FLASHSOLDERING UPDATE – EXTENDING FINE MAGNET WIRE JOINING APPLICATIONS

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Abstract: FlashSoldering was first developed in 1998 as a new innovative, non-contact, localized reflow soldering process for terminating fine insulated copper magnet wires to electronic contacts without first removing the wire insulation.

Subsequent research in 1999 has extended FlashSoldering applications from miniature magnetic component packages to soldering insulated single and multiple magnet wires and Litz wire to high-speed data connectors and other forms of electronic contacts.

Quality issues concerned with copper-tin inter-metallic growth and what happens to the magnet wire insulation during FlashSoldering were successfully resolved.

Applications for FlashSoldering have broadened to include: single and multiple toroidal transformer packaging; LAN filters; low power DC-DC converters; single or multiple form coils and inductors; woven or braided high speed data cables; and connecting a single wire to a Litz wire bundle.

Key Words: Chip Inductors, DC-DC Converter, Diode Laser, Electronic Contact, FlashSoldering, High Speed Data Cables, Insulated Magnet Wire, LAN Filters, and Miniature Toroidal Transformer.

I. INTRODUCTION

A. 1998 - FlashSoldering Research Efforts

FlashSoldering was originally developed in 1998 as a non-contact bonding method to solder very small #38 AWG (0.10 mm) polyurethane-nylon insulated magnet wires to surface mount (SMT) electronic component packages containing one or more miniature toroids.

Solder Dipping, Solder Wire Feed, TC Bonding, and Hot Bar Reflow bonding processes can produce a component production failure rate as high as 10%.

The majority of these failures are caused multiple handling of the fine wire leads, the wire "neck down" effect caused by solder dipping, and the heavy wire deformation produced by the TC Bonding and Hot Bar Reflow processes. FlashSoldering was successful in reducing all of the above failure sources.

B. 1999 - New FlashSoldering Applications & Ongoing Research Efforts

FlashSoldering successes in packaging small magnetic components led to inquiries from the high-speed data connector industry as to the viability of FlashSoldering fine insulated magnet wires, ranging from #33 to #28 AWG (0.18 mm to 0.32 mm), to the special electronic connectors used in the computer and data transmission industry. Electronic contacts capable of capturing single and multiple insulated magnet wires were developed and successfully tested in a prototype environment.

Requests to join fine gage Litz wire to a single magnet wire, without having to first strip the Litz wire, were addressed and solved.

Research into stripping and soldering fine polyimide and polyurethane insulated magnet wire was undertaken. The results point to the continued use of excimer lasers as being the best polyimide insulation stripping tool compared to diode lasers. However, diode lasers were successful in FlashSoldering #44 AWG (50 um) polyurethane insulated magnet wire when the wire was wrapped around a solder bearing terminal.

In the research process, the authors expanded their understanding of the FlashSoldering process to include four distinct elements as opposed to the two elements previously discussed in their EMCW '98 technical paper.

Lastly, questions concerning the quality of the solder joint in terms of copper-tin intermetallic growth and what happens to the insulation during the FlashSoldering process were successfully resolved.

II. DISCUSSION

A. 1999 FlashSoldering System - A More Complete Understanding

Additional research performed in 1999 caused the authors to re-think their understanding of the elements involved in FlashSoldering. As a result of their research process, the authors have now expanded the number of system components from two to four elements. As a system, FlashSoldering now includes: electronic contacts, solder, magnet wire, and a heat source.

B. Electronic Contact Design – General Concept

The electronic contact used in the FlashSoldering process represents a sophisticated heat transfer system. The electronic contact has multiple functions:

1. Capture and securely hold the insulated magnet wire during diode laser heating.
2. Conduct heat building up in the contact to the wire capture area to remove the magnet wire insulation.
3. Transfer solder from the plated contact surface or solder bearing lead (SBL) to the now exposed copper wire.

The authors have successfully experimented with two different electronic contacts designed for the magnetics component industry and one contact created for the high-speed data cable industry.

C. SMT Contact

The SMT contact uses a wire capture slot that is sized to accept a specific diameter insulated copper magnet wire from a toroidal transformer. The entire SMT contact is plated with a very precise thickness of 90/10 tin-lead solder, which melts about 230 to 240°C.

The thermal characteristics of the SMT contact are critical to both the insulation removal and reflow soldering process. Alloys such C17410 can be thermally too conductive, dissipating the heat away from the wire capture slot. Conversely, high nickel content alloys, such as alloy 42 are thermally too resistive and prevent the heat from reaching the wire capture slot. In either case, if the heat does not build up in the area behind the wire capture slot, the insulation does not separate from the copper wire nor does the plated solder flow properly to the copper wire.

Figure 1 shows an end view of the SMT contact with its wire capture slot sized for #38 AWG wire (100 um/.004 inch). The contact is 0.25 mm thick, 1.00 mm wide and deep and 0.75 mm high. The "L" shape design facilitates inserting the magnet wire into the wire capture slot, which is located on the inside corner. The wire capture slot also protects the magnet wire during laser heating by reducing the area of exposed magnet wire.

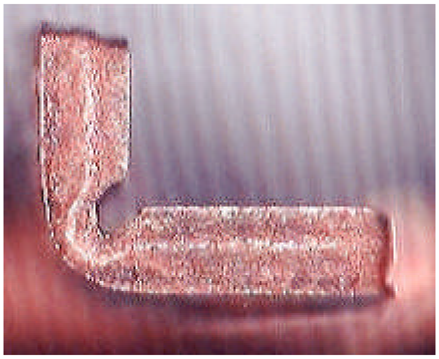

Figure 1 - End view of SMT Contact with wire capture slot.

D. Coil or Transformer Contact – SBL Terminal

A coil or transformer contact was also designed and tested for the magnetics industry by the authors. The Solder Bearing Lead (SBL) Terminal uses the manufacturers' own 0.64 mm (.025 inch) or smaller square post. The post is pressed into the plastic bobbin core containing a Solder Bearing Clip (SBC) to form a complete Solder Bearing Lead assembly.

The automatic coil-winding machine then tightly wraps three to four turns of insulated magnet wire around one SBL terminal close to the Solder Bearing Clip. After completing the bobbin winding, the machine then wraps the remaining SBL terminal with several turns, breaking off the magnet wire as the coil winding head moves away from the completed assembly. The coil or transformer is now ready for the FlashSoldering process. Figure 2 shows the complete SBL Terminal.

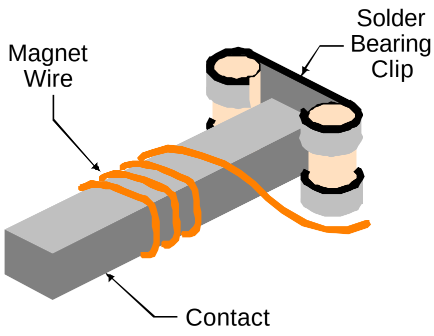

Figure 2 – SBL Terminal with Solder Bearing Clip (SBC) and magnet wire wrapped on

E. SBL Data Contact

The SBL Data Contact is used to manufacture high-speed data transmission connectors. The computer industry has developed complex woven or braided cable assemblies with dual ground wires surrounding one signal wire. This new design minimizes the leakage or "crosstalk" between adjacent signal lines.

Until FlashSoldering became available, these new cables were hand soldered to one edge of a "transition" circuit board. An I/O connector was then soldered to the opposite edge of this same PCB. Production throughput was very slow and additional inspection was required to detect solder "bridges" and mis-positioned wires.

The SBL Data Contact completely eliminates soldering bridging and increases production throughput by a factor of three to four times. Assembly operators now use semi-automated tooling to insert each ground wire and signal wire into their proper SBL Data Contact on the connector.

Each contact has retention clips for guiding the wire into the contact and holding it in place. The solder bearing "nugget provides a precise amount of solder and flux to bond two or more wires in one contact. Figure 3 shows a single SBL Data Contact with a #33 AWG (0.18 mm) insulated magnet wire trapped in the wire capture area. The solder bearing "nugget" lies in front of the wire.

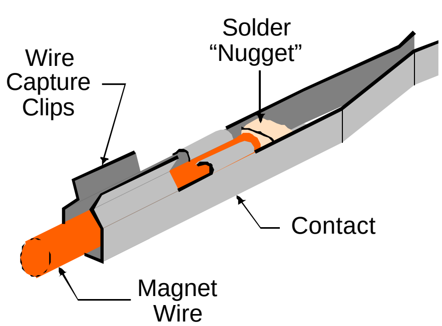

Figure 3 - SBL Data Contact with wire capture clips and solder "nugget".

F. Solder and Its Application

All FlashSoldering Contacts are plated with a precise amount of specified solder alloy like 90/10 tin-lead or 96/4 tin-silver for the SMT contact or they utilize Solder Bearing Lead (SBL) technology. SBL technology attaches a precise amount of solder or solder and flux onto each terminal or contact. Solder Bearing Clips (SBC) can also be pressed over wire posts or impregnated in the coil bobbin.

The authors have only experimented with 90/10 and 63/37 tin-lead and 96/4 tin-silver solder alloys. Future testing will be extended to lead-free solder alloys that are copper-tin based.

G. Magnet Wire

FlashSoldering has been proven to work with fine 44 to #28 AWG (0.05 to 0.32 mm). FlashSoldering was initially developed using heavy polyurethane-nylon insulated magnet wire.

Polyimide insulation removal is still highly problematic using diode laser heating. Polyimide is hydroscopic, meaning that contains a lot of water. Water has a strong absorption band at 980 nm, which helps to absorb heat created by a 980 nm diode laser. The added absorption capability is not sufficiently strong to cleanly remove the polyimide insulation.

The authors found that by placing a black paper surface behind a #38 AWG (0.10 mm) polyimide insulated magnet wire, they could carbonize the polyimide insulation in under 40 milli-seconds. However, the carbon had to be vacuumed or mechanically removed before the wire could be snapped into the wire capture slot on the SMT Contact or wrapped around a SBL Contact. Testing to remove polyimide insulated magnet wire trapped in the SMT Contact wire capture slot was not successful.

Polyurethane insulated fine magnet wire could be removed by diode laser heat, but only if the magnet wire was wrapped around the SBL Contact. When the insulated wire was trapped in the SMT Contact wire capture slot, the polyurethane insulation melted into a sticky mass, preventing the solder from flowing between the contact and copper wire.

Application testing continues to determine the practical wire size and insulation thickness limits of FlashSoldering. Diode laser power and wavelength, contact geometry and the insulation polymer chemistry are the main factors that will determine these limits.

H. Localized Heat Source - The Diode Laser

In the past several years various lasers have been used in the attempt to simultaneously remove the insulation from and terminate fine magnet wire. To date, these existing laser technologies have not been highly successful.

Excimer lasers, with an operating wavelength in the 300 nano-meter range, are excellent devices for non-contact, no damage, wire insulation stripping. However, the stripping mechanism that protects the copper wire also precludes the melting of solder.

1064 nano-meters, have been used in the past to try to simultaneously remove magnet wire insulation and reflow solder paste or plated solder between a contact pin and magnet wire.

These experiments have not been highly successful because the peak power nature of YAG laser causes:

1. Pitting or blow out of the copper wire.
2. Incomplete insulation removal.
3. Solder paste expulsion or vaporization.
4. Uncontrollable solder ball formation that can cause electrical shorts in the final product.

The recent introduction of continuous operation, solid state diode lasers, with an operating wavelength of 820 to 980 nano-meters (nm), now makes possible reflow soldering of solder paste, plated solder, and applied solder, such as used in solder bearing lead technology. Diode laser heating eliminates all of the detrimental characteristics produced by the pulsed YAG laser.

Testing by the authors demonstrated that a 820-nm wavelength diode laser can be used to remove polyurethane-nylon insulation from #28 AWG (0.32 mm) and smaller magnet wire.

A 980-nm wavelength diode laser will remove polyimide insulation from #38 AWG (0.10 mm) and smaller wire, but will not simultaneously remove the insulation and reflow solder when polyimide insulated magnet wire is placed in a SMT Contact or wrapped around the SBL Contact.

III. FLASHSOLDERING TESTING

A. FlashSoldering the SMT Contact

Prototype SMT contacts 1.00 mm long and wide by 0.75 mm high and 0.25 mm thick were fabricated from a variety of beryllium-copper, copper, nickel, and steel alloys. Alloy C17200 proved to provide the best thermal balance, given prototype dimensions. The SMT Contacts were plated with 90/10 tin-lead, 12.5 um thick. See Figure 1. A wire capture slot was designed to trap a #38 AWG (0.10 mm) polyurethane-nylon insulated copper magnet wire.

A 15-watt diode laser, with a fiber optic and lens system for energy delivery, was used to create an infrared spot of 0.50 mm in diameter. Experimenting with different energy levels produced optimum pulse energy of 11 watts at 0.2 seconds for this application.

Diode laser heating works by heating the wire and solder from the "Inside Out". The infrared laser beam spot is deliberately focused onto the upper portion of the SMT Contact, not the insulated wire. A portion of the laser energy is reflected onto the lower SMT contact surface. Focusing the laser beam directly on the embedded magnet wire causes the magnet wire to "bow out" of the wire capture slot during heating. Figure 4 shows the diode laser beam applied to the SMT contact.

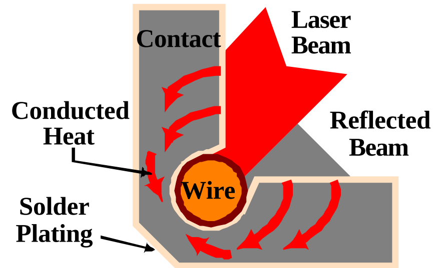

Figure 4 - Laser beam heating the SMT Contact.

Heat flows by conduction towards the insulated wire, melting the high temperature solder alloy. The melting solder burns off the wire insulation and pushes the residue away from the solder joint. In the case of polyimide insulation, the diode laser wavelength matches the absorption band of the polyimide and it is vaporized just prior to solder reflow. Figure 5 shows how heat is conducted into the wire capture area.

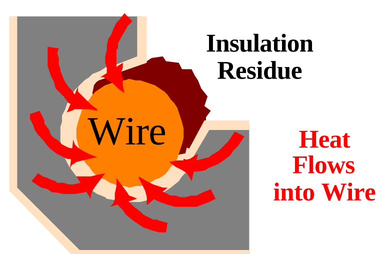

Figure 5 - Heat Conduction into the SMT Contact wire capture area.

The final solder joint covers the copper wire and secures it to the contact. The degree of coverage is determined by the plating thickness. After FlashSoldering, the solder joint is internally free of insulation particles.

Figure 6 shows a #38 AWG copper magnet wire in the wire capture slot surrounded by the 90/10 solder. Note the absence of solder voids or insulation trapped behind the copper magnet wire.

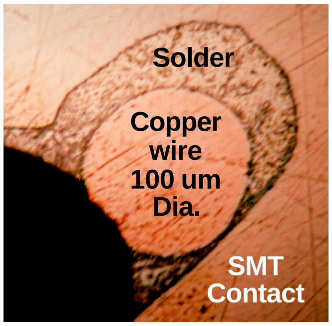

Figure 6 - Cross-section of FlashSoldered SMT Contact (200x).

Figure 7 shows another #38 AWG copper wire section as captured by a Scanning Electron Microscope (SEM) at 350x magnification. The very narrow copper-tin inter-metallic zone (fuzzy line) surrounding the copper wire indicates a good solder joint.

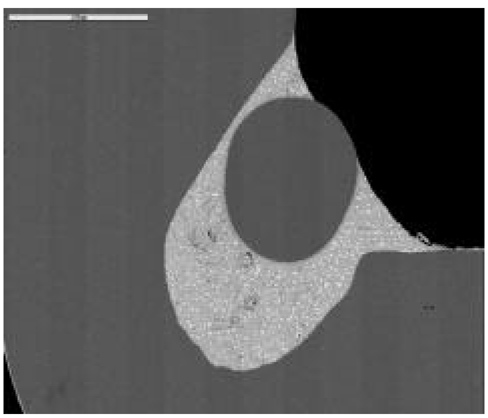

Figure 7 - Cross-section of FlashSoldered SMT Contact viewed with Scanning Electron Microscope.

B. FlashSoldering the SBL Terminal

The authors successfully used FlashSoldering to solder three to four turns of # 33 AWG (0.18 mm) diameter polyurethane-nylon insulated magnet wire onto on a 0.64 mm square SBL terminal. The SBL terminal used a single 63/37 tin-lead solder SBL clip to provide the necessary solder volume. See Figure 2

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The same 15-watt diode laser system was used to solder the magnet wire to the SBL terminal using 14 watts at 1.7 seconds. Optimized heating using a larger laser spot or several laser spots will reduce the heating time and also help prevent any solder voids from occurring. Figure 8 shows three turns of #33 AWG wire FlashSoldered to a single SBL terminal.

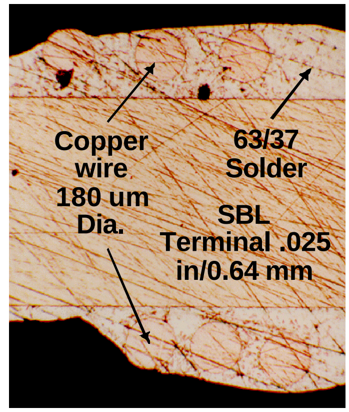


Figure 8 - Cross-section of three turns of #33 AWG magnet wire FlashSoldered to a 0.64 mm square SBL Terminal.

C. FlashSoldering the SBL Data Contact

FlashSoldering was also successfully used by the authors to solder multiple size polyurethane-nylon insulated magnet wires into a single 0.5 mm wide SBL data contact. The SBL data contact contained one 63/37 tin-lead solder "nugget". See Figure 3.

A 0.5 mm diameter diode laser beam was focused at 45° angle onto the wire in an area just in front of the wire retention clips.

14-watts at 0.5 seconds provided sufficient heat to remove the insulation and reflow the solder a single 28 AWG wire (0.32 mm) to the SBL Data Contact. See Figures 9 and 10. The SEM photo in Figure 10 clearly shows the very narrow copper-tin inter-metallic band surrounding the copper wire. The narrowness of the inter-metallic band indicates an excellent solder joint.

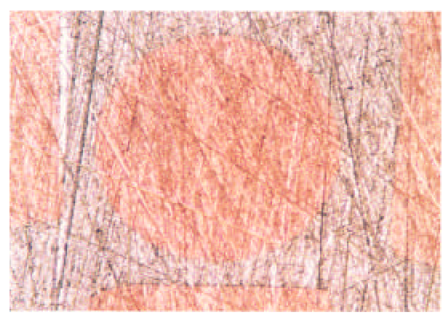


Figure 9 - Cross-section of SBL Data Contact containing a single #28 AWG magnet wire.

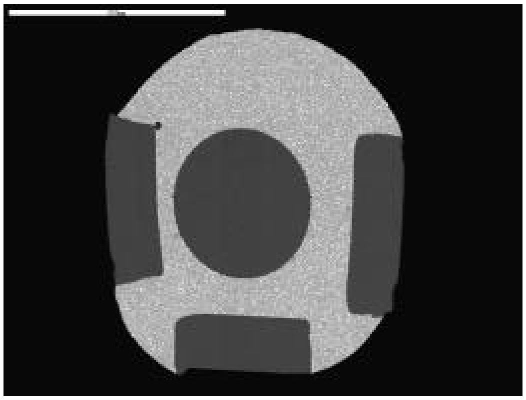


Figure 10 - Cross-section of same SBL Data Contact containing a single #28 AWG magnet wire, photographed with Scanning Electron Microscope.

D. FlashSoldering Litz Wire to the SBL Data Contact

Sandia National Laboratories in Albuquerque, New Mexico, USA, presented the authors with a very unusual magnet wire application involving “Skeined” wire.

To make Skeined Wire, Sandia’s magnetic engineers looped a single #44 AWG (50 um diameter) polyurethane-nylon insulated magnet wire back and forth over a short distance to build up 19 strands. The resulting wire bundle is similar to Litz wire, but its function is only to add mass to a single flying lead in order to make it more manageable in hand termination situations. In this case, the single #44 AWG wire needed to be soldered to a printed circuit board.

After placing the Skeined Wire in a SBL Data Contact, the authors successfully FlashSoldered it to the contact using a 0.5 mm diameter diode laser beam set to 13-watts for 0.75 seconds. Figures 11 and 12 show the FlashSoldered results at 30x and 200x magnification.

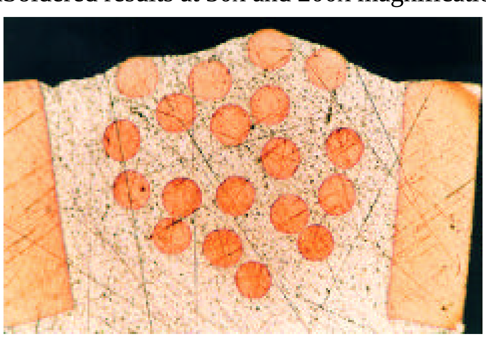


Figure 11 - 19 strands of #44 AWG (50 um) diameter Litz wire FlashSoldered to a single SBL Data Contact.

All 19 individual wires can be counted! Each wire is surrounded by a complete matrix of 63/37 tin-lead solder. There were no traces of carbon indicative of the polyurethane-nylon insulation in any part of the completed solder joint.

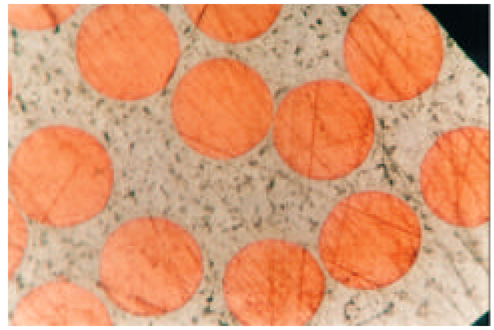


Figure 12 - 19 strands of #44 AWG (50 um/.002 inch) diameter copper Litz wire FlashSoldered to a single SBL Data Contact. 200x magnification.

E. Solder Quality and Insulation Residue Issues

Several SBL Data Contacts were FlashSoldered and submitted to Sandia National Laboratories for scanning electron microscope (SEM) analysis. Objectives included finding out if the magnet wire insulation residue was trapped in the final solder joint and to what extent the copper-tin intermetallics were present in the tin-lead matrix.

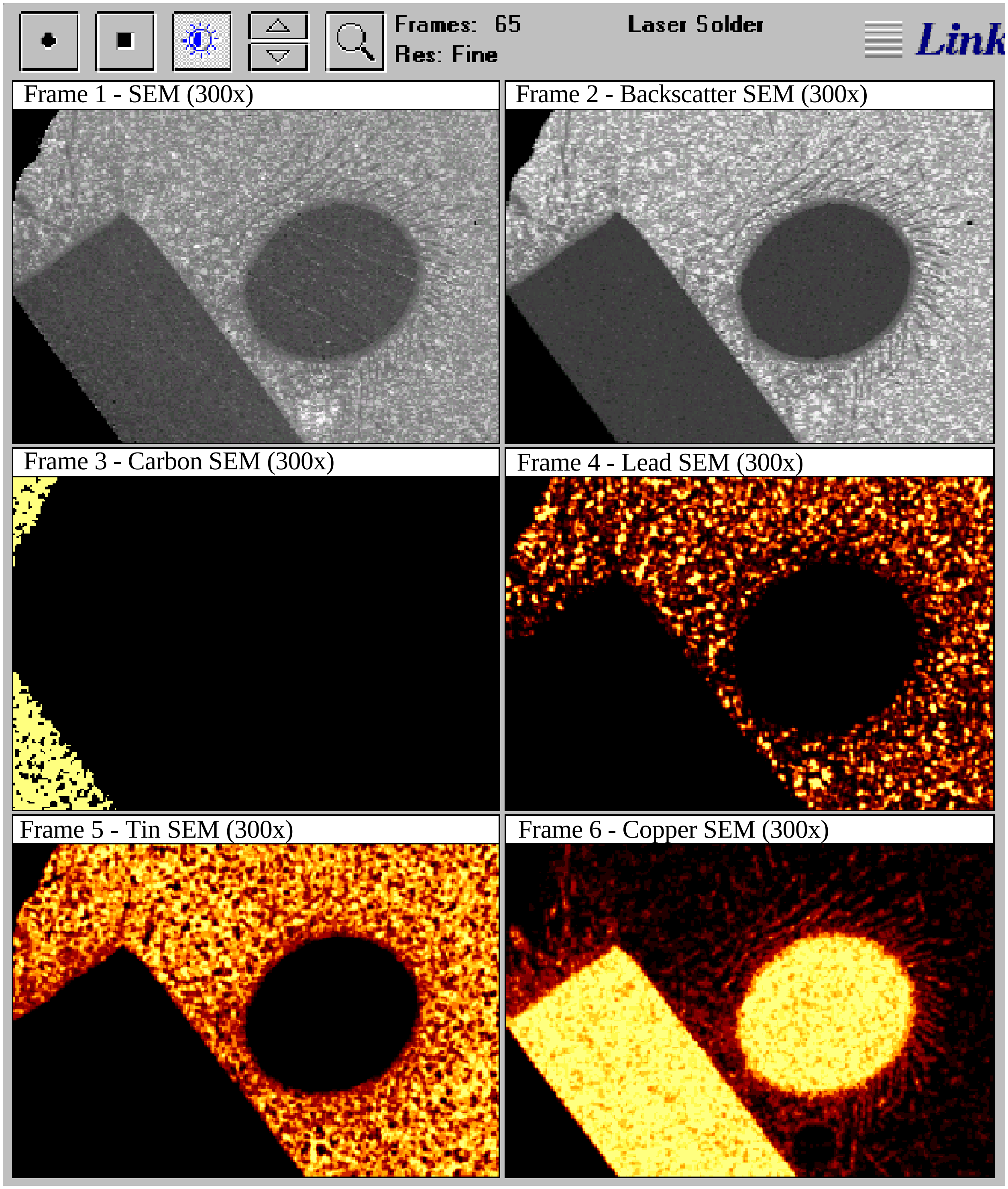
Setting the SEM energy to a specific level captures different elements such as carbon, copper, lead, and tin. A brighter image indicates a higher concentration of the specific element. In the scan for carbon, which represents the insulation residue, none was found in the solder matrix so the image core shows black.

The Cu_5Sn_6 intermetallic is a brittle compound that typically appears on the copper wire circumference as a “fuzzy” ring. The goal in creating a reliable solder joint is to minimize this alloy.

The SBL Data Contact shown on the following page was deliberately overheated during the FlashSoldering process. The dark lines radiating outward from the copper wire in Frame 2 indicate heavy copper migration. The bright lines radiating outward from the copper wire and beryllium-copper Data Contact also represent a high concentration of copper migration.

Proper heating levels are depicted in the SEM photos shown in Figures 7 and 10. No copper migration is present, only the thinnest trace of the Cu_5Sn_6 intermetallic can be seen surrounding the copper wire.

Scanning Electron Microscope Photos of a single
FlashSoldered SBL Data Contact.



IV. Conclusions

FlashSoldering offers the magnetic and electronic components industry a new non-contact reflow soldering process for producing and assembling a variety of miniature insulated magnet wire based electronic components and interconnection systems without damaging the fine magnet wire.

As indicated by scanning electron microscope analysis, the insulation residue does not end up in the solder matrix and the undesirable Cu_5Sn_6 intermetallics are kept to a very minimum thickness, thus ensuring a reliable, long lasting solder joint.

FlashSoldering can reduce labor and handling costs, prevent solder shorts, and eliminate copper wire "neck down", and simultaneously remove fine magnet wire insulation while reflow soldering the wire to an electronic contact.

V. Acknowledgements

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