The First 7,000 Years of Soldering, Part I

By Dr. Ken Gilleo

This is the first installment of a two-part article. The second half will appear in the November issue of Circuits Assembly.

Nearly a million years ago, mankind’s technological march through time began after fire was mastered. Metalworking, which evolved into metallurgy, is the oldest and most successful technology. It spans at least 12,000 years (Figure 1). Soldering, a key metal joining technology, was probably developed about 7,000 years ago when lower melting, naturally occurring metal alloys were placed in the blowpipe-fanned fires of that day.* Early man used these precious metal alloys to join castings made of gold or silver.

The earliest solders were based on gold and included gold alloys of silver or tin. All early metallurgy was developed in the name of art. The earliest solders, of course, were lead-free and environmentally friendly.

The Romans developed soft solders for utilitarian purposes, such as plumbing, and these joining materials also found use in the artwork of the bronze age. They gave us eutectic tin-lead solder, which is now the workhorse alloy of modern electronic assembly (Figures 2, 3).

Fast Forward: Silicon Valley and Beyond
The three most basic elements of electronics are the device (especially the IC), wiring structures (typified by the PCB) and joining materials.

The youngest component, the solid-state device, is always on the forefront of technology. Its performance doubles and quadruples in ever shortening time spans.

Wiring structure technology evolves slowly. The mainstay process, etching, was borrowed from the printing industry nearly 100 years ago, and the PCB industry has never really caught up to the demands of electronic devices. This has brought on MCM mania, where processes borrowed from the IC industry attempt to bring wiring into the present century as the IC moves on into the twenty-first.

Yet, ICs and high-density MCMs are completely impotent entities unless we can initiate a successful mating. The oldest technology, metal joining, consummates the marriage.

*7,000 years is speculation by the author, not a documented number.
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allurgical soldering were developed in ancient times. Essentially, soldering has remained unaltered for 25 centuries. Our tin-lead solder paste for fine pitch has the same chemical and mechanical characteristics and properties as the material used to connect Roman sewer pipes.

Why does tin-lead have the features of an immutable chemical element? Only the shape has changed, from ingot to bar, to wire, to paste to bump and ball—all of which have given the false impression of progress. Let’s travel back in time to examine the history of soldering and seek out reasons for solder’s consistency and inertia to change.

**Hard Solders**

Early solders were based on gold, other noble metals and some common metals such as tin. Although written records describing soldering date back to only 3,500 B.C., it is likely that the process was known much earlier. Drawings used as a means of recording history before writing showed many metal processes, including casting.

Gold was readily available within traveling distance from the center of advanced civilization, the Nile Valley. Copper, platinum, silver and meteoric iron were also found in their native elemental state. Gold casting processes were practiced by pyramid builders who sealed magnificent works of art in the massive tombs. The Egyptians learned to generate the higher temperatures needed for gold melting by using blowpipes and bellows on charcoal fires. Only platinum, requiring over 3,000°F, could not be melted by ancient technology.

Eventually, even complex casting molds could not produce the intricate shapes desired by artists. At first, mechanical attachment was used to connect cast parts together. But then, as an understanding of metallurgy emerged, soldering was discovered, and solder was available in a natural form.

Electrum, a mineral composed of silver and gold, was also known to the early Egyptians (Figure 4). Most likely, this lighter colored and lower melting metal was initially considered a different metal. This silver-gold alloy may well have been the first binary metal solder.

However, platinum, which defied all melting attempts, could be mixed with gold and heated to form a composite material. The platinum did not melt or alloy to the gold. The gold, in a process we now call sintering, melted and fused to the platinum particles—a form of soldering. Gold may have been the first single metal solder. While it is uncertain whether pure gold or gold alloy was the first solder, it is fairly certain that it was a precious metal composition.

Many other cultures also developed high levels of metal-working technology. Sadly, many of the metallurgical processes developed by ancient artisans were lost forever when iron metallurgy was discovered and adopted as the technology of war and destruction. Tomorrow’s metallurgy will be driven, in part, by the need to protect the earth and its inhabitants.

**Soft Solders**

Much later, after the Egyptian developments in gold soldering, lead-based solders were developed and became the dominant joining material. Since the addition of tin lowers the melting point and improves wetting, the tin-lead alloy was adopted by Romans and others in both art and public works projects. This soft solder was used to join copper, bronze and pure lead.

The most famous use of tin-lead is on the aqueducts (Figure 5). These masonry structures were lined with lead sheeting to efficiently convey water. Tin-lead alloy was an ideal
solder to seal the joints. Lead pipes also needed a “glue” to connect the lengths together, and tin-lead became the common joining material of Roman plumbers. In fact, the chemical symbol for lead, Pb, is derived from the Latin word “plumbum,” which means plumber.

Today, lead solder has been banned in drinking water plumbing, as well as paint, coatings and gasoline (some countries still permit tetraethyl lead use). Electronics, although not the largest user of lead, stands out as a significant consumer because of the attention being focused on electronics.

Although tin-lead solder is plagued with numerous deficiencies, the industry has learned to adjust and compensate.

The electronics industry, unlike other lead users, does not recycle solder, except for the waste products generated in the factory. Although we can point out that car batteries consume a much greater amount of lead, nearly all used up batteries are returned for recycling. Lead-containing electronic products are discarded, often after a very limited life. Tons of electronic lead-based solder find their way into landfills and incinerators. Who can unequivocally argue and guarantee that this will not contaminate earth, air and water?

The successful curtailment of CFCs and the electronics industry’s demonstrated ability to cope with CFC elimination has given a green light to anti-lead legislation. CFC environmental action has become the model for the eventual restriction of lead. A lead tax and eventual ban are in the minds and hearts of many environmentalists and lawmakers. Each year, new laws are placed before Congress, and a tax may be imposed by the year 2000. While the electronics industry may feel that it is illogical and unfair to tax this industry to pay for the errors of the paint manufacturers, many lawmakers and the kin of lead-poisoned children see justice. Some argue that the present sins of the electronics industry may have to be atoned for by yet another industry in the distant future.

One more contention is that everyone uses electronic products, and a lead tax would essentially tax everyone. The tax-it-out strategy is favored because the taxee can become exempt by switching to a safer alternative. The clock is now ticking, and it is powered by heavy clock weights made of lead.

Alternatives
There are three fundamental approaches to interconnection: mechanical, soldering and polymers. At the
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As environmental regulation prompts many electronics manufacturers to switch to no-clean soldering, one company that made the move has also documented significant quality and financial advantages.

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chip level, mechanically produced metallurgical junctions are the most common. This type of assembly has not been successfully applied to packaged component assembly, and no significant effort is planned. Components will either be soldered with non-lead alloys or adhesively bonded. These two strategies are now being intensely pursued. Rumors of a metal Velcro® emerge from time to time, but the task is not trivial, and a functional product could be expensive.

While lead-free solders have existed for perhaps as long as 7,000 years, viable and cost-effective alloys for electronic assembly are not readily available. Bismuth and indium solders are not even close to being drop-in replacements. Indium, for example, is a costly semi-precious metal with limited abundance. Alloys with a high bismuth content expand cooling requirements, an unacceptable characteristic for many applications.

Research is moving rapidly to develop useful lead-free alloys. The search will not be easy. The product will most likely be costly, and many compositions may be required to replace the single eutectic tin-lead alloy. Lead-free assembly is a serious and toilsome challenge for the industry, and any attempt to minimize the statement of difficulty is a disservice to all.

Conclusion

Solder assembly has enjoyed an extremely long life because its composition is simple, processing is well understood and performance is reasonably good. While hard solders made of gold were the first to be discovered, soft solders based on lead eventually became dominant. Although tin-lead solder is plagued with numerous deficiencies, including higher temperature processing, thermo-mechanical failure and relatively poor electrical properties, the industry has learned to adjust and compensate. Electronics has nearly recovered from CFC legislation but now faces a much more serious challenge as lead becomes the obscenity whispered by environmentalists and legislators. We could be moving through the “no” phase of electronics—no CFCs, no lead and no solder.

Enter the chemist. What can the chemist do for us? If he is involved in polymer chemistry, more than you think. For more information on polymer chemistry, read Part II of this article, appearing in the November issue of Circuits Assembly.

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