How Induction Soldering Improves the Process and Quality of Coax and Interconnect Assembly

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Abstract — Induction heating technology has advanced, permitting a multitude of benefits over traditional soldering techniques. Inducing heat in the work-piece directly allows for higher energy densities; decreasing cycle times while solving problems such as line-of-sight restrictions. More tightly focused and more rapidly generated heat produces higher quality solder joints with finer grains and thinner interfacial layers while mitigating thermal damage to adjacent components. Ideal reflow frequencies for interconnection manufacture lie in the RF range below 500 kHz due an ideal blend of surface penetration, electrodynamic involvement, energy density, and ponderomotive solder mixing. Induction's higher level of control, repeatability and precision serve to increase yields and part surface quality while higher reliability, efficiency, and ease of automation decrease production and maintenance costs.

Index Terms — Electromagnetic coupling, electromagnetic forces, electromagnetic induction, process control, radiowave propagation, RF signals, soldering.

I. Introduction

An abundance of traditional soldering methods are used across the globe to accomplish the task of interconnection cable manufacture. The most common methods include: conductive soldering (such as a solder iron or a flame/ furnace), convective soldering, and infrared soldering. Conductive and convective soldering require both a thermal transfer medium; a solid or gas respectively, and time for thermal energy to transfer from that heated medium into the work-piece. Infrared radiation can bypass the need for a thermal medium at the expense of a larger, less focused heating area. There are novel soldering methods available such as laser reflow or ultrasonic soldering that can circumvent some of these shortcomings but with shortcomings of their own such as high costs, inability to heat larger areas, or the incapacity to access the targeted heating area due to line-of-sight restrictions.

II. Induction Overview

Unlike the aforementioned soldering techniques requiring thermal energy transfer, inductive solder reflow utilizes electromagnetic fields to transfer energy directly to the work-piece and solder itself. The work-piece essentially becomes the heating element. This is accomplished by passing an alternating current through precisely engineered coil architectures. As current flows through the coil it creates an energy dense alternating magnetic field that is tightly focused and steered into the work-piece through the implementation of magnetic flux concentrators. Assuming the work-piece is electrically conductive these dense magnetic fluxes induce eddy currents that flow within the material in direct opposition to the magnetic field. The material's internal resistance to the flow of these currents along with the reversing of magnetic dipole orientations in ferromagnetic materials rapidly produces heat through ohmic loss.

III. Cycle Time and Yield Improvement

The generation of heat directly in the work-piece as opposed to that of an intermediate transfer media allows for quicker response times with induction soldering. This is due to several factors, the first of which being that the energy density achieved with induction is remarkably high: 10^4 W/cm^2 [1]. This value is far greater than that of convection: 0.5 W/cm^2, radiation (electric muffle furnace): 8 W/cm^2, or flame/ soldering iron: 10^3 W/cm^2 [1]. The efficiency of conductive heating elements is further hindered by the addition of the dielectric required to isolate the 'live' electrical heating element [2] thus requiring inefficient superheating of the resistive element to overcome the inherent thermally resistive properties of electrical insulators.

The second reason induction can improve soldering process time is due to its high level of repeatability allowing for more aggressive cycle times. Precise control of process parameters such as frequency, duty cycle, power level, and coil design permit more consistent results. Such control coupled with induction's non-contact energy transfer methodology means that quickly and consistently reaching the soldering temperature is more safely achieved. The risk of thermal damage due to temperature gradients that inherently occur from conductive overheating as a result of inconsistent contact conditions such as contact pressure, surface porosity, surface cleanliness, or contact area are negated with induction. Quicker response times also means there is less time for radiation and convective surface losses to occur [3]. It follows that any decrease in both soldering time and thermal damage leads to an increase in both production rates and yield.

IV. Process Flexibility and Capability

Precisely generating dense magnetic flux lines affords the ability to heat the targeted area very specifically with induction. Furthermore, if an application requires a temperature gradient it can be realized with the correct coil architecture. As mentioned, coil design and flux concentrator use can steer magnetic flux lines precisely where they are needed, yet turns ratios and gap sizes can add or subtract flux density where required. Additionally, the depth of heat penetration or the size of the localized area can be chosen specifically as a result of the skin depth for a given frequency, with higher frequencies allowing for more focused heat [4]. For interconnection manufacture and most inductive applications radio frequencies below 500 kHz are typically chosen as the best frequencies due to their ideal blend of skin effect surface penetration, good electrodynamic involvement, high energy density, and low dependence on electrophysical materials characteristics [5].

The non-contact nature of induction also serves well the goal of process improvement. Parts movement does not occur as a result of a forced convective system or indexing heating element. Coil gaps can allow for easy integration of pick and place systems as the inductive coil itself does not need to make physical contact. A contact-free methodology also serves to allow soldering of components that cannot be otherwise reached, such as the array of solder balls between a printed circuit board and a board component [6]. The nature of induction is also such that it can be used in any environment including inert gas or vacuum [5]. In some applications alloys can even be chosen purposefully such that inductive temperature self-regulation occurs when the Curie temperature of the work-piece material is chosen just above that of the melting temperature of the solder [7].

V. Superior Solder Joint Quality

The ability to quickly heat a localized and targeted area in an inductive application not only means the parts are subjected to heat for a smaller amount of time, it also means that adjacent materials are not unnecessary targets of excess heat. Plastic casings, printed circuit boards, or integrated circuit caps for example can all suffer from distortion, surface corrosion, oxidation, and hence potential failure as a result of stray heat from convective, conductive, and radiant environments [4]. Damage from excess heat is further aggravated by the fact that more and more cable assemblies are requiring lead-free solder alloys, sometimes even by law. Lead-free soldering has become so widespread that average soldering temperatures have increased by 40°C meaning reflow temperatures now approach the maximum temperature allowed by many of the soldered components themselves [8].

Perhaps the greatest advantage of soldering inductively however is for the increase in the quality of the solder joint itself. Because only the targeted area is heated cleaner joints with less spatter are produced [9]. Spattering is further mitigated by the involvement of ponderomotive forces, the effects of which also serve to aid in the mixing of solder alloys and the spreading of solder over soldering surfaces [8]. The ability to more quickly heat the work-piece to the solder reflow temperature along with the ability to localize the heat to a smaller area both compound such that the surrounding metal and other structures stay much cooler. These structures in turn act as heat sinks immediately following completion of the solder joint such that the solder cooling rate is greatly increased improving both solder grain refinement and the solder’s mechanical properties [10]. Since cooling rates are lower with induction than that of both convective reflow and infrared reflow both finer grains and a thinner interfacial layer are produced [6].

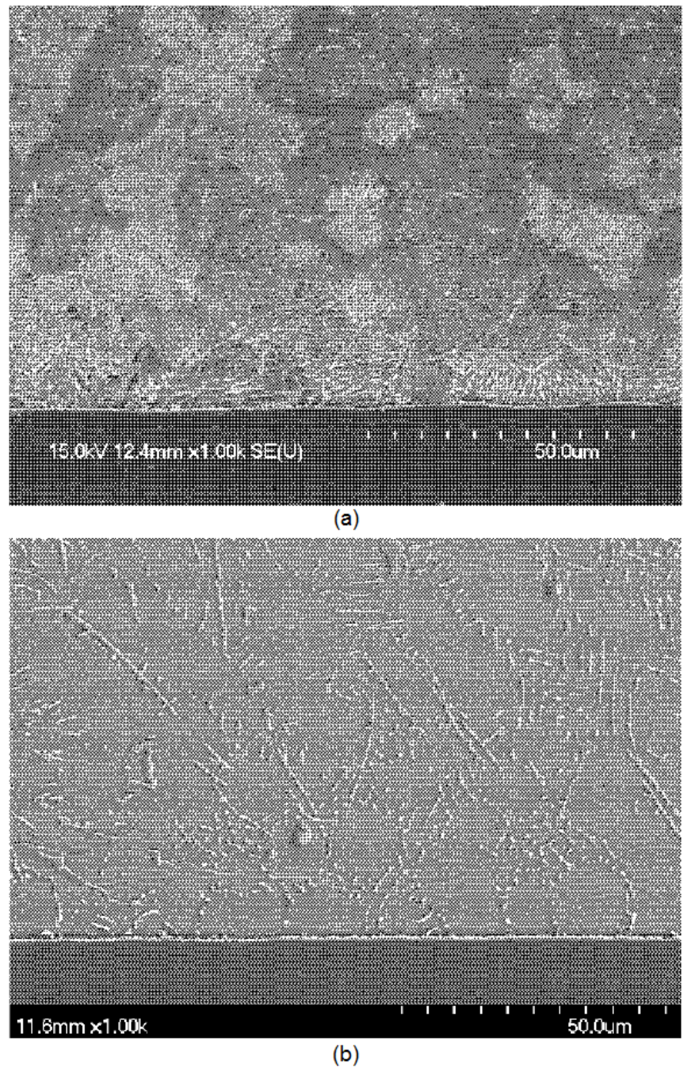

Fig 1. Comparison of interfacial morphologies for lead-free solder between (a) conventional thermal reflow and (b) electromagnetic inductive reflow [6].

VI. Cost Improvement

Minimizing the amount of energy needed for solder reflow and hence the operating cost is aided by targeting only the active soldering area in an application. Furthermore, induction systems are consistent, reliable, and easily automated all of which help to reduce labor rates. Equipment lifespan also plays a role in the costs of maintenance. Inductive coils more readily maintain mechanical integrity as they are not required to, and typically not permitted to reach high temperatures. Resistive heating equipment on the other hand generates heat from the passage of current through thin resistive elements that are subjected to continual expansion and contraction. This constant deformation leads to the development of micro-cracks at the surface that penetrate deeper with time allowing for oxidization and ultimately failure [2]. Startup times for induction equipment are nearly instantaneous as they are not required to reach an operating temperature. This means that induction equipment on production lines are more readily powered down and back up to save energy costs, a stark contrast when compared to thermal systems such as furnaces or solder pots.

VII. Conclusion

While convective, conductive, and infrared heating technology has largely stagnated for decades, induction heating technology has been rapidly advancing. Developments such as solid-state power supplies, Harmonic Inductive Gain (HIG™) technology, load monitoring, and flux concentrator utilization have all allowed for greater and more precise power delivery with induction than ever before. Today's advanced systems are efficient enough to permit air-cooling for both the power supply and the coil thus decreasing capital and maintenance costs, yet they still offer the robustness and reliability expected from modern solid-state technology. The benefits associated with soldering quality and process flexibility, reliability, and capability are numerous. If induction was once deemed unsuitable or incompatible for your application it is likely worthwhile to give the present market a second look.

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