) of a 5%Cu/95%Al sample shows **microsegregation**, and the two phases can not be resolved microscopically. The solid is low in solute, resulting in large "cored" dendrites, with the solute-rich liquid segregated in between (perhaps of composition CuAl?)

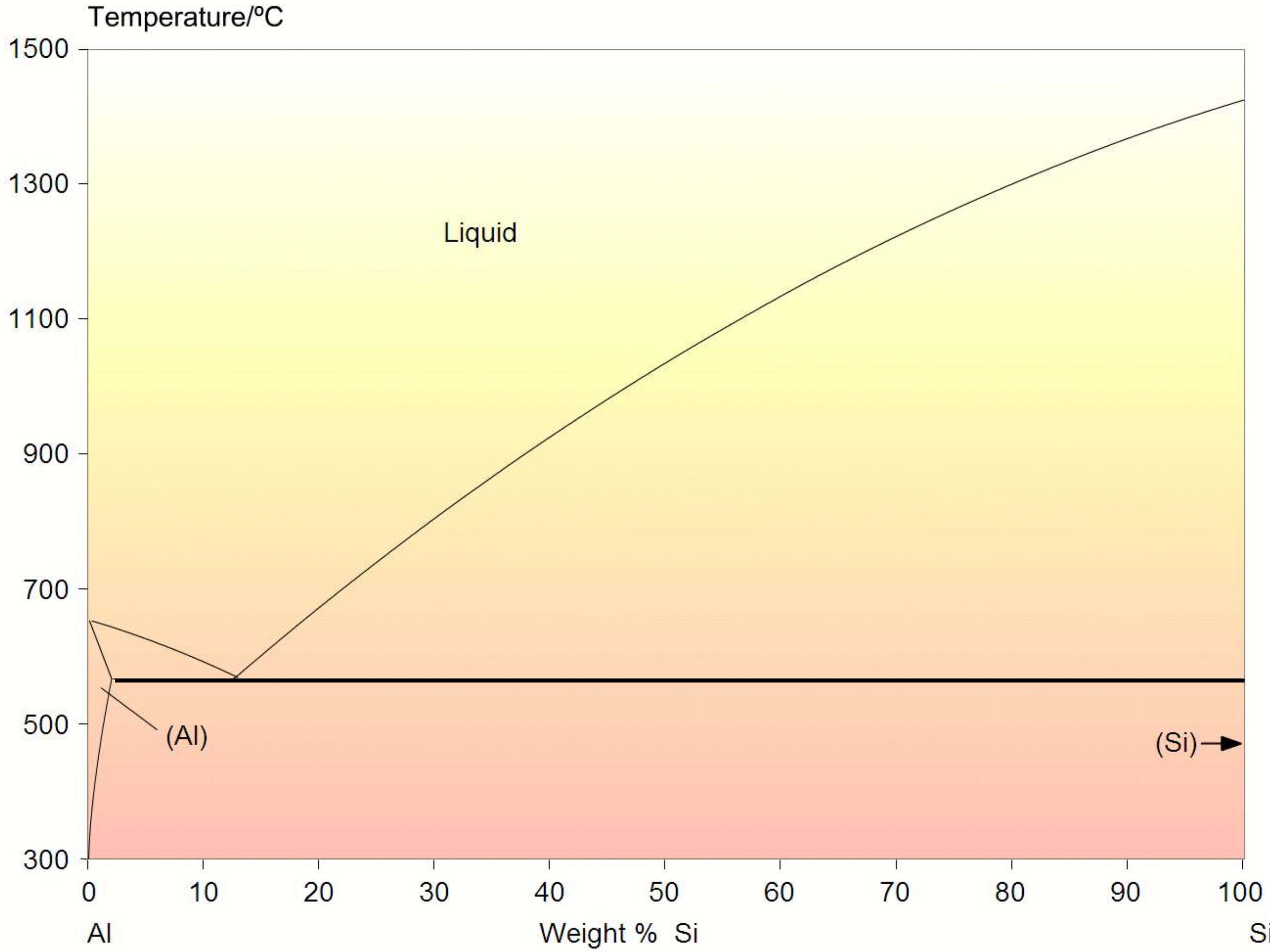




Finally, the 4%Cu/96%Al sample (left) has been aged after quenching to enable the growth of precipitates from a supersaturated solid solution. The strength of the alloy has been greatly improved by **precipitation hardening**. The "θ" phase is an intermetallic compound with a composition close to CuAl2. The depletion of Cu near the boundaries to these precipitates forms precipitation free zones (PFZ).

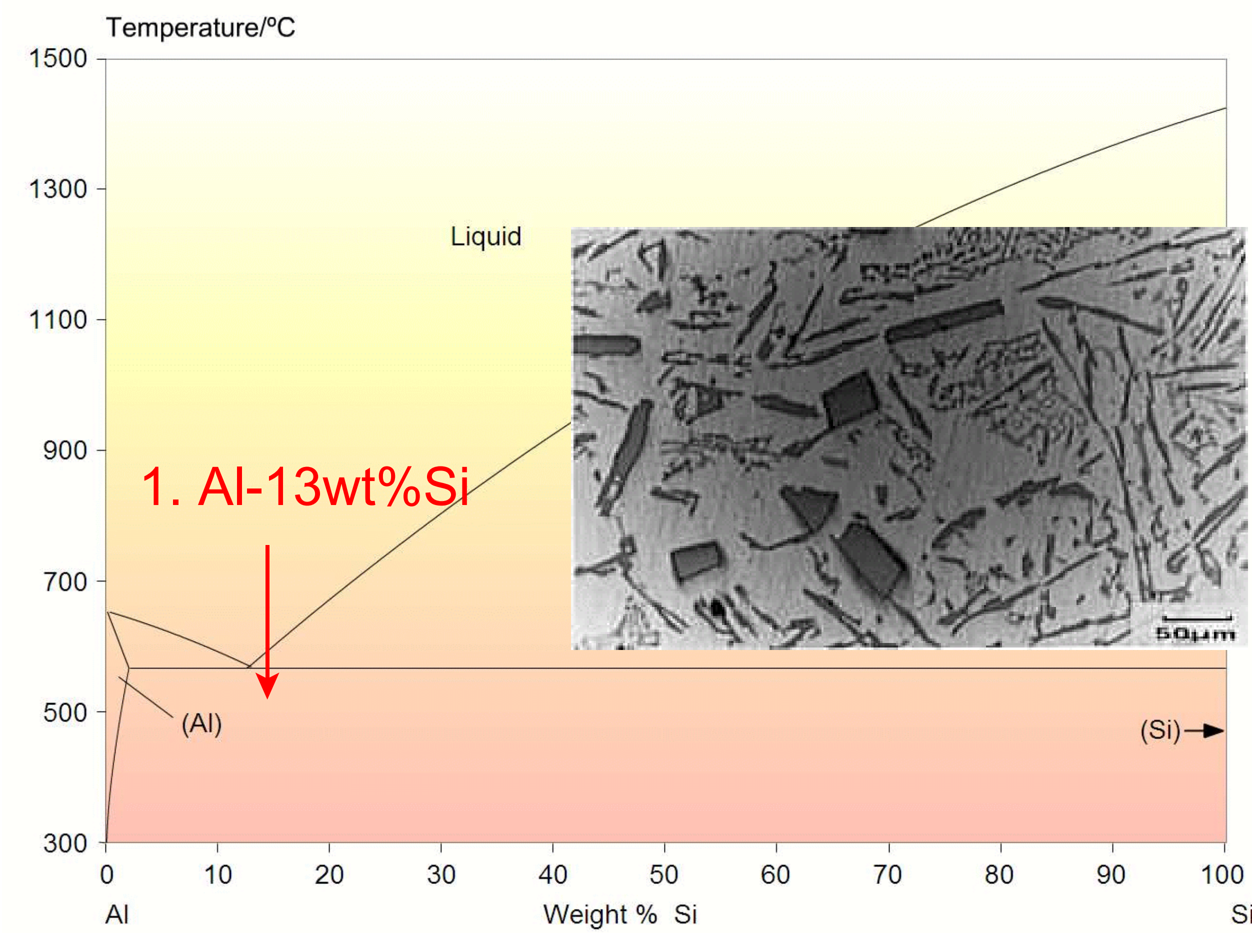
Si/Al Phase Diagram

Try to identify the phases, eutectic point, metling points of pure Al and Si, and any other features on this diagram. Note that the Al has **zero solid solubility** in the Si at all temperatures (i.e., it will not dissolve and form a solid solution).



Si/Al Phase Diagram, 2

There are two alloys we will consider:
1. Al-13wt%Si (slightly hypereutectic)
2. Al-13wt%Si-0.01%Na (doped with trace amounts of Na)

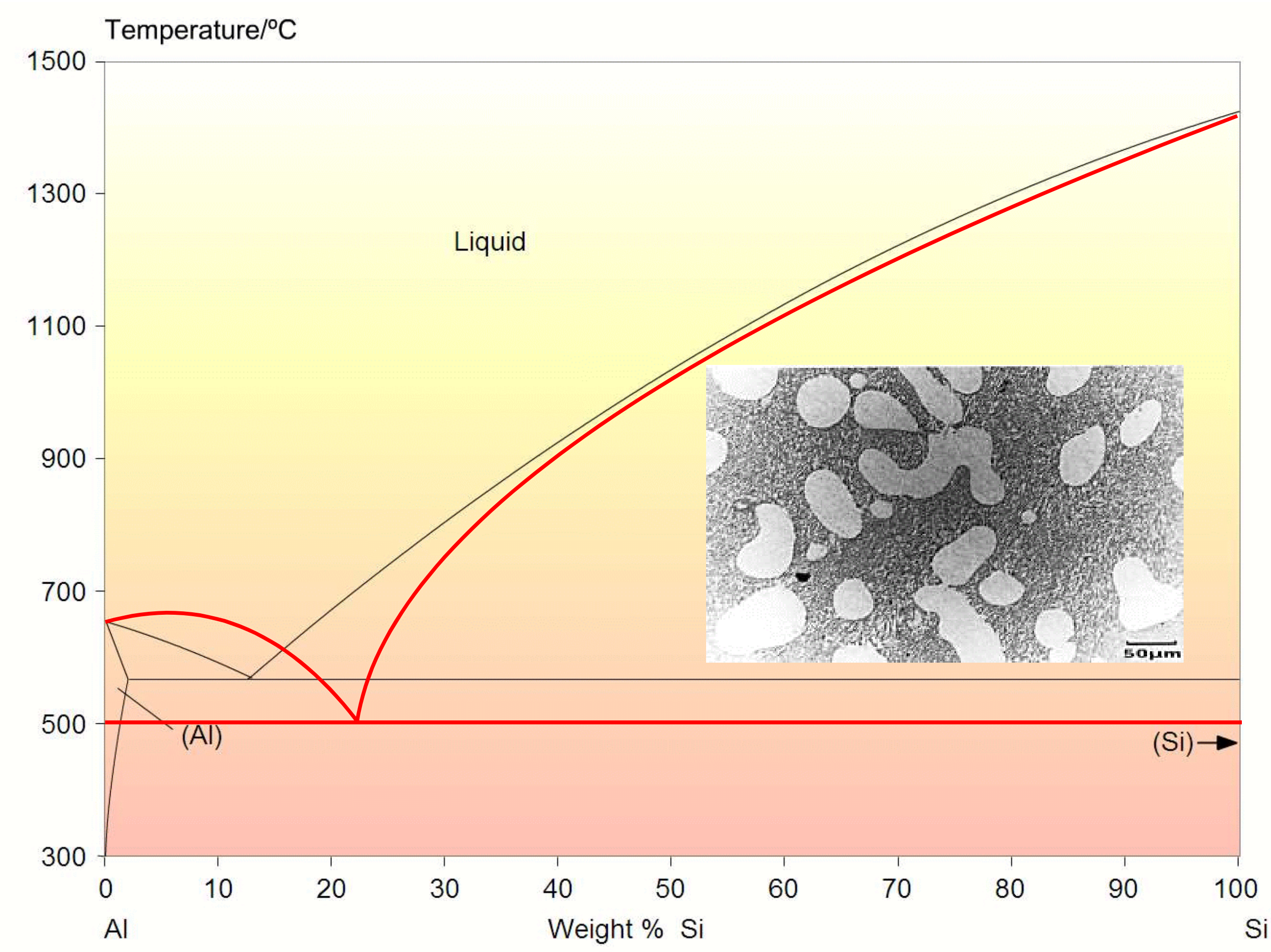


Alloy 1 will be a eutectic mixture composed primarily of phase α, with a small amount of hypereutectic Si precipitated out into the solid.

The RLM micrograph shows coarse flakes of Si contained in what appears to be a non-lamellar phase. The flakes make the material brittle, which is undesirable. A strong lamellar condition is desired.

Si/Al Phase Diagram

Most Si/Al alloys are cast near this eutectic point, they are cheap to manufacture; but cuboid Si flakes cause brittleness. **Doping** with 0.01% Na alters the compositional and temperature of the eutectic point (red lines):



Alloy 2, which has the same relative amounts of Si and Al, now precipitates in a hypoeutectic fashion. A fibrous lamellar Si/Al phase forms, which contains dendrites of the α phase instead of the flaky, cuboid Si precipitate which causes brittleness.

The addition of a **ternary element** like Na can complete alter the atomic arrangements, the microstructure of the materials, and hence the bulk observable properties

Why Phase Diagrams & Micrographs?

Microstructural changes strongly influence the engineering properties of an alloy. The lamellar nature of the eutectic phase, for instance, impedes dislocation movement through the alloy when stress is appled.

Therefore, if dislocations cannot move easily then the material will not yield until a higher stress is applied, i.e., lamellar structure may increase the strength of the alloy is increased.

By understanding how phase diagrams work, as well as the relationship between the various parts of the phase diagram and the microstructure or nanostructure, we can predict ways of refining alloys to give us the properties we desire.

For more information, see the 59-240 animations page:
Southampton University (**try the interactive phase diagram to visualize micrographs**): **Check out the Cu/Al, Si/Al and Fe/C (steel) phase diagrams**
http://www.soton.ac.uk/~pasr1/index.htm
University of Cambridge:
http://www.doitpoms.ac.uk/miclib/phase_diagrams.php
Denver University:
http://www.du.edu/~jcalvert/phys/phase.htm