Solder

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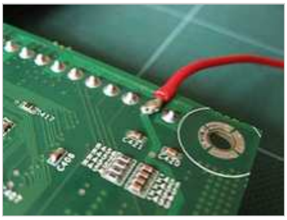

A soldered joint used to attach a wire to the pin of a component on the rear of a printed circuit board.

Solder (/ˈsoʊldə/,[1] /ˈsɒldə/[1] or in USA /ˈsɒdər/[2]) is a fusible metal alloy used to join together metal workpieces and having a melting point below that of the workpiece(s).

Soft solder is typically thought of when solder or soldering is mentioned, with a typical melting range of 90 to 450 °C (190 to 840 °F).[3] It is commonly used in electronics, plumbing, and assembly of sheet metal parts. Manual soldering uses a soldering iron or soldering gun. Alloys that melt between 180 and 190 °C (360 and 370 °F) are the most commonly used. Soldering performed using alloys with a melting point above 450 °C (840 °F) is called 'hard soldering', 'silver soldering', or brazing.

For certain proportions an alloy becomes eutectic and melts at a single temperature; non-eutectic alloys have markedly different *solidus* and *liquidus* temperatures, and within that range they exist as a paste of solid particles in a melt of the lower-melting phase. In electrical work, if the joint is disturbed in the pasty state before it has solidified totally, a poor electrical connection may result; use of eutectic solder reduces this problem. The pasty state of a non-eutectic solder can be exploited in plumbing as it allows molding of the solder during cooling, e.g. for ensuring watertight joint of pipes, resulting in a so-called 'wiped joint'.

For electrical and electronics work solder wire is available in a range of thicknesses for hand-soldering, and with cores containing flux. It is also available as a paste or as a preformed foil shaped to match the workpiece, more suitable for mechanized mass-production. Alloys of lead and tin were universally used in the past, and are still available; they are particularly convenient for hand-soldering. Lead-free solder, somewhat less convenient for hand-soldering, is often used to avoid the environmental effect of lead.

Plumbers often use bars of solder, much thicker than the wire used for electrical applications. Jewelers often use solder in thin sheets which they cut into snippets.

The word solder comes from the Middle English word *soudur*, via Old French *solduree* and *soulder*, from the Latin *solidare*, meaning "to make solid".[4]

With the reduction of the size of circuit board features, the size of interconnects shrinks as well. Current densities above 10^4 A/cm^2 are often achieved and electromigration becomes a concern. At such current densities the Sn63Pb37 solder balls form hillocks on the anode side and voids on the cathode side; the increased content of lead on the anode side suggests lead is the primary migrating species.[5]

Contact with molten solder can cause 'solder embrittlement' of materials, a type of liquid metal embrittlement.[*citation needed*]

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Lead solder

Tin/lead solders, also called soft solders, are commercially available with tin concentrations between 5% and 70% by weight. The greater the tin concentration, the greater the solder's tensile and shear strengths. Alloys commonly used for electrical soldering are 60/40 Tin/lead (Sn/Pb) which melts at 370 °F or 188 °C and 63/37 Sn/Pb used principally in electrical/electronic work. The 63/37 is a eutectic alloy, which:

1. has the lowest melting point (183 °C or 361.4 °F) of all the tin/lead alloys; and

2. the melting point is truly a *point* — not a range.


$Sn_{60}Pb_{40}$ solder

In plumbing, a higher proportion of lead was used, commonly 50/50. This had the advantage of making the alloy solidify more slowly, so that it could be wiped over the joint to ensure watertightness, the pipes being physically fitted together before soldering. Although lead water pipes were displaced by copper when the significance of lead poisoning began to be fully appreciated, lead solder was still used until the 1980s because it was thought that the amount of lead that could leach into water from the solder was negligible from a properly soldered joint. The electrochemical couple of copper and lead promotes corrosion of the lead and tin, however tin is protected by insoluble oxide. Since even small amounts of lead have been found detrimental to health,[6] lead in plumbing solder was replaced by silver (food grade applications) or antimony, with copper often added, and the proportion of tin was increased (see Lead-free solder.)

The addition of tin—more expensive than lead—improves wetting properties of the alloy; lead itself has poor wetting characteristics. High-tin tin-lead alloys have limited use as the workability range can be provided by a cheaper high-lead alloy.[7]

In electronics, components on printed circuit boards (PCBs) are connected to the printed circuit, and hence to other components, by soldered joints. For miniaturized PCB joints with surface mount components, solder paste has largely replaced solid solder.

Lead-tin solders readily dissolve gold plating and form brittle intermetallics.[8]

Sn60Pb40 solder oxidizes on the surface, forming a complex 4-layer structure: tin(IV) oxide on the surface, below it a layer of tin(II) oxide with finely dispersed lead, followed by a layer of tin(II) oxide with finely dispersed tin and lead, and the solder alloy itself underneath.[9]

Lead, and to some degree tin, as used in solder contains small but significant amounts of radioisotope impurities. Radioisotopes undergoing alpha decay are a concern due to their tendency to cause soft errors. Polonium-210 is especially problematic; lead-210 beta decays to bismuth-210 which then beta decays to polonium-210, an intense emitter of alpha particles. Uranium-238 and thorium-232 are other significant contaminants of alloys of lead.[5][10]

Lead-free solder


Pure tin solder wire


Soldering copper pipes using a propane torch and lead-free solder

On July 1, 2006 the European Union Waste Electrical and Electronic Equipment Directive (WEEE) and Restriction of Hazardous Substances Directive (RoHS) came into effect prohibiting the inclusion of significant quantities of lead in most consumer electronics produced in the EU. Manufacturers in the U.S. may receive tax benefits by reducing the use of lead-based solder. Lead-free solders in commercial use may contain tin, copper, silver, bismuth, indium, zinc, antimony, and traces of other metals. Most lead-free replacements for conventional Sn60/Pb40 and Sn63/Pb37 solder have melting points from 5 to 20 °C higher,[11] though solders with much lower melting points are available.

Drop-in replacements for silkscreen with solder paste soldering operations are available. Minor modification to the solder pots (e.g. titanium liners or impellers) used in wave-soldering operations may be desired to reduce maintenance costs associated with the increased tin-scavenging effects of high tin solders. Since the properties of lead-free solders are not as thoroughly known, they may therefore be considered less desirable for critical applications, like certain aerospace or medical projects. "Tin whiskers" were a problem with early electronic solders, and lead was initially added to the alloy in part to eliminate them.

Sn-Ag-Cu (Tin-Silver-Copper) solders are used by two thirds of Japanese manufacturers for reflow and wave soldering, and by about 75% of companies for hand soldering. The widespread use of this popular lead-free solder alloy family is based on the reduced melting point of the Sn-Ag-Cu ternary eutectic behavior (217 ˚C), which is below the Sn-3.5Ag (wt.%) eutectic of 221 °C and the Sn-0.7Cu eutectic of 227 °C (recently revised by P. Snugovsky to Sn-0.9Cu). The ternary eutectic behavior of Sn-Ag-Cu and its application for electronics assembly was discovered (and patented) by a team of researchers from Ames Laboratory, Iowa State University, and from Sandia National Laboratories-Albuquerque.

Much recent research has focused on selection of 4th element additions to Sn-Ag-Cu to provide compatibility for the reduced cooling rate of solder sphere reflow for assembly of ball grid arrays, e.g., Sn-3.5Ag-0.74Cu-0.21Zn (melting range of 217–220 ˚C) and Sn-3.5Ag-0.85Cu-0.10Mn (melting range of 211–215 ˚C).

Tin-based solders readily dissolve gold, forming brittle intermetallics; for Sn-Pb alloys the critical concentration of gold to embrittle the joint is about 4%. Indium-rich solders (usually indium-lead) are more suitable for soldering thicker gold layer as the dissolution rate of gold in indium is much slower. Tin-rich solders also readily dissolve silver; for soldering silver metallization or surfaces, alloys with addition of silvers are suitable; tin-free alloys are also a choice, though their wettability is poorer. If the soldering time is long enough to form the intermetallics, the tin surface of a joint soldered to gold is very dull.[8]

Flux-core solder

Main article: Flux (metallurgy)

Electrical solder with an integrated rosin core, visible as a dark spot in the cut end of the solder wire.

Flux is a reducing agent designed to help reduce (return oxidized metals to their metallic state) metal oxides at the points of contact to improve the electrical connection and mechanical strength. The two principal types of flux are acid flux, used for metal mending and plumbing, and rosin flux, used in electronics, where the corrosiveness of acid flux and vapors released when solder is heated would risk damaging delicate circuitry.

Due to concerns over atmospheric pollution and hazardous waste disposal, the electronics industry has been gradually shifting from rosin flux to water-soluble flux, which can be removed with deionized water and detergent, instead of hydrocarbon solvents.

In contrast to using traditional bars or coiled wires of all-metal solder and manually applying flux to the parts being joined, much hand soldering since the mid-20th century has used flux-core solder. This is manufactured as a coiled wire of solder, with one or more continuous bodies of non-acid flux embedded lengthwise inside it. As the solder melts onto the joint, it frees the flux and releases that on it as well.

Hard solder

Hard solders are used for brazing, and melt at higher temperatures. Alloys of copper with either zinc or silver are the most common.

In silversmithing or jewelry making, special hard solders are used that will pass assay. They contain a high proportion of the metal being soldered and lead is not used in these alloys. These solders vary in hardness, designated as "enameling", "hard", "medium" and "easy". Enameling solder has a high melting point, close to that of the material itself, to prevent the joint desoldering during firing in the enameling process. The remaining solder types are used in decreasing order of hardness during the process of making an item, to prevent a previously soldered seam or joint desoldering while additional sites are soldered. Easy solder is also often used for repair work for the same reason. Flux or rouge is also used to prevent joints from desoldering.

Silver solder is also used in manufacturing to join metal parts that cannot be welded. The alloys used for these purposes contain a high proportion of silver (up to 40%), and may also contain cadmium.

Solder alloys

Composition	M.P. °C S/L	Toxic	Eutectic	Comments	Sn	Pb	Ag	Cu	Sb	Bi	In	Zn	Cd	Au	oth.!
$Sn_{50}Zn_{49}Cu_{1}$	200/300[12]		no	**Galvanite** Lead free galvanizing solder formulation designed specifically for high quality repairs to galvanized Steel surfaces. Simple, effective and easy to use, in both manufacturing and field applications. Metallurgically bonds to the Steel, for a seamless protective barrier.[12]	50			1				49			
$Sn_{90}Zn_{7}Cu_{3}$	200/222[13]		no	**Kapp Eco-Babbitt**[13] Commonly used in capacitor manufacturing as protective coating to shield against electromotive force (EMF) and electromagnetic interference (EMI) with the specified performance of the capacitor, to prevent current and charge leakage out of and within the layers of the capacitor, and to prevent the development of electron flows within the coating material itself, that would dimminish capacitor performance, coating, and capacitor life.[13]	90			3				7			
$Pb_{90}Sn_{10}$	268/302[14] 275/302[15]	Pb	no	**Sn10**, **UNS L54520**, **ASTM10B**. Balls for CBGA	10	90									

				components, replaced by $Sn_{95.5}Ag_{3.9}Cu_{0.6}$.[11] Low cost and good bonding properties. Rapidly dissolves gold and silver, not recommended for those.[16] Used for fabrication of car radiators and fuel tanks, for coating and bonding of metals for moderate service temperatures. Body solder.[17] Has low thermal EMF, can be used as an alternative to Cd70 where parasitic thermocouple voltage has to be avoided.[18]											
$Pb_{88}Sn_{12}$	254/296[17]	Pb	no	Used for fabrication of car radiators and fuel tanks, for coating and bonding of metals for moderate service temperatures. Body solder.	12	88									
$Pb_{85}Sn_{15}$	227/288[17]	Pb	no	Used for coating tubes and sheets and fabrication of car radiators. Body solder.	15	85									
$Pb_{80}Sn_{20}$	183/280[15]	Pb	no	**Sn20**, **UNS L54711**. Used for coating radiator tubes for joining fins.[17]	20	80									
$Pb_{75}Sn_{25}$	183/266[14]	Pb	no	Crude solder for construction plumbing works, flame-melted. Used for soldering car engine radiators. Used for machine, dip and hand soldering of plumbing fixtures and fittings.	25	75									

				Superior body solder.[17]											
$Pb_{70}Sn_{30}$	185/255[14] 183/257[15]	Pb	no	**Sn30**, **UNS L54280**, crude solder for construction plumbing works, flame-melted, good for machine and torch soldering.[19] Used for soldering car engine radiators. Used for machine, dip and hand soldering of plumbing fixtures and fittings. Superior body solder.[17]	30	70									
$Pb_{68}Sn_{32}$	253	Pb	no	"Plumber solder", for construction plumbing works [20]	32	68									
$Pb_{68}Sn_{30}Sb_{2}$	185/243[15]	Pb	no	**Pb68**	30	68			2						
$Sn_{30}Pb_{50}Zn_{20}$	177/288[21]	Pb	no	**Kapp GalvRepair** Economical solder for repairing & joining most metals including Aluminum and cast Iron. Have been the used for cast Iron and galvanized surface repair.[21]	30	50						20			
$Sn_{33}Pb_{40}Zn_{28}$	230/275[21]	Pb	no	Economical solder for repairing & joining most metals including Aluminum and cast Iron. Have been the used for cast Iron and galvanized surface repair.[21]	33	40						28			
$Pb_{67}Sn_{33}$	187–230	Pb	no	PM 33, crude solder for construction plumbing works, flame-melted, temperature depends on additives	33	67									

$Pb_{65}Sn_{35}$	183/250[15]	Pb	no	**Sn35**. Used as a cheaper alternative of $Sn_{60}Pb_{40}$ for wiping and sweating joints.[17]	35	65									
$Pb_{60}Sn_{40}$	183/238[14] 183/247[15]	Pb	no	**Sn40**, **UNS L54915**. For soldering of brass and car radiators.[19] For bulk soldering, and where wider melting point range is desired. For joining cables. For wiping and joining lead pipes. For repairs of radiators and electrical systems.[17]	40	60									
$Pb_{55}Sn_{45}$	183/227[17]	Pb	no	For soldering radiator cores, roof seams, and for decorative joints.	45	55									
$Sn_{50}Pb_{50}$	183/216[14] 183–212[15]	Pb	no	**Sn50**, **UNS L55030**. "Ordinary solder", for soldering of brass, electricity meters, gas meters, formerly also tin cans. General purpose, for standard tinning and sheetmetal work. Becomes brittle below −150 °C.[8][20] Low cost and good bonding properties. Rapidly dissolves gold and silver, not recommended for those.[16] For wiping and assembling plumbing joints for non-potable water.[17]	50	50									

$Sn_{50}Pb_{48.5}Cu_{1.5}$	183/215[22]	Pb	no	**Savbit**, **Savbit 1**, **Sav1**. Minimizes dissolution of copper. Originally designed to reduce erosion of the soldering iron tips. About 100 times slower erosion of copper than ordinary tin/lead alloys. Suitable for soldering thin copper platings and very thin copper wires.[23]	50	48.5		1.5							
$Sn_{60}Pb_{40}$	183/190[14] 183/188[15]	Pb	near	**Sn60**, **ASTM60A**, **ASTM60B**. Common in electronics, most popular leaded alloy for dipping. Low cost and good bonding properties. Used in both SMT and through-hole electronics. Rapidly dissolves gold and silver, not recommended for those.[16] Slightly cheaper than $Sn_{63}Pb_{37}$, often used instead for cost reasons as the melting point difference is insignificant in practice. On slow cooling gives slightly duller joints than $Sn_{63}Pb_{37}$.[23]	60	40									
$Sn_{60}Pb_{38}Cu_{2}$	183/190[15][24]	Pb		**Cu2**. Copper content increases hardness of the alloy and inhibits dissolution of soldering iron tips and part leads in molten solder.	60	38		2							
$Sn_{60}Pb_{39}Cu_{1}$		Pb	no		60	39		1							
				"Tinman's solder", used for tinplate											

				fabrication work.[20]											
$Sn_{63}Pb_{37}$	182 183[25]	Pb	yes	**Sn63**, **ASTM63A**, **ASTM63B**. Common in electronics; exceptional tinning and wetting properties, also good for stainless steel. One of most common solders. Low cost and good bonding properties. Used in both SMT and through-hole electronics. Rapidly dissolves gold and silver, not recommended for those.[16] $Sn_{60}Pb_{40}$ is slightly cheaper and is often used instead for cost reasons, as the melting point difference is insignificant in practice. On slow cooling gives slightly brighter joints than $Sn_{60}Pb_{40}$.[23]	63	37									
$Sn_{63}Pb_{37}P_{0.0015–0.04}$	183[26]	Pb	yes	**Sn63PbP**. A special alloy for HASL machines. Addition of phosphorus reduces oxidation. Unsuitable for wave soldering as it may form metal foam.	63	37									P
$Sn_{62}Pb_{37}Cu_{1}$	183[24]	Pb	yes	Similar to $Sn_{63}Pb_{37}$. Copper content increases hardness of the alloy and inhibits dissolution of soldering iron tips and part leads in molten solder.	62	37		1							
$Sn_{70}Pb_{30}$	183/193[14]	Pb	no	**Sn70**	70	30									

$Sn_{90}Pb_{10}$	183/213[15]	Pb	no	formerly used for joints in food industry	90	10									
$Sn_{95}Pb_{5}$	238	Pb	no	plumbing and heating	95	5									
$Pb_{92}Sn_{5.5}Ag_{2.5}$	286/301[24]	Pb	no	For higher-temperature applications.	5.5	92	2.5								
$Pb_{80}Sn_{12}Sb_{8}$		Pb	no	Used for soldering iron and steel[20]	12	80			8						
$Pb_{80}Sn_{18}Ag_{2}$	252/260[15]	Pb	no	Used for soldering iron and steel[20]	18	80	2								
$Pb_{79}Sn_{20}Sb_{1}$	184/270	Pb	no	**Sb1**	20	79			1						
$Pb_{55}Sn_{43.5}Sb_{1.5}$		Pb	no	General purpose solder. Antimony content improves mechanical properties but causes brittleness when soldering cadmium, zinc, or galvanized metals.[20]	43.5	55			1.5						
$Sn_{43}Pb_{43}Bi_{14}$	144/163[14]	Pb	no	**Bi14**. Good fatigue resistance combined with low melting point. Contains phases of tin and lead-bismuth.[27] Useful for step soldering.	43	43				14					
$Sn_{46}Pb_{46}Bi_{8}$	120/167[15]	Pb	no	**Bi8**	46	46				8					
$Bi_{52}Pb_{32}Sn_{16}$	96	Pb	yes?	**Bi52**. Good fatigue resistance combined with low melting point. Reasonable shear strength and fatigue properties. Combination with lead-tin solder may dramatically lower melting point and lead to joint failure.[27]	16	32				52					
$Bi_{46}Sn_{34}Pb_{20}$	100/105[15]	Pb	no	**Bi46**	34	20				46					
$Sn_{62}Pb_{36}Ag_{2}$	179[14]	Pb	yes	**Sn62**. Common in electronics. The strongest tin-lead solder. Appearance identical to	62	36	2								

				Sn60Pb40 or Sn63Pb37. Crystals of Ag_3Sn may be seen growing from the solder. Extended heat treatment leads to formation of crystals of binary alloys. Silver content decreases solubility of silver, making the alloy suitable for soldering silver-metallized surfaces, e.g. SMD capacitors and other silver-metallized ceramics.[8][23][27] Not recommended for gold.[16] General-purpose.											
$Sn_{62.5}Pb_{36}Ag_{2.5}$	179[14]	Pb	yes		62.5	36	2.5								
$Pb_{88}Sn_{10}Ag_2$	268/290[14] 267/299[28]	Pb	no	**Sn10**, **Pb88**. Silver content reduces solubility of silver coatings in the solder. Not recommended for gold.[16] Forms a eutectic phase, not recommended for operation above 120 °C.	10	88	2								
$Pb_{90}Sn_5Ag_5$	292[14]	Pb	yes		5	90	5								
$Pb_{92.5}Sn_5Ag_{2.5}$	287/296[14] 299/304[15]	Pb	no	**Pb93**.	5	92.5	2.5								
$Pb_{93.5}Sn_5Ag_{1.5}$	296/301[14] 305/306[15]	Pb	no	**Pb94**, **HMP alloy**, **HMP**. Service temperatures up to 255 °C. Useful for step soldering. Also can be used for extremely low temperatures as it remains ductile down to −200 °C, while solders with more than 20% tin become brittle below	5	93.5	1.5								

				−70 °C. Higher strength and better wetting than $Pb_{95}Sn_5$.[23]											
$Pb_{95.5}Sn_2Ag_{2.5}$	299/304[14]	Pb	no		2	95.5	2.5								
$In_{97}Ag_3$	143[29]	–	yes	Wettability and low-temperature malleability of indium, strength improved by addition of silver. Particularly good for cryogenic applications. Used for packaging of photonic devices.			3				97				
$In_{90}Ag_{10}$	143/237[30]	–	no	Nearly as wettable and low-temperature malleable as indium. Large plastic range. Can solder silver, fired glass and ceramics.			10				90				
$In_{75}Pb_{25}$	156/165[16]	Pb	no	Less gold dissolution and more ductile than lead-tin alloys. Used for die attachment, general circuit assembly and packaging closures.[16]		25					75				
$In_{70}Pb_{30}$	160/174[14] 165/175[15][31]	Pb	no	**In70**. Suitable for gold, low gold-leaching. Good thermal fatigue properties.		30					70				
$In_{60}Pb_{40}$	174/185[14] 173/181[15]	Pb	no	**In60**. Low gold-leaching. Good thermal fatigue properties.		40					60				

$In_{50}Pb_{50}$	180/209[16] 178/210[15]	Pb	no	**In50**. Only one phase. Resoldering with lead-tin solder forms indium-tin and indium-lead phases and leads to formation of cracks between the phases, joint weakening and failure.[27] On gold surfaces gold-indium intermetallics tend to be formed, and the joint then fails in the gold-depleted zone and the gold-rich intermetallic.[32] Less gold dissolution and more ductile than lead-tin alloys.[16] Good thermal fatigue properties.		50					50				
$In_{50}Sn_{50}$	118/125[33]	–	no	**Cerroseal 35**. Fairly well wets glass, quartz and many ceramics. Malleable, can compensate some thermal expansion differences. Low vapor pressure. Used in low temperature physics as a glass-wetting solder.[34]	50						50				
$In_{70}Sn_{15}Pb_{9.6}Cd_{5.4}$	125[35]	Pb,Cd			15	9.6					70		5.4		
$Pb_{75}In_{25}$	250/264[16] 240/260[36]	Pb	no	**In25**. Low gold-leaching. Good thermal fatigue properties. Used for die attachment of e.g. GaAs dies.[32] Used also for general circuit assembly and packaging closures. Less dissolution of gold and more ductile than tin-lead alloy.[16]		75					25				

$Sn_{70}Pb_{18}In_{12}$	162[14] 154/167[37]	Pb	yes	General purpose. Good physical properties.	70	18					12				
$Sn_{37.5}Pb_{37.5}In_{25}$	134/181[16]	Pb	no	Good wettability. Not recommended for gold.[16]	37.5	37.5					25				
$Pb_{90}In_{5}Ag_{5}$	290/310[14]	Pb	no			90	5				5				
$Pb_{92.5}In_{5}Ag_{2.5}$	300/310[14]	Pb	no	**UNS L51510**. Minimal leaching of gold, good thermal fatigue properties. Reducing atmosphere frequently used..		92.5	2.5				5				
$Pb_{92.5}In_{5}Au_{2.5}$	300/310[15]	Pb	no	**In5**		92.5					5			2.5	
$Pb_{94.5}Ag_{5.5}$	305/364[15] 304/343[38]	Pb	no	**Ag5.5**, **UNS L50180**		94.5	5.5								
$Pb_{95}Ag_{5}$	305/364[39]	Pb	no			95	5								
$Pb_{97.5}Ag_{2.5}$	303[14] 304[15] 304/579[40]	Pb	yes no	**Ag2.5**, **UNS L50132**. Used during World War II to conserve tin. Poor corrosion resistance; joints suffered corrosion in both atmospheric and underground conditions, all had to be replaced with Sn-Pb alloy joints.[41] Torch solder.		97.5	2.5								
$Sn_{97.5}Pb_{1}Ag_{1.5}$	305	Pb	yes	Important for hybrid circuits assembly.[8]	97.5	1	1.5								

$Pb_{97.5}Ag_{1.5}Sn_{1}$	309[14]	Pb	yes	**Ag1.5**, **ASTM1.5S**. High melting point, used for commutators, armatures, and initial solder joints where remelting when working on nearby joints is undesirable.[19] Silver content reduces solubility of silver coatings in molten solder. Not recommended for gold.[16] Standard PbAgSn eutectic solder, wide use in semiconductor assembly. Reducing protective atmosphere (e.g. 12% hydrogen) often used. High creep resistance, for use at both elevated and cryogenic temperatures.	1	97.5	1.5								
$Pb_{54}Sn_{45}Ag_{1}$	177–210	Pb		exceptional strength, silver gives it a bright long-lasting finish; ideal for stainless steel [19]	45	54	1								
$Pb_{96}Ag_{4}$	305	Pb		high-temperature joints[19]		96	4								
$Pb_{96}Sn_{2}Ag_{2}$	252/295[15]	Pb		**Pb96**	2	96	2								
$Sn_{61}Pb_{36}Ag_{3}$		Pb		[8]	61	36	3								
$Sn_{56}Pb_{39}Ag_{5}$		Pb		[8]	56	39	5								
$Sn_{98}Ag_{2}$		–		[8]	98		2								
$Sn_{65}Ag_{25}Sb_{10}$	233	–	yes	Very high tensile strength. For die attachment. Very brittle. Old Motorola die attach solder.	65		25		10						
$Sn_{96.5}Ag_{3.0}Cu_{0.5}$	217/220 217/218[15][42]	–	near	**SAC305**. It is the JEITA recommended alloy for wave and reflow soldering, with alternatives	96.5		3	0.5							

				SnCu for wave and SnAg and SnZnBi for reflow soldering. Usable also for selective soldering and dip soldering. At high temperatures tends to dissolve copper; copper buildup in the bath has detrimental effect (e.g. increased bridging). Copper content must be maintained between 0.4–0.85%, e.g. by refilling the bath with $Sn_{97}Ag_{3}$ alloy. Nitrogen atmosphere can be used to reduce losses by dross formation. Dull, surface shows formation of dendritic tin crystals.											
$Sn_{95.8}Ag_{3.5}Cu_{0.7}$	217–218	–	near	**SN96C-Ag3.5** A commonly used alloy. Used for wave soldering. Usable also for selective soldering and dip soldering. At high temperatures tends to dissolve copper; copper buildup in the bath has detrimental effect (e.g. increased bridging). Copper content must be maintained between 0.4–0.85%, e.g. by refilling the bath with $Sn_{96.5}Ag_{3.5}$ alloy (designated e.g. **SN96Ce**). Nitrogen atmosphere can be used to reduce losses	95.8		3.5	0.7							

				by dross formation. Dull, surface shows formation of dendritic tin crystals.											
$Sn_{95.6}Ag_{3.5}Cu_{0.9}$	217	–	yes	Determined by NIST to be truly eutectic.	95.6		3.5	0.9							
$Sn_{95.5}Ag_{3.8}Cu_{0.7}$	217[43]	–	almost	**SN96C**. Preferred by the European IDEALS consortium for reflow soldering. Usable also for selective soldering and dip soldering. At high temperatures tends to dissolve copper; copper buildup in the bath has detrimental effect (e.g. increased bridging). Copper content must be maintained between 0.4–0.85%, e.g. by refilling the bath with $Sn_{96.2}Ag_{3.8}$ alloy (designated e.g. **SN96Ce**). Nitrogen atmosphere can be used to reduce losses by dross formation. Dull, surface shows formation of dendritic tin crystals.	95.5		3.8	0.7							
$Sn_{95.25}Ag_{3.8}Cu_{0.7}Sb_{0.25}$		–		Preferred by the European IDEALS consortium for wave soldering.	95.25		3.8	0.7	0.25						
$Sn_{95.5}Ag_{3.9}Cu_{0.6}$	217[44]	–	yes	Recommended by the US NEMI consortium for reflow soldering. Used as balls for BGA/CSP and CBGA components, a replacement for $Sn_{10}Pb_{90}$. Solder paste for rework of BGA	95.5		3.9	0.6							

				boards.[11] Alloy of choice for general SMT assembly.											
$Sn_{95.5}Ag_4Cu_{0.5}$	217[45]	–	yes	Lead Free, Cadmium Free formulation designed specifically to replace Lead solders in Copper and Stainless Steel plumbing, and in electrical and electronic applications.[46]	95.5		4	0.5							
$Sn_{96.5}Ag_{3.5}$	221[14]	–	yes	**Sn96**, **Sn96.5**, **96S**. Fine lamellar structure of densely distributed Ag_3Sn. Annealing at 125 °C coarsens the structure and softens the solder.[11] Creeps via dislocation climb as a result of lattice diffusion.[10] Used as wire for hand soldering rework; compatible with $SnCu_{0.7}$, $SnAg_3Cu_{0.5}$, $SnAg_{3.9}Cu_{0.6}$, and similar alloys. Used as solder spheres for BGA/CSP components. Used for step soldering and die attachment in high power devices. Established history in the industry.[11] Widely used. Strong lead-free joints. Silver content minimizes solubility of silver coatings. Not recommended for gold.[16] Marginal wetting. Good for step soldering. Used for soldering	96.5		3.5								

				stainless steel as it wets stainless steel better than other soft solders. Silver content does not suppress dissolution of silver metallizations.[23] High tin content allows absorbing significant amount of gold without embrittlement.[47]											
$Sn_{96}Ag_4$	221–229	–	no	**ASTM96TS**. "Silver-bearing solder". Food service equipment, refrigeration, heating, air conditioning, plumbing.[19] Widely used. Strong lead-free joints. Silver content minimizes solubility of silver coatings. Not recommended for gold.[16]	96		4								
$Sn_{95}Ag_5$	221/254[48]	–	no	Widely used. Strong lead-free joints. Silver content minimizes solubility of silver coatings. Not recommended for gold. Produces strong and ductile joints on Copper and Stainless Steel. The resulting joints have high tolerance to vibration and stress, with tensile strengths to 30,000 psi on Stainless.[48]	95		5								
$Sn_{94}Ag_6$	221/279[48]	–	no	Produces strong and ductile joints on Copper and Stainless Steel. The resulting joints have high tolerance to vibration and stress, with tensile strengths	94		6								

				to 30,000 psi on Stainless.[48]											
$Sn_{93}Ag_7$	221/302[48]	–	no	Produces strong and ductile joints on Copper and Stainless Steel. The resulting joints have high tolerance to vibration and stress, with tensile strengths to 31,000 psi on Stainless.[48] Audio industry standard for vehicle and home theater speaker installations. Its 7% Silver content requires a higher temperature range, but yields superior strength and vibration resistance.[49]	93		7								
$Sn_{95}Ag_4Cu_1$		–			95		4	1							
Sn	232	–	pure	**Sn99**. Good strength, non-dulling. Use in food processing equipment, wire tinning, and alloying.[19] Susceptible to tin pest.	99.99										
$Sn_{99.3}Cu_{0.7}$	227	–	yes	**Sn99Cu1**. Also designated as $Sn_{99}Cu_1$. Cheap alternative for wave soldering, recommended by the US NEMI consortium. Coarse microstructure with ductile fractures. Sparsely distributed Cu_6Sn_5.[50] Forms large dendritic ß-tin crystals in a network of eutectic microstructure with finely dispersed Cu_6Sn_5. High melting point unfavorable for SMT use. Low strength, high ductility.	99.3			0.7							(Ni)

				Susceptible to tin pest.[10] Addition of small amount of nickel increases its fluidity; the highest increase occurs at 0.06% Ni. Such alloys are known as **nickel modified** or **nickel stabilized**.[51]											
$Sn_{99}Cu_{0.7}Ag_{0.3}$	217/228[52]	–	no	**SCA**, **SAC**, or **SnAgCu**. Tin-silver-copper alloy. Relatively low-cost lead-free alloy for simple applications. Can be used for wave, selective and dip soldering. At high temperatures tends to dissolve copper; copper buildup in the bath has detrimental effect (e.g. increased bridging). Copper content must be maintained between 0.4–0.85%, e.g. by refilling the bath with $Sn_{96.2}Ag_{3.8}$ alloy (designated e.g. **SN96Ce**). Nitrogen atmosphere can be used to reduce losses by dross formation. Dull, surface shows formation of dendritic tin crystals.	99		0.3	0.7							
$Sn_{97}Cu_3$	227/250[53] 232/332[17]	–		For high-temperature uses. Allows removing insulation from an enameled wire and applying solder coating in a single operation. For radiator repairs, stained glass	97			3							

				windows, and potable water plumbing.											
$Sn_{97}Cu_{2.75}Ag_{0.25}$	228/314[17]	–		High hardness, creep-resistant. For radiators, stained glass windows, and potable water plumbing. Excellent high-strength solder for radiator repairs. Wide range of patina and colors.	97		0.25	2.75							
Zn_{100}	419	–	pure	For soldering aluminium. Good wettability of aluminium, relatively good corrosion resistance.[54]								100			
Bi_{100}	271	–	pure	Used as a non-superconducting solder in low-temperature physics. Does not wet metals well, forms a mechanically weak joint.[34]						100					
$Sn_{91}Zn_9$	199[55]	–	yes	**KappAloy9** Designed specifically for Aluminum-to-Aluminum and Aluminum-to-Copper soldering. It has good corrosion resistance and tensile strength. Lies between soft solder and silver brazing alloys, thereby avoiding damage to critical electronics and substrate deformation and segregation. Best solder for Aluminum wire to Copper busses or Copper wire to Aluminum busses or contacts.[55] UNS#: L91090	91							9			
$Sn_{85}Zn_{15}$	199/260[55]	–	no	**KappAloy15** Designed specifically for Aluminum-to-Aluminum and Aluminum-to-	85							15			

				Copper soldering. It has good corrosion resistance and tensile strength. Lies between soft solder and silver brazing alloys, thereby avoiding damage to critical electronics and substrate deformation and segregation. Has a wide plastic range this makes it ideal for hand soldering Aluminum plates and parts, allowing manipulation of the parts as the solder cools.[55]											
$Zn_{95}Al_5$	382	–	yes	For soldering aluminium. Good wetting.[54]								95			Al_5
$Sn_{91.8}Bi_{4.8}Ag_{3.4}$	211/213[56]	–	no	Do not use on lead-containing metallizations. U.S. Patent 5,439,639 (ICA Licensed Sandia Patent).	91.8		3.4			4.8					
$Sn_{70}Zn_{30}$	199/316[55]	–	no	**KappAloy30** For soldering of aluminium. Good wetting. Used extensively in spray wire form for capacitors and other electronic parts. Higher temperature and higher tensile strength compared to 85Sn/15Zn and 91Sn/9Zn.[55]	70							30			
$Sn_{80}Zn_{20}$	199/288[55]	–	no	**KappAloy20** For soldering of aluminium. Good wetting. Used extensively in spray wire form for capacitors and other electronic parts. Higher temperature and higher tensile strength compared to	80							20			

				85Sn/15Zn and 91Sn/9Zn.[55]											
$Sn_{60}Zn_{40}$	199/343[55]	–	no	**KappAloy40** For soldering of aluminium. Good wetting. Used extensively in spray wire form for capacitors and other electronic parts. Higher temperature and higher tensile strength compared to 85Sn/15Zn and 91Sn/9Zn.[55]	60							40			
$Pb_{63}Sn_{35}Sb_2$	185/243[15]	Pb	no	**Sb2**	35	63			2						
$Pb_{63}Sn_{34}Zn_3$	170/256	Pb	no	Poor wetting of aluminium. Poor corrosion rating.[41]	34	63						3			
$Pb_{92}Cd_8$	310?	Pb,Cd	?	For soldering aluminium. US patent 1,333,666.[57]		92							8		
$Sn_{48}Bi_{32}Pb_{20}$	140/160[24]	Pb	no	For low-temperature soldering of heat-sensitive parts, and for soldering in the vicinity of already soldered joints without their remelting.	48	20				32					
$Sn_{89}Zn_8Bi_3$	191–198	–		Prone to corrosion and oxidation due to its zinc content. On copper surfaces forms a brittle Cu-Zn intermetallic layer, reducing the fatigue resistance of the joint; nickel plating of copper inhibits this.[58]	89					3		8			
$Sn_{83.6}Zn_{7.6}In_{8.8}$	181/187[59]	–	no	High dross due to zinc. Covered by U.S. Patent # 5,242,658.	83.6						8.8	7.6			
$Sn_{86.5}Zn_{5.5}In_{4.5}Bi_{3.5}$	174/186[60]	–	no	Lead-free. Corrosion concerns and high drossing due to zinc content.	86.5					3.5	4.5	5.5			

$Sn_{86.9}In_{10}Ag_{3.1}$	204/205[61]	–		Potential use in flip-chip assembly, no issues with tin-indium eutectic phase.	86.9		3.1				10				
$Sn_{95}Ag_{3.5}Zn_{1}Cu_{0.5}$	221L[58]	–	no		95		3.5	0.5				1			
$Sn_{95}Sb_{5}$	235/240[14] 232/240[15]	–	no	**Sb5**, **ASTM95TA**. The US plumbing industry standard. It displays good resistance to thermal fatigue and good shear strength. Forms coarse dendrites of tin-rich solid solution with SbSn intermetallic dispersed between. Very high room-temperature ductility. Creeps via viscous glide of dislocations by pipe diffusion. More creep-resistant than $SnAg_{3.5}$. Antimony can be toxic. Used for sealing chip packagings, attaching I/O pins to ceramic substrates, and die attachment; a possible lower-temperature replacement of AuSn.[10] High strength and bright finish. Use in air conditioning, refrigeration, some food containers, and high-temperature applications.[19] Good wettability, good long-term shear strength at 100 °C. Suitable for potable water systems. Used for stained glass, plumbing, and radiator repairs.	95				5						

$Sn_{97}Sb_3$	232/238[62]	–	no		97				3						
$Sn_{99}Sb_1$	232/235[63]	–	no		99				1						
$Sn_{99}Ag_{0.3}Cu_{0.7}$		–			99		0.3	0.7							
$Sn_{96.2}Ag_{2.5}Cu_{0.8}Sb_{0.5}$	217–225 217[15]	–		**Ag03A**. Patented by AIM alliance.	96.2		2.5	0.8	0.5						
$Sn_{88}In_{8.0}Ag_{3.5}Bi_{0.5}$	197–208	–		Patented by Matsushita/ Panasonic.	88		3.5			0.5	8				
$Bi_{57}Sn_{42}Ag_1$	137/139 139/140[64]	–		Addition of silver improves mechanical strength. Established history of use. Good thermal fatigue performance. Patented by Motorola.	42		1			57					
$Bi_{58}Sn_{42}$	138[14][16]	–	yes	**Bi58**. Reasonable shear strength and fatigue properties. Combination with lead-tin solder may dramatically lower melting point and lead to joint failure.[27] Low-temperature eutectic solder with high strength.[16] Particularly strong, very brittle.[14] Used extensively in through-hole technology assemblies in IBM mainframe computers where low soldering temperature was required. Can be used as a coating of copper particles to facilitate their bonding under pressure/ heat and creating a conductive metallurgical joint.[58] Sensitive to shear rate. Good for electronics. Used in	42					58					

				thermoelectric applications. Good thermal fatigue performance.[65] Established history of use. Expands slightly on casting, then undergoes very low further shrinkage or expansion, unlike many other low-temperature alloys which continue changing dimensions for some hours after solidification.[34]											
$Bi_{58}Pb_{42}$	124/126[66]	Pb				42				58					
$In_{80}Pb_{15}Ag_{5}$	142/149[15] 149/154[67]	Pb	no	**In80**. Compatible with gold, minimum gold-leaching. Resistant to thermal fatigue. Can be used in step soldering.		15	5				80				
$Pb_{60}In_{40}$	195/225[15]	Pb	no	**In40**. Low gold-leaching. Good thermal fatigue properties.		60					40				
$Pb_{70}In_{30}$	245/260[15]	Pb	no	**In30**		70					30				
$Sn_{37.5}Pb_{37.5}In_{26}$	134/181[15]	Pb	no	**In26**	37.5	37.5					26				
$Sn_{54}Pb_{26}In_{20}$	130/154[15] 140/152[68]	Pb	no	**In20**	54	26					20				
$Pb_{81}In_{19}$	270/280[15] 260/275[69]	Pb	no	**In19**. Low gold-leaching. Good thermal fatigue properties.		81					19				
$In_{52}Sn_{48}$	118	–	yes	**In52**. Suitable for the cases where low-temperature soldering is needed. Can be used for glass sealing.[58] Sharp melting point. Good wettability of glass, quartz, and many ceramics. Good	48						52				

				low-temperature malleability, can compensate for different thermal expansion coefficients of joined materials.											
$Sn_{52}In_{48}$	118/131[14]	–	no	very low tensile strength	52						48				
$Sn_{58}In_{42}$	118/145[70]	–	no		58						42				
$Sn_{51.2}Pb_{30.6}Cd_{18.2}$	145[71]	Pb,Cd	yes	General-purpose. Maintains creep strength well. Unsuitable for gold.	51.2	30.6							18.2		
$Sn_{77.2}In_{20}Ag_{2.8}$	175/187[72]	–	no	Similar mechanical properties with $Sn_{63}Pb_{37}$, $Sn_{62}Pb_{36}Ag_2$ and $Sn_{60}Pb_{40}$, suitable lead-free replacement. Contains eutectic Sn-In phase with melting point at 118 °C, avoid use above 100 °C.	77.2		2.8				20				
$In_{74}Cd_{26}$	123[73]	Cd	yes								74		26		
$In_{61.7}Bi_{30.8}Cd_{7.5}$	62[74]	Cd	yes							30.8	61.7		7.5		
$Bi_{47.5}Pb_{25.4}Sn_{12.6}Cd_{9.5}In_5$	57/65[75]	Pb,Cd	no		12.6	25.4				47.5	5		9.5		
$Bi_{48}Pb_{25.4}Sn_{12.8}Cd_{9.6}In_4$	61/65[76]	Pb,Cd	no		12.8	25.4				48			9.6		
$Bi_{49}Pb_{18}Sn_{15}In_{18}$	58/69[77]	Pb	no		15	18				49	18				
$Bi_{49}Pb_{18}Sn_{12}In_{21}$	58	Pb	yes	**Cerrolow 136**. Slightly expands on cooling, later shows slight shrinkage in couple hours afterwards. Used as a solder in low-temperature physics.[34]	12	18				49	21				
$Bi_{50.5}Pb_{27.8}Sn_{12.4}Cd_{9.3}$	70/73[78]	Pb,Cd	no		12.4	27.8				50.5			9.3		
$Bi_{50}Pb_{26.7}Sn_{13.3}Cd_{10}$	70	Pb,Cd	yes	**Cerrobend**. Used in low-temperature physics as a solder.[34]	13.3	26.7				50			10		
				Cerrolow 117. Used as a solder in low-											

				temperature physics.[34]											
$In_{60}Sn_{40}$	113/122[14]	–	no		40						60				
$In_{51.0}Bi_{32.5}Sn_{16.5}$	60.5	–	yes	Field's metal	16.5					32.5	51				
$Bi_{49.5}Pb_{27.3}Sn_{13.1}Cd_{10.1}$	70.9	Pb,Cd	yes	Lipowitz Metal	13.1	27.3				49.5			10.1		
$Bi_{50.0}Pb_{25.0}Sn_{12.5}Cd_{12.5}$	71	Pb,Cd	yes	Wood's metal, mostly used for casting.	12.5	25				50			12.5		
$Bi_{50.0}Pb_{31.2}Sn_{18.8}$	97	Pb	no	Newton's metal	18.8	31.2				50					
$Bi_{50}Pb_{28}Sn_{22}$	109	Pb	no	Rose's metal. It was used to secure cast iron railings and balusters in pockets in stone bases and steps. Does not contract on cooling.	22	28				50					
$Cd_{95}Ag_{5}$	338/393[79]	Cd	no	**KappTec** General purpose solder that will join all solderable metals except Aluminum. High temperature, high strength solder. It is used in applications where alloys melting higher than soft solders are required, but the cost and strength of Silver-brazing alloys is not necessary.[79]			5						95		
$Cd_{82.5}Zn_{17.5}$	265[80]	Cd	yes	Medium temperature alloy that provide strong, corrosion-resistant joints on most metals.[80] Also for soldering aluminium and die-cast zinc alloys.[20] Used in cryogenic physics for ataching electrical potential leads to specimens of metals, as this alloy does not become superconductive at liquid helium								17.5	82.5		

				temperatures.[34]											
$Cd_{70}Zn_{30}$	265/300[80]	Cd	no	Medium temperature alloy that provide strong, corrosion-resistant joints on most metals. Works especially well on Aluminum-to-Aluminum and Aluminum-to-Copper joints, with excellent corrosion resistance and superior strength in high vibration and high stress applications in electronics, lighting and electrical products.[80]								30	70		
$Cd_{60}Zn_{40}$	265/316[80]	Cd	no	Medium temperature alloy that provide strong, corrosion-resistant joints on most metals. Works especially well on Aluminum-to-Aluminum and Aluminum-to-Copper joints, with excellent corrosion resistance and superior strength in high vibration and high stress applications in electronics, lighting and electrical products.[80]								40	60		
$Cd_{78}Zn_{17}Ag_5$	249/316[81]	Cd	no	**KappTecZ** High temperature, high strength solder that may be used on most metals, but works extremely well on Aluminum, Copper and Stainless Steel. It has a high tolerance to vibration and stress, and good elongation for use on			5					17	78		

				dissimilar metals. Above its liquidus of 600°F, this solder is extremely fluid and will penetrate the closest joints.[81]											
$Sn_{40}Zn_{27}Cd_{33}$	176/260[82]	Cd	no	**KappRad**[82] Developed specifically to join and repair Aluminum and Aluminum/ Copper radiators and heat exchangers. A lower melting point makes delicate repair work easier.[82]	40							27	33		
$Zn_{90}Cd_{10}$	265/399	Cd		For soldering aluminium. Good wetting.[54]								90	10		
$Zn_{60}Cd_{40}$	265/335	Cd		For soldering aluminium. Very good wetting.[54]								60	40		
$Cd_{70}Sn_{30}$	140/160[15]	Cd	no	**Cd70**, **thermal-free solder**. Produces low thermal EMF joints in copper, does not form parasitic thermocouples. Used in low-temperature physics.[34]	29.56								70.44		
$Sn_{50}Pb_{32}Cd_{18}$	145[15]	Cd,Pb		**Cd18**	50	32							18		
$Sn_{40}Pb_{42}Cd_{18}$	145[83]	Cd,Pb		Low melting temperature allows repairing pewter and zinc objects, including die-cast toys.	40	42							18		
$Zn_{70}Sn_{30}$	199/376	–	no	For soldering aluminium. Excellent wetting.[41] Good strength.	30							70			
$Zn_{60}Sn_{40}$	199/341	–	no	For soldering aluminium. Good wetting.[54]	40							60			
$Zn_{95}Sn_{5}$	382	–	yes?	For soldering aluminium. Excellent wetting.[41]	5							95			
$Sn_{90}Au_{10}$	217[84]	–	yes		90									10	

$Au_{80}Sn_{20}$	280	–	yes	**Au80**. Good wetting, high strength, low creep, high corrosion resistance, high thermal conductivity, high surface tension, zero wetting angle. Suitable for step soldering. The original flux-less alloy, does not need flux. Used for die attachment and attachment of metal lids to semiconductor packages, e.g. kovar lids to ceramic chip carriers. Coefficient of expansion matching many common materials. Due to zero wetting angle requires pressure to form a void-free joint. Alloy of choice for joining gold-plated and gold-alloy plated surfaces. As some gold dissolves from the surfaces during soldering and moves the composition to non-eutectic state (1% increase of Au content can increase melting point by 30 °C), subsequent desoldering requires higher temperature.[85] Forms a mixture of two brittle intermetallic phases, AuSn and Au_5Sn.[86] Brittle. Proper wetting achieved usually by using nickel surfaces with gold layer on top on both sides of the	20									80	

				joint. Comprehensively tested through military standard environmental conditioning. Good long-term electrical performance, history of reliability.[32] Low vapor pressure, suitable for vacuum work. Generally used in applications that require a melting temperature over 150°C.[87] Good ductility. Also classified as a braze.											
$Au_{98}Si_{2}$	370/800[15]	–		**Au98**. A non-eutectic alloy used for die attachment of silicon dies. Ultrasonic assistance is needed to scrub the chip surface so a eutectic (3.1% Si) is reached at reflow.										98	Si_{2}
$Au_{96.8}Si_{3.2}$	370[15] 363[88]	–	yes	**Au97**.[85] $AuSi_{3.2}$ is a eutectic with melting point of 363 °C. AuSi forms a meniscus at the edge of the chip, unlike AuSn, as AuSi reacts with the chip surface. Forms a composite material structure of submicron silicon plates in soft gold matrix. Tough, slow crack propagation.[50]										96.8	$Si_{3.2}$
$Au_{87.5}Ge_{12.5}$	361 356[15]	–	yes	**Au88**. Used for die attachment of some chips.[14] The high temperature may be detrimental to the chips and limits										87.5	$Ge_{12.5}$

				reworkability.[32]											
$Au_{82}In_{18}$	451/485[15]	–	no	**Au82**. High-temperature, extremely hard, very stiff.							18			82	
In_{100}	157	–	pure	**In99**. Used for die attachment of some chips. More suitable for soldering gold, dissolution rate of gold is 17 times slower than in tin-based solders and up to 20% of gold can be tolerated without significant embrittlement. Good performance at cryogenic temperatures.[89] Wets many surfaces incl. quartz, glass, and many ceramics. Deforms indefinitely under load. Does not become brittle even at low temperatures. Used as a solder in low-temperature physics, will bond to aluminium. Can be used for soldering to thin metal films or glass with an ultrasonic soldering iron.[34]							99.99				

Notes on the above table

Temperature ranges for solidus and liquidus (the boundaries of the mushy state) are listed as solidus/liquidus.[14]

In the Sn-Pb alloys, tensile strength increases with increasing tin content. Indium-tin alloys with high indium content have very low tensile strength.[14]

For soldering semiconductor materials, e.g. die attachment of silicon, germanium and gallium arsenide, it is important that the solder contains no impurities that could cause doping in the wrong direction. For soldering n-type semiconductors, solder may be doped with antimony; indium may be added for soldering p-type semiconductors. Pure tin and pure gold can be used.[41]

Various fusible alloys can be used as solders with very low melting points; examples include Field's metal, Lipowitz's alloy, Wood's metal, and Rose's metal.

Properties

The thermal conductivity of common solders ranges from 32 to 94 W/(m·K) and the density from 9.25 to 15.00 g/cm^3.[90][91]

Material	Thermal conductivity [W/(m*K)]	Melting point [°C]
Sn-37Pb (eutectic)	50.9	183
Sn-2.8Ag-20.0In	53.5	175 – 186
Sn-2.5Ag-0.8Cu-0.5Sb	57.26	215 – 217
Pb-5Sn	63	310
Lead (Pb)	35.0	327.3
Tin (Sn)	73.0	231.9
Aluminum (Al)	240	660.1
Copper (Cu)	393 - 401	1083
FR-4	1.7	

[91]

Solidifying

The solidifying behavior depends on the alloy composition. Pure metals solidify at a sharply defined temperature, forming crystals of one phase. Eutectic alloys also solidify at a single temperature, all components precipitating simultaneously in so-called coupled growth. Non-eutectic compositions on cooling start to first precipitate the non-eutectic phase; dendrites when it is a metal, large crystals when it is an intermetallic compound. Such a mixture of solid particles in a molten eutectic is referred to as a **mushy** state. Even a relatively small proportion of solids in the liquid can dramatically lower its fluidity.[51]

The temperature of total solidification is the solidus of the alloy, the temperature at which all components are molten is the liquidus.

The mushy state is desired where a degree of plasticity is beneficial for creating the joint, allowing filling larger gaps or being wiped over the joint (e.g. when soldering pipes). In hand soldering of electronics it may be detrimental as the joint may appear solidified while it is not yet. Premature handling of such joint then disrupts its internal structure and leads to compromised mechanical integrity.

Alloying element roles

Different elements serve different roles in the solder alloy:

- Antimony is added to increase strength without affecting wettability. Prevents tin pest. Should be avoided on zinc, cadmium, or galvanized metals as the resulting joint is brittle.[20]
- Bismuth significantly lowers the melting point and improves wettability. In presence of sufficient lead and tin, bismuth forms crystals of $Sn_{16}Pb_{32}Bi_{52}$ with melting point of only 95 °C, which diffuses along the grain boundaries and may cause a joint failure at relatively low temperatures. A high-power part pre-tinned with an alloy of lead can therefore desolder under load when soldered with a bismuth-containing solder. Such joints are also prone to cracking. Alloys with more than 47% Bi expand upon cooling, which may be used to offset thermal expansion mismatch stresses. Retards growth of tin whiskers. Relatively expensive, limited availability.
- Copper lowers the melting point, improves resistance to thermal cycle fatigue, and improves wetting properties of the molten solder. It also slows down the rate of dissolution of copper from the board and part leads in the liquid solder. Forms intermetallic compounds. May promote growth of tin whiskers. Supersaturated (by about 1%) solution of copper in tin may be employed to inhibit dissolution of thin-film under-bump metallization of BGA chips, e.g. as $Sn_{94}Ag_3Cu_3$.[92]
- Nickel can be added to the solder alloy to form a supersaturated solution to inhibit dissolution of thin-film under-bump metallization.[92]
- Indium lowers the melting point and improves ductility. In presence of lead it forms a ternary compound that undergoes phase change at 114 °C. Very high cost (several times of silver), low availability. Easily oxidizes, which causes problems for repairs and reworks, especially when oxide-removing flux cannot be used, e.g. during GaAs die attachment. Indium alloys are used for cryogenic applications, and for soldering gold as gold dissolves in indium much less than in tin. Indium can also solder many nonmetals (e.g. glass, mica, alumina, magnesia, titania, zirconia, porcelain, brick, concrete, and marble). Prone to diffusion into semiconductors and cause undesired doping. At elevated temperatures easily diffuses through metals. Low vapor pressure, suitable for use in vacuum systems. Forms brittle intermetallics with gold; indium-rich solders on thick gold are unreliable. Indium-based solders are prone to corrosion, especially in presence of chloride ions.[93]
- Lead is inexpensive and has suitable properties. Worse wetting than tin. Toxic, being phased out. Retards growth of tin whiskers, inhibits tin pest. Lowers solubility of copper and other metals in tin.
- Silver provides mechanical strength, but has worse ductility than lead. In absence of lead, it improves resistance to fatigue from thermal cycles. Using SnAg solders with HASL-SnPb-coated leads forms $SnPb_{36}Ag_2$ phase with melting point at 179 °C, which moves to the board-solder interface, solidifies last, and separates from the board.[11] Addition of silver to tin significantly lowers solubility of silver coatings in the tin phase. In eutectic tin-silver (3.5% Ag) alloy it tends to form platelets of Ag_3Sn, which, if formed near a high-stress spot, may serve as initiating sites for cracks; silver content needs to be kept below 3% to inhibit such problems.[92]
- Tin is the usual main structural metal of the alloy. It has good strength and wetting. On its own it is prone to tin pest, tin cry, and growth of tin whiskers. Readily dissolves silver, gold and to less but still significant extent many other metals, e.g. copper; this is a particular concern for tin-rich alloys with higher melting points and reflow temperatures.
- Zinc lowers the melting point and is low-cost. However it is highly susceptible to corrosion and oxidation in air, therefore zinc-containing alloys are unsuitable for some purposes, e.g. wave soldering, and zinc-containing solder pastes have shorter shelf life than zinc-free. Can form brittle Cu-Zn intermetallic layers in contact with copper. Readily oxidizes which impairs wetting, requires a suitable flux.

- Germanium in tin-based lead-free solders influences formation of oxides; at below 0.002% it increases formation of oxides. Optimal concentration for suppressing oxidation is at 0.005%.[94]

Impurities in solders

Impurities usually enter the solder reservoir by dissolving the metals present in the assemblies being soldered. Dissolving of process equipment is not common as the materials are usually chosen to be insoluble in solder.[95]

- Aluminium – little solubility, causes sluggishness of solder and dull gritty appearance due to formation of oxides. Addition of antimony to solders forms Al-Sb intermetallics that are segregated into dross.
- Antimony – added intentionally, up to 0.3% improves wetting, larger amounts slowly degrade wetting
- Arsenic – forms thin intermetallics with adverse effects on mechanical properties, causes dewetting of brass surfaces
- Cadmium – causes sluggishness of solder, forms oxides and tarnishes
- Copper – most common contaminant, forms needle-shaped intermetallics, causes sluggishness of solders, grittiness of alloys, decreased wetting
- Gold – easily dissolves, forms brittle intermetallics, contamination above 0.5% causes sluggishness and decreases wetting. Lowers melting point of tin-based solders. Higher-tin alloys can absorb more gold without embrittlement.[47]
- Iron – forms intermetallics, causes grittiness, but rate of dissolution is very low; readily dissolves in lead-tin above 427 °C.[8]
- Nickel – causes grittiness, very little solubility in Sn-Pb
- Phosphorus – forms tin and lead phosphides, causes grittiness and dewetting, present in electroless nickel plating
- Silver – often added intentionally, in high amounts forms intermetallics that cause grittiness and formation of pimples on the solder surface
- Sulfur – forms lead and tin sulfides, causes dewetting
- Zinc – in melt forms excessive dross, in solidified joints rapidly oxidizes on the surface; zinc oxide is insoluble in fluxes, impairing repairability; copper and nickel barrier layers may be needed when soldering brass to prevent nickel migration to the surface

Intermetallics in solders

Many different intermetallic compounds are formed during solidifying of solders and during their reactions with the soldered surfaces.[95]

The intermetallics form distinct phases, usually as inclusions in a ductile solid solution matrix, but also can form the matrix itself with metal inclusions or form crystalline matter with different intermetallics. Intermetallics are often hard and brittle. Finely distributed intermetallics in a ductile matrix yield a hard alloy while coarse structure gives a softer alloy. A range of intermetallics often forms between the metal and the solder, with increasing proportion of the metal; e.g. forming a structure of $Cu-Cu_3Sn-Cu_6Sn_5-Sn$.

Layers of intermetallics can form between the solder and the soldered material. These layers may cause mechanical reliability weakening and brittleness, increased electrical resistance, or electromigration and formation of voids. The gold-tin intermetallics layer is responsible for poor mechanical reliability of tin-soldered gold-plated surfaces where the gold plating did not completely dissolve in the solder.

Gold and palladium readily dissolve in solders. Copper and nickel tend to form intermetallic layers during normal soldering profiles. Indium forms intermetallics as well.

Indium-gold intermetallics are brittle and occupy about 4 times more volume than the original gold. Bonding wires are especially susceptible to indium attack. Such intermetallic growth, together with thermal cycling, can lead to failure of the bonding wires.[96]

Copper plated with nickel and gold is often used. The thin gold layer facilitates good solderability of nickel as it protects the nickel from oxidation; the layer has to be thin enough to rapidly and completely dissolve so bare nickel is exposed to the solder.[10]

Lead-tin solder layers on copper leads can form copper-tin intermetallic layers; the solder alloy is then locally depleted of tin and form a lead-rich layer. The Sn-Cu intermetallics then can get exposed to oxidation, resulting in impaired solderability.[97]

Two processes play role in a solder joint formation: interaction between the substrate and molten solder, and solid-state growth of intermetallic compounds. The base metal dissolves in the molten solder in an amount depending on its solubility in the solder. The active constituent of the solder reacts with the base metal with a rate dependent on the solubility of the active constituents in the base metal. The solid-state reactions are more complex - the formation of intermetallics can be inhibited by changing the composition of the base metal or the solder alloy, or by using a suitable barrier layer to inhibit diffusion of the metals.[98]

	Tin	Lead	Indium
Copper	Cu_4Sn, **Cu_6Sn_5**, **Cu_3Sn**, Cu_3Sn_8		Cu_3In, Cu_9In_4
Nickel	Ni_3Sn, Ni_3Sn_2, **Ni_3Sn_4** $NiSn_3$		Ni_3In, NiIn Ni_2In_3, Ni_3In_7
Iron	FeSn, $FeSn_2$		
Indium	In_3Sn, $InSn_4$	In_3Pb	–
Antimony	SbSn		
Bismuth		$BiPb_3$	
Silver	Ag_6Sn, Ag_3Sn		Ag_3In, $AgIn_2$
Gold	**Au_5Sn**, **AuSn** $AuSn_2$, **$AuSn_4$**	Au_2Pb, $AuPb_2$	AuIn, $AuIn_2$
Palladium	Pd_3Sn, Pd_2Sn, Pd_3Sn_2, PdSn, $PdSn_2$, $PdSn_4$		Pd_3In, Pd_2In, PdIn Pd_2In_3
Platinum	Pt_3Sn, Pt_2Sn, PtSn, Pt_2Sn_3, $PtSn_2$, $PtSn_4$	Pt_3Pb, PtPb $PtPb_4$	Pt_2In_3, $PtIn_2$, Pt_3In_7

- Cu_6Sn_5 – common on solder-copper interface, forms preferentially when excess of tin is available; in presence of nickel $(Cu,Ni)_6Sn_5$ compound can be formed
- Cu_3Sn – common on solder-copper interface, forms preferentially when excess of copper is available, more thermally stable than Cu_6Sn_5, often present when higher-temperature soldering occurred
- Ni_3Sn_4 – common on solder-nickel interface
- $FeSn_2$ – very slow formation
- Ag_3Sn - at higher concentration of silver (over 3%) in tin forms platelets that can serve as crack initiation sites.
- $AuSn_4$ – β-phase – brittle, forms at excess of tin. Detrimental to properties of tin-based solders to gold-plated layers.
- $AuIn_2$ – forms on the boundary between gold and indium-lead solder, acts as a barrier against further dissolution of gold

Glass solder

Glass solders are used to join glasses to other glasses, ceramics, metals, semiconductors, mica, and other materials, in a process called glass frit bonding. The glass solder has to flow and wet the soldered surfaces well below the temperature where deformation or degradation of either of the joined materials or nearby structures (e.g., metallization layers on chips or ceramic substrates) occurs. The usual temperature of achieving flowing and wetting is between 450 and 550 °C.

Two types of glass solders are used: vitreous, and devitrifying. Vitreous solders retain their amorphous structure during remelting, can be reworked repeatedly, and are relatively transparent. Devitrifying solders undergo partial crystallization during solidifying, forming a glass-ceramic, a composite of glassy and crystalline phases. Devitrifying solders usually create a stronger mechanical bond, but are more temperature-sensitive and the seal is more likely to be leaky; due to their polycrystalline structure they tend to be translucent or opaque.[99] Devitrifying solders are frequently "thermosetting", as their melting temperature after recrystallization becomes significantly higher; this allows soldering the parts together at lower temperature than the subsequent bake-out without remelting the joint afterwards. Devitrifying solders frequently contain up to 25% zinc oxide. In production of cathode ray tubes, devitrifying solders based on PbO-B_2O_3-ZnO are used.

Very low temperature melting glasses, fluid at 200–400 °C, were developed for sealing applications for electronics. They can consist of binary or ternary mixtures of thallium, arsenic and sulfur.[100] Zinc-silicoborate glasses can also be used for passivation of electronics; their coefficient of thermal expansion must match silicon (or the other semiconductors used) and they must not contain alkaline metals as those would migrate to the semiconductor and cause failures.[101]

The bonding between the glass or ceramics and the glass solder can be either covalent, or, more often, van der Waals.[102] The seal can be leak-tight; glass soldering is frequently used in vacuum technology. Glass solders can be also used as sealants; a vitreous enamel coating on iron lowered its permeability to hydrogen 10 times.[103] Glass solders are frequently used for glass-to-metal seals and glass-ceramic-to-metal seals.

Glass solders are available as frit powder with grain size below 60 micrometers. They can be mixed with water or alcohol to form a paste for easy application, or with dissolved nitrocellulose or other suitable binder for adhering to the surfaces until being melted.[104] The eventual binder has to be burned off before melting proceeds, requiring careful firing regime. The solder glass can be also applied from molten state to the area of the future joint during manufacture of the part. Due to their low viscosity in molten state, lead glasses with high PbO content (often 70–85%) are frequently used. The most common compositions are based on lead borates (leaded borate glass or borosilicate glass). Smaller amount of zinc oxide or aluminium oxide can be added for increasing chemical stability. Phosphate glasses can be also employed. Zinc oxide, bismuth trioxide, and copper(II) oxide can be added for influencing the thermal expansion; unlike the alkali oxides, these lower the softening point without increasing of thermal expansion.

Glass solders are frequently used in electronic packaging. CERDIP packagings are an example. Outgassing of water from the glass solder during encapsulation was a cause of high failure rates of early CERDIP integrated circuits. Removal of glass-soldered ceramic covers, e.g., for gaining access to the chip for failure analysis or reverse engineering, is best done by shearing; if this is too risky, the cover is polished away instead.[105]

As the seals can be performed at much lower temperature than with direct joining of glass parts and without use of flame (using a temperature-controlled kiln or oven), glass solders are useful in applications like subminiature vacuum tubes or for joining mica windows to vacuum tubes and instruments (e.g., Geiger tube). Thermal expansion coefficient has to be matched to the materials being joined and often is chosen in between the coefficients of expansion of the materials. In case of having to compromise, subjecting the joint to compression stresses is more desirable than to tensile stresses. The expansion matching is not critical in applications where thin layers are used on small areas, e.g., fireable inks, or where the joint will be subjected to a permanent compression (e.g., by an external steel shell) offsetting the thermally introduced tensile stresses.[100]

Glass solder can be used as an intermediate layer when joining materials (glasses, ceramics) with significantly different coefficient of thermal expansion; such materials cannot be directly joined by diffusion welding.[106] Evacuated glazing windows are made of glass panels soldered together.[107]

A glass solder is used, e.g., for joining together parts of cathode ray tubes and plasma display panels. Newer compositions lowered the usage temperature from 450 to 390 °C by reducing the lead(II) oxide content down from 70%, increasing the zinc oxide content, adding titanium dioxide and bismuth(III) oxide and some other components. The high thermal expansion of such glass can be reduced by a suitable ceramic filler. Lead-free solder glasses with soldering temperature of 450 °C were also developed.

Phosphate glasses with low melting temperature were developed. One of such compositions is phosphorus pentoxide, lead(II) oxide, and zinc oxide, with addition of lithium and some other oxides.[108]

Conductive glass solders can be also prepared.

Preform

A preform is a pre-made shape of solder specially designed for the application where it is to be used.[109] Many methods are used to manufacture the solder preform, stamping being the most common. The solder preform may include the solder flux needed for the soldering process. This can be an internal flux, inside the solder preform, or external, with the solder preform coated.[110]

See also

- Body solder
- RoHS
- Solderability
- Solder mask

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External links

- Physical Properties Table of Solders (http://www.indium.com/products/alloy_sorted_by_temperature.pdf)
- Lead-free solder alloys (http://www.kester.com/en-us/leadfree/alloys.aspx)
- Common solder alloys and their melting ranges (http://www.bhavanimetals.com/Solder_Wire_Rosin_Core_Solder.htm)
- Phase diagrams of different types of solder alloys (http://www.metallurgy.nist.gov/phase/solder/solder.html)
- Phase diagrams for lead free solders (http://mtdata.software.googlepages.com/periodictableSolders.htm)

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