Criteria for Selecting a Lead-free Solder

By K.W. Sweatman
Nihon Superior Co. Ltd

As the implementation of the European Community's RoHS Directive rapidly approaches many companies are still not sure about what to look for in choosing a lead-free solder. And their choice is made more difficult by the widely promoted view that tin-silver-copper (SAC) is their only option.

Quite apart from any other consideration the fact that the inclusion of even 3% Ag more than doubles the cost of raw materials forces consideration of whether that investment yields a commensurate return in terms of properties and performance compared with silver-free options. Even the 0.3% Ag of the so called "Low SAC" alloys adds about US$1.20/kg to the cost of raw materials of a basic SN100C with no clearly identifiable benefit. The practical experience on more than 1500 production lines around the world using SN100C, a silver-free Ni-modified Sn-0.7%Cu alloy is that results at least as good as those obtained with SAC alloys can be obtained at much the same process temperatures.

The original reason for the silver addition to the SN100C was primarily the 10°C reduction in melting point that was expected to be reflected in lower process temperatures. However, practical production experience is that the melting point is only one factor in determining the required process temperatures. Although SAC alloy paste can be reflowed in profiles with a peak temperature as low as 235°C in practice most SAC is being reflowed with profiles with a peak temperature in the range 245-250°C at which temperature it is possible to reflow the Ni-modified SN100C alloy. The situation is similar for wave soldering where temperatures in the range 250-265°C are needed for both alloys depending on the type of board being soldered.

In wave soldering another consideration is through-hole filling and it has been widely argued that silver is necessary to achieve that. Again the practical experience is that very good hole filling and topside fillet formation can be achieved with the Ni-modified SN100C solder, often at a lower preheat than required by SAC alloys.

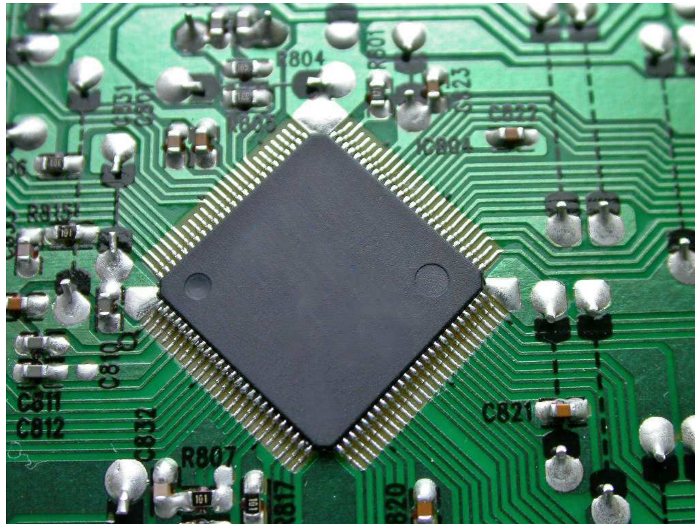
If melting point and silver content are not the most important factor in determining the performance of a lead-free solder what should users be looking for when choosing an alloy? The best guidance in that regard is the tin-lead solder that they now have to replace. Something that distinguishes the electronics industry's "workhorse" 63/37 tin/lead from most of the lead-free solder options is its eutectic behaviour. Clearly that eutectic behaviour was considered an important aspect of its properties because in the early 1970s the industry migrated from the "traditional" 60/40 tin/lead to an alloy closer to the true eutectic despite the small but significant increase in raw materials cost resulting from the replacement of some of the cheap lead with ten times more expensive tin.

What are the advantages that eutectic behaviour brings to a solder? There are at least three characteristics of eutectic that are useful in a solder that is used in electronics assembly.

One is that the solder solidifies with a smooth bright finish, largely free of shrinkage cavities. That might be considered a purely cosmetic feature and it has been widely claimed that even quite distinct shrinkage cavities do not present a reliability issue. However, one of the much appreciated advantages of tin-lead solder was "rule of thumb" that, in general, "if a joint looks good it is good". The wider availability of X-ray inspection means that the many companies can go beyond the superficial impression of joint appearance in assessing joint quality but in practice there are many situations where visual appearance is the only indication available.

Another advantage of eutectic behaviour is the strength and ductility that goes with the fine uniform dispersion of phases that occurs in an alloy that has solidified as a eutectic. At least some of the reliability problems being encountered with lead-free solders are associated with large irregular primary phases, tin dendrites or intermetallic crystals that precipitate during solidification, even of alloys such as Sn-3.8%Ag-0.7%Cu and Sn-0.7% Cu that are nominally eutectic.

An additional advantage that has only recently been recognised is the greater fluidity of alloys that solidify as true eutectics. In this context the fluidity of interest is not the reciprocal of viscosity used to characterise a liquid in the science of fluid mechanics but simply the ease with which cooling molten solder flows into a joint. This property is particularly important in wave soldering where filling through holes is important but it is also significant in reflow where fillet formation is also important. Because a true eutectic freezes by growth of eutectic “colonies” from nuclei evenly dispersed throughout the molten solder it remains uniformly fluid until the point at which those colonies start to impact on each other. By contrast flow of an alloy that is not solidifying as a eutectic is quickly clogged by the “forest” of primary phase, usually tin dendrites, growing up from all joint surfaces.



Bridge-free wave soldering of an 0.5mm pitch QFP made possible by the high fluidity of SN100C

The problem with the combinations of elements available for formulating a practical lead-free solder is that even when the composition is one which, according to the thermodynamic calculations, should be a eutectic other thermodynamic factors mitigate against eutectic behaviour. That is the consequence of a critical difference between tin-lead of eutectic composition and lead-free solders of nominally eutectic composition. In tin-lead the two phases that constitute the eutectic are both metallic- one is tin with some dissolved lead and the other is lead with some dissolved tin. Both can nucleate easily that that there is no thermodynamic obstacle to eutectic solidification. By contrast the second and third phases in lead-free solders are intermetallic compounds Cu_6Sn_5 and Ag_3Sn. These are phases that are non-metallic in character that solidify as faceted crystals. Nucleation of these phases requires substantial additional energy input and the consequence is that primary tin dendrites, that nucleate much more readily dominate the microstructure of the alloy before the intermetallic phases are able to nucleate and eutectic solidification proceed. The characteristic grainy finish of some lead-free solders is a reflection of that dominance of primary tin dendrites. As the remaining liquid freezes it contracts away from the network of tin dendrites leaving them exposed on the surface.

The good news is, however, that a way of modifying at least one of the attractive lead-free alloy formulations so that it does behave as a eutectic has been developed. Nihon Superior discovered that an addition of nickel to the Sn-0.75 Cu alloy at a specific level facilitates nucleation of the Cu_6Sn_5 phases so that the alloy can solidify as a eutectic. The result is, SN100C, an alloy that offers all the advantages of eutectic behaviour- smooth bright fillets, a good combination of mechanical properties and performance in practical soldering processes that comes close to matching that of the tin-lead solder it is replacing. And all of this can be achieved at process temperatures not much different from those required by silver-containing alloys. This technology is patented in 24 countries but is now widely available through Nihon Superior’s global manufacturing and customer service network.

DKL Metals Ltd
Avontoun Works
Linlithgow
West Lothian
EH49 6QD
e-mail: sales@dklmetals.co.uk
Internet: www.dklmetals.co.uk