Effectiveness of Different Materials as Heat Shields during Reflow/Rework

Abstract:

As device density continues to maximize the PCB real estate the threat of reflowing neighboring components or damaging heat-sensitive components continues to cause problems. Devices either have to be removed, thereby reducing rework throughout or devices get damaged during the reflow process. The solutions offered today either cannot be delivered in a timely fashion or offer very limited protection to these heat sensitive devices. A new, flexible heat shielding solution is now available that can be easily modified by the users and is inexpensive enough to have on hand. Most importantly it is an effective way to reduce the temperature on nearby components during the reflow/rework process so that neighboring devices do not go into reflow. This discussion documents and the temperatures experienced by the shielding material.

Overview:

There are a variety of temperature sensitive components that may be damaged during the rework process in many cases this not only sends the device to be reworked in to reflow but either softens up or reflows components in the vicinity . These include but are certainly not limited to aluminum and tantalum ceramic capacitors, crystals, oscillators, plastic-bodied components such as connectors that restrict the peak reflow temperatures as well as the time above liquidus. These components' long term reliability may be impacted by this exposure to heat even though they may not be immediately damaged. While these components may be able to withstand the peak temperature of 260°C as defined in J-STD-002, there may be medium and longer term impacts to their reliability.

This work examines the current state of shielding options that rework technicians have in protecting neighboring devices. This is followed by a study which compared and contrasted a few approaches to solving this dilemma.

The increased liquidus temperature of lead free solder systems has driven processing temperatures into areas where sensitive components have significant body temperature and time limitations. In many cases, the protocol for the placement of thermocouples does not necessarily call for measuring the temperature on these heat sensitive components.

IPC J-STD-075 is the standard for maximum time/temperature exposure for all non-semiconductor devices. Developed jointly by IPC, JEDEC, and ECA, J-STD-075, "Classification of Non-IC Electronic Components for Assembly Processes" expands on existing standards to provide test methods and classification levels to identify worst-case thermal process limitations for all electronic components that may be processed as part of circuit card assembly.

Historically, non-semiconductor components have been able to meet the reflow requirements of the board assembly temperature conditions. For lead-free reflow, wave soldering components are qualified for 275°C for 10 seconds per the IPC-9504 "Assembly Process Simulation for the

Evaluation of non IC components, though actual wave soldering temperatures can be below 265°C. Similarly, for SMT reflow soldering, components are qualified for 260°C for 40 seconds though component body temperatures can reach 260C during reflow. Little work has been done in the reliability of passive components while most work has been concentrated on the active components.

Solutions

The property of a material that will "shield" something from thermal energy is known as radiant heat; it is the major source of heat transfer, energy in the form of infrared waves. It travels at the speed of light, even through a vacuum, and is either transmitted through, absorbed into, or reflected by any material it comes in contact with. Air, water, and glass, for example, transmit visible light in varying degrees. A white surface, such as snow, reflects it while a black surface absorbs it. Low thermal conductivity as well as thermal shock resistant. Convection is another process by which heat can be transferred from the outside environment to a PCB. Thermal conductivity heat transfer occurs at a higher rate across materials of high thermal conductivity than across materials of low thermal conductivity. Correspondingly, materials of high thermal conductivity are widely used in heat sink applications and materials of low thermal conductivity are used as thermal insulation. Thermal conductivity of materials is temperature dependent.

Watt/m K @ 330C

Air	Kapton Type MT	304 stainless	Copper	Ceramic Fiber	Cold Shield
0.03	0.37	≈18	379	0.14	Unknown

Not only can heat be transmitted through space to components in the surrounding area, absorbing the radiant energy, but the PCB itself, either through the directed rework heat or through the bottom side heating process can radiate heat throughout the board otherwise known as "conduction". The greater the surface area of the copper, the greater the ability to conduct heat through the conduction mechanism. There is no effective manner to stop this phenomenon; it is a function of the material properties of the PCB and its associated layout and geometries.

Stainless sheet metal shields are designed to shield a component from absorbing excessive heat either by dissipating, reflecting or simply absorbing the heat. The installation of a heat shield is one of the most widely used heat management option due to its cost-effectiveness and ease to fit. The physical properties of Stainless Steel's reflectivity and emissivity, thermal conductivity and specific heat capacity make it the ideal material for the fabrication of heat shields. The high reflectivity and low emissivity of the Stainless surface ensure that it both absorbs and reemits little infrared radiation. The relatively low conductivity of stainless steel 304 makes it easily able to resist changes in temperature.

Copper tape allows a copper shield to be flexible and easily applied to a PCB. The adhesive side allows it to adhere to a board surface and stay tacked down. The tape is relatively inexpensive and is a reasonable, although not ideal, choice for a heat shield. If used for too long, the shield may become unusable, but this is not much of a problem as it can be bought in large reels and is commonly available.

Kapton™ tape is the most commonly used (and misused) methodology for masking areas on a PCB. The historical usage of Kapton™ tape in the wave soldering and conformal coatings areas has made its way to the PCB rework area. The ability of Kapton™ to maintain excellent physical, electrical, and mechanical properties over a wide temperature range has opened new design and application areas. The ability to flexibly apply this tape by easily cutting it to size, it being able to be configured easily in and around parts as well as the ability to being "stuck" to various areas a PCB makes it a favorite with PCB rework and repair technicians. Finally, its thin structure allows it to be easily fit in between different areas a PCB. While it does work well to hold a thermocouple to the board, it is a poor thermal insulator.

HeatShieldGel™ is a product which has been used in welding applications (particularly the automotive industry) due to its extreme resistance to heat. The gel contains mainly deionized water and clay. It is non-toxic and is not classified as dangerous even when ingested, although its effectiveness on printed circuit boards is mostly unknown. The product is easily applied and, due to its consistency, able to work its way into small spaces. After heat is applied, the water in the product begins to evaporate until a layer of gray clay is deposited on the circuit board. This clay is not as effective of a shield as the wet product and should be reapplied once the water "burns off." The level of heat resistance in this product is very high.

Ceramic

Ceramic non-woven shields. These specialty ceramic fiber non-woven shields, previously relegated to aerospace, nuclear energy and high temperature processing industrial environments can now offer users these same characteristics offer users low thermal conductivity and low bio-persistence, meaning that if the fibers are inhaled, they're eliminated from the body within days. This material can be used at 1,100°C continuously with excursions to 1650°C. This ceramic fiber material offers several advantages including the properties of high-temperature stability, low thermal conductivity, high heat reflectance and the ability to be easily wrapped, cut to shape. Since these materials are compressible, they can be easily fit in between components making it an ideal material for shielding. Combined with metal shields for adding structure this material is highly effective at shielding nearby components from higher temperature rework/reflow.

The Method

In order to determine the shielding effectiveness of various materials, a controlled heat source, simulating a rework process, was placed onto a reference site of an Intel type D815EEA 4-10 layered printed circuit board <Figure #3>. The board utilized tin/lead solder, with a HASL finish. A heating area was established that contained no ground planes. A reference site component, BGA U3, was then established. Various heat-sensitive components on the board were then identified, and the distance from the reference site was measured with a pair of calipers. Since the idea of a good thermal shield is to keep the temperatures below a point in which a component can be damaged or prevent underfill and glue from softening, a temperature well above the reflow point of solder, 350°C was established with a duration of 2 minutes for the trials.

Four Omega type K thermocouples were attached to heat-sensitive components and the underside of the reference IC site using Kapton™ tape and Loctite HYS D051 epoxy. The epoxy was cured in a Blue M reference number 10462 oven at 86°C for 45 minutes. The Kapton™ tape was removed afterwards. The thermocouples were connected to a MOLE scan thermal profile scanning system, part number: E42-6672-40. This was then connected via serial port to a Dell computer running windows XP. The software used was M.O.L.E.scan® V5.20a.

Five different materials <Figure #2> were chosen to test their shielding effectiveness. The first, stainless steel 304 squares, were of sizes 38x38mm Kapton coated and 26x26mm bare. The second, product number 1650 Venture Tape, was a copper based shielding tape. Next, a ceramic fiber heat shield was used. Kapton™ tape was used to hold one 38x38mm piece and one 38x76 piece in place. Kapton™ tape of one inch in width was then used by itself as a shield, and a control condition with no shielding followed. Each material including the control no shield test was heated five times for a total of twenty five heating cycles. A screenshot of sample data <Figure #1> and a picture of the materials are given below; figures A-F contain results.

Sample Program Data

Figure #1 – Time vs. temperature at various points on test board, Ceramic shield

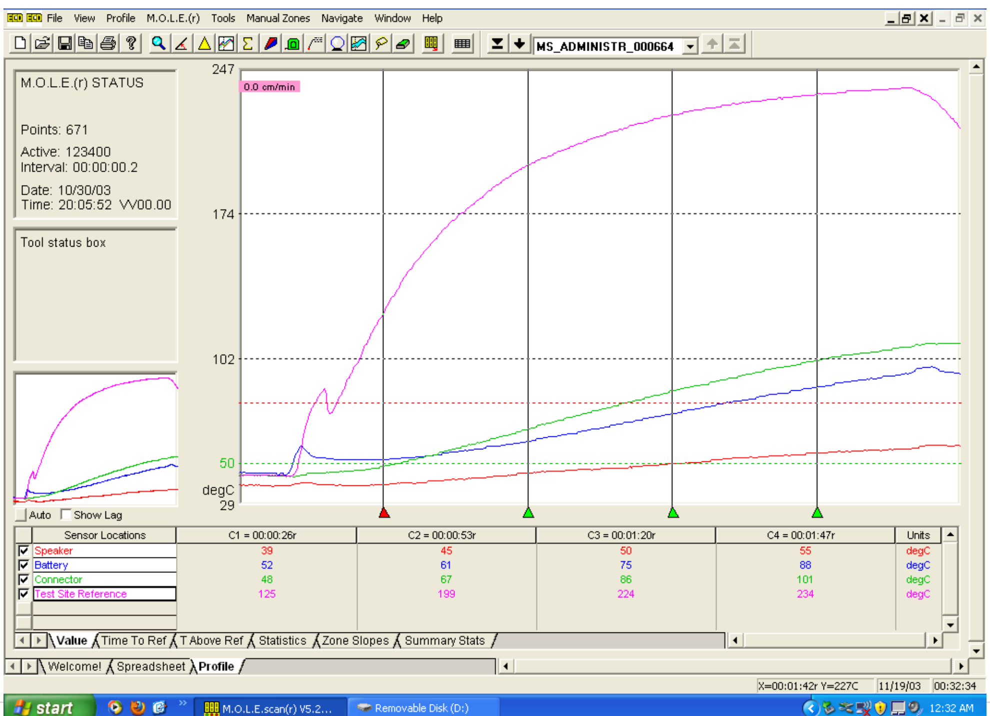


Figure #2 – Shield materials used in study

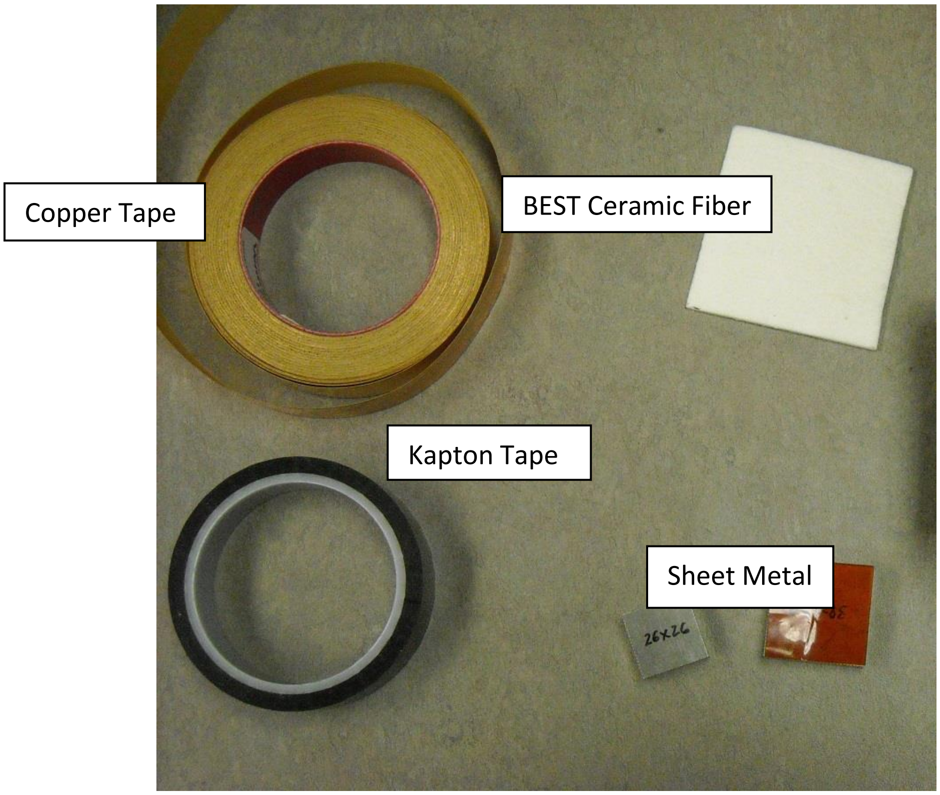


Figure #3 - The board was first placed on a board holder as part of the Metcal QX-2 hot air system used for the trials. Kapton^{TM} tape was used to hold four thermocouples in place until epoxy was added.

Figure #4 - The wires were coated with a thin layer of epoxy and allowed to cure in an oven to speed the drying process. The wires were placed on a speaker, connector, battery, and IC reference site

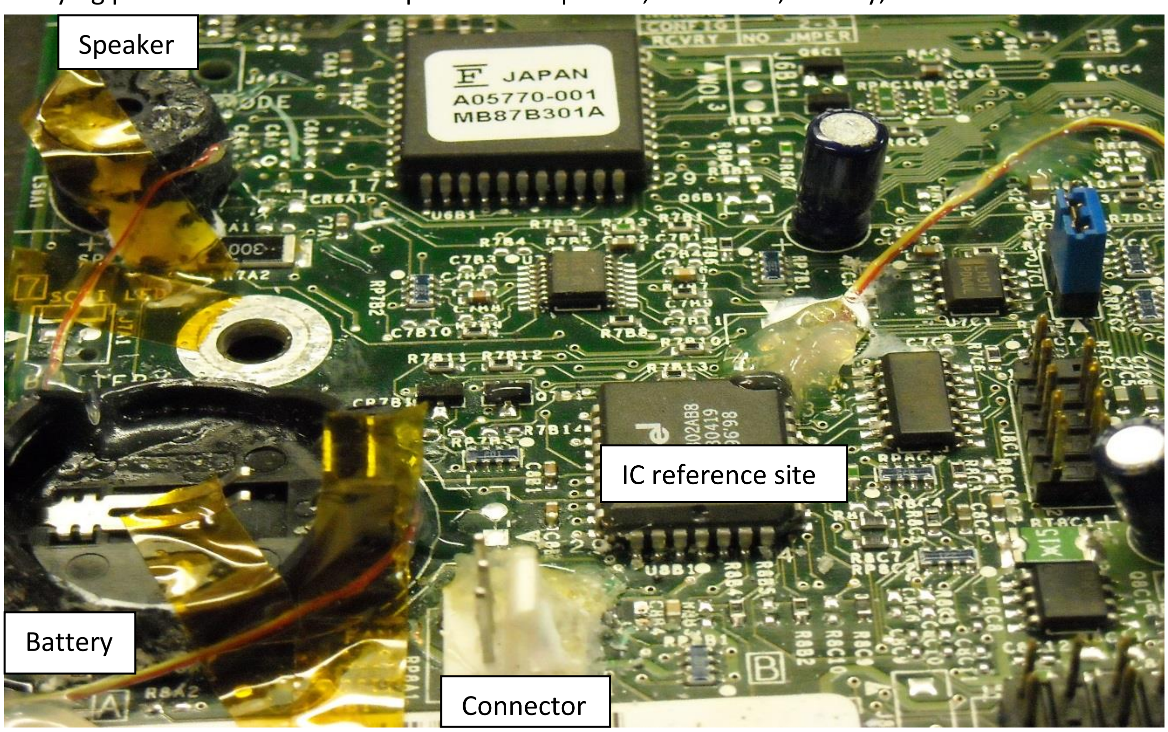


Figure #5 - Ceramic fiber heat shield was then taped using Kapton™ tape to the board in order to protect the connector, battery, and speaker. Note the IC is left unprotected for a reference site temperature reading

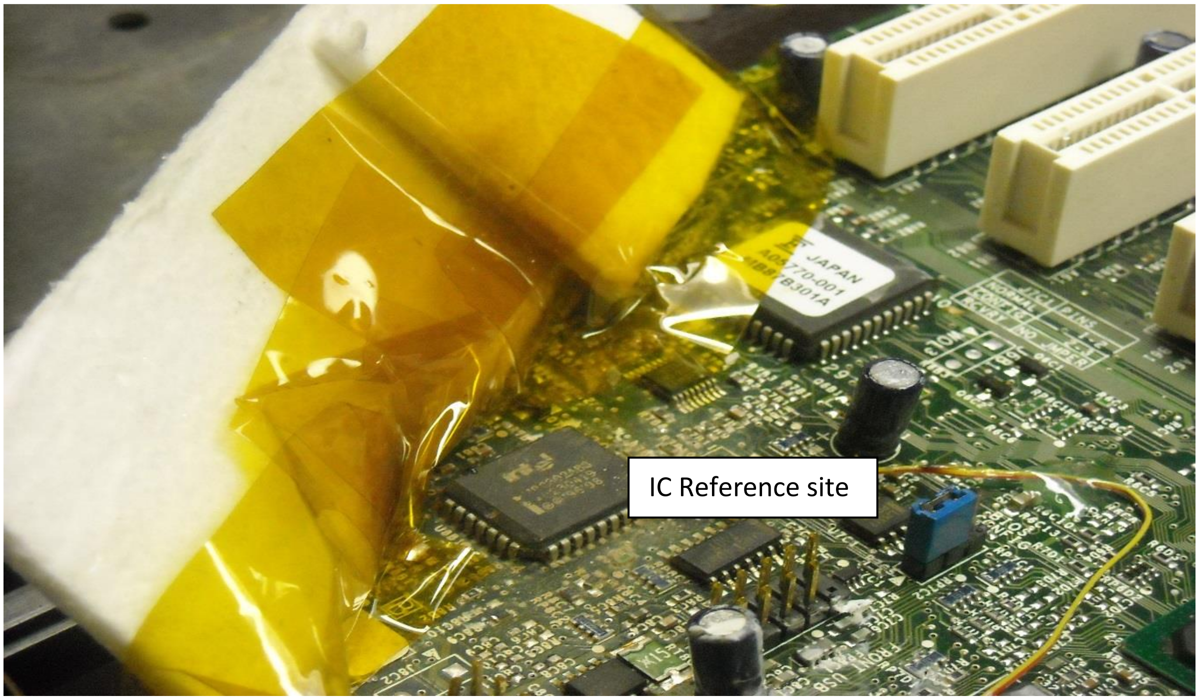


Figure #6 - The heating element was preheated then turned on 350° C for 2 minutes. This provided a high enough temperature to stimulate a lead free reflow process. Heat measurements from the four components in five trials were gathered for each shielding material.

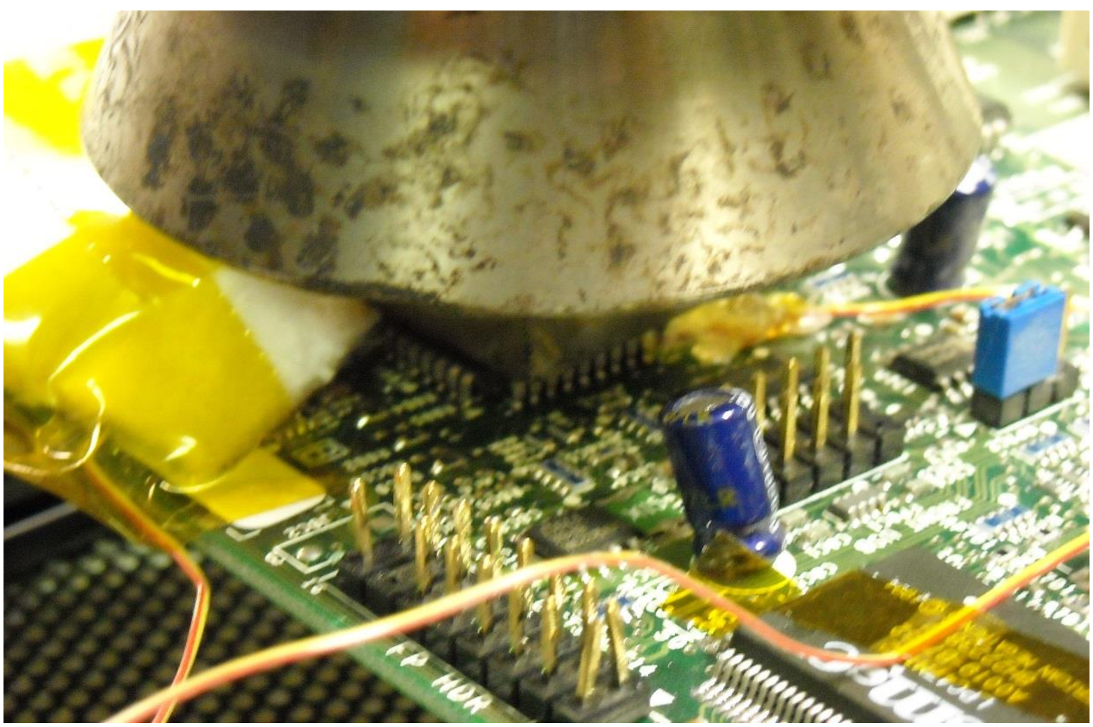


Figure #7 - Copper tape was then applied. The epoxy holding the thermocouple became brown and eventually black with repeated heating

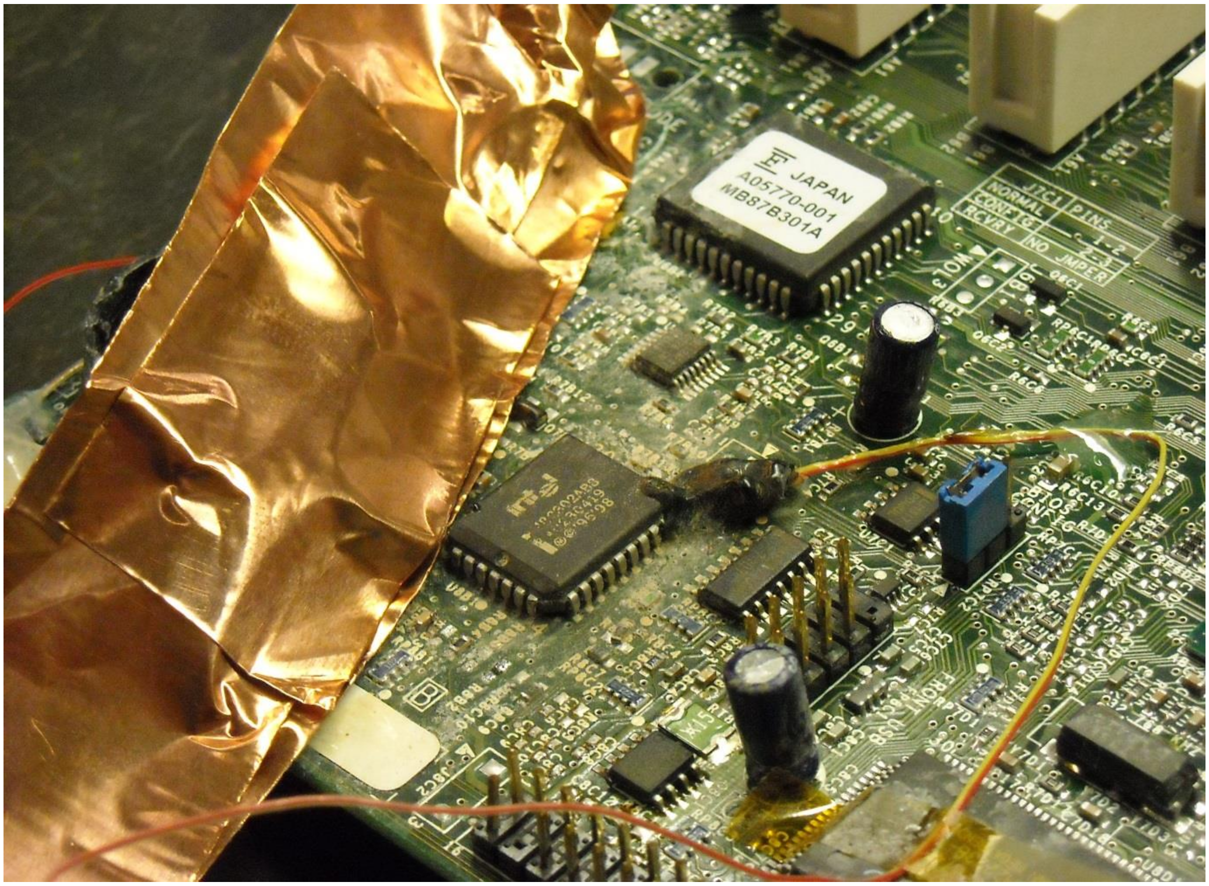


Figure #8 - After repeated heating, the copper also became discolored. This did not affect performance

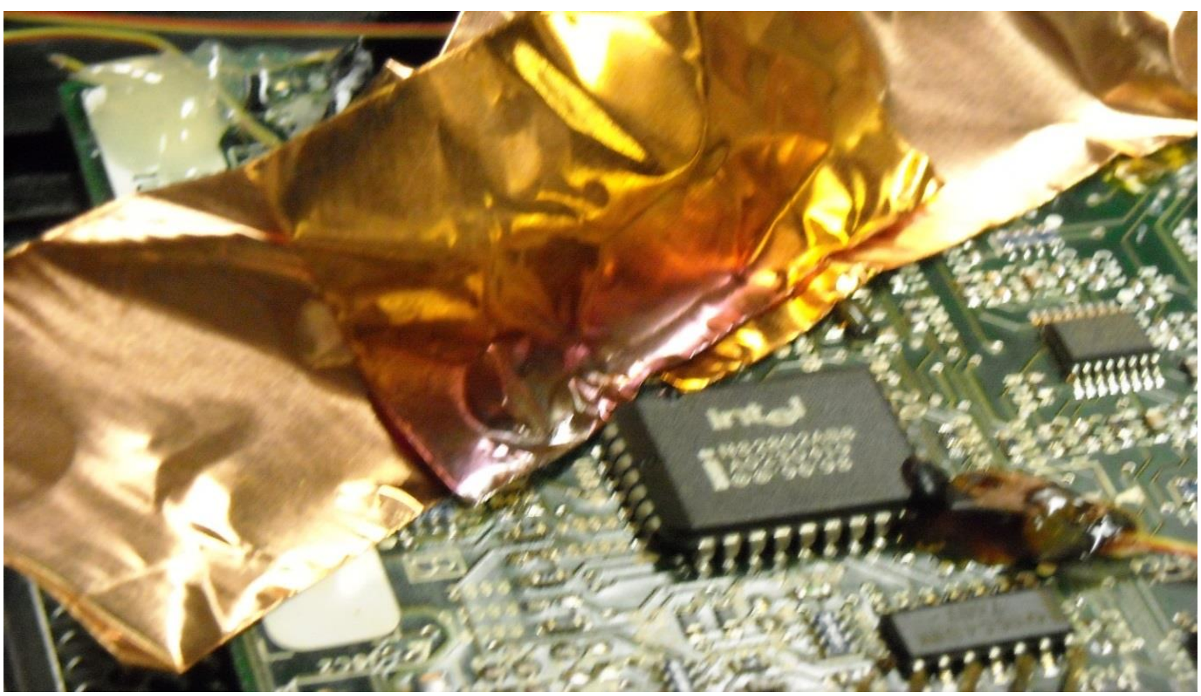


Figure #9 – Kapton™ tape was applied liberally and used as shielding material on its own

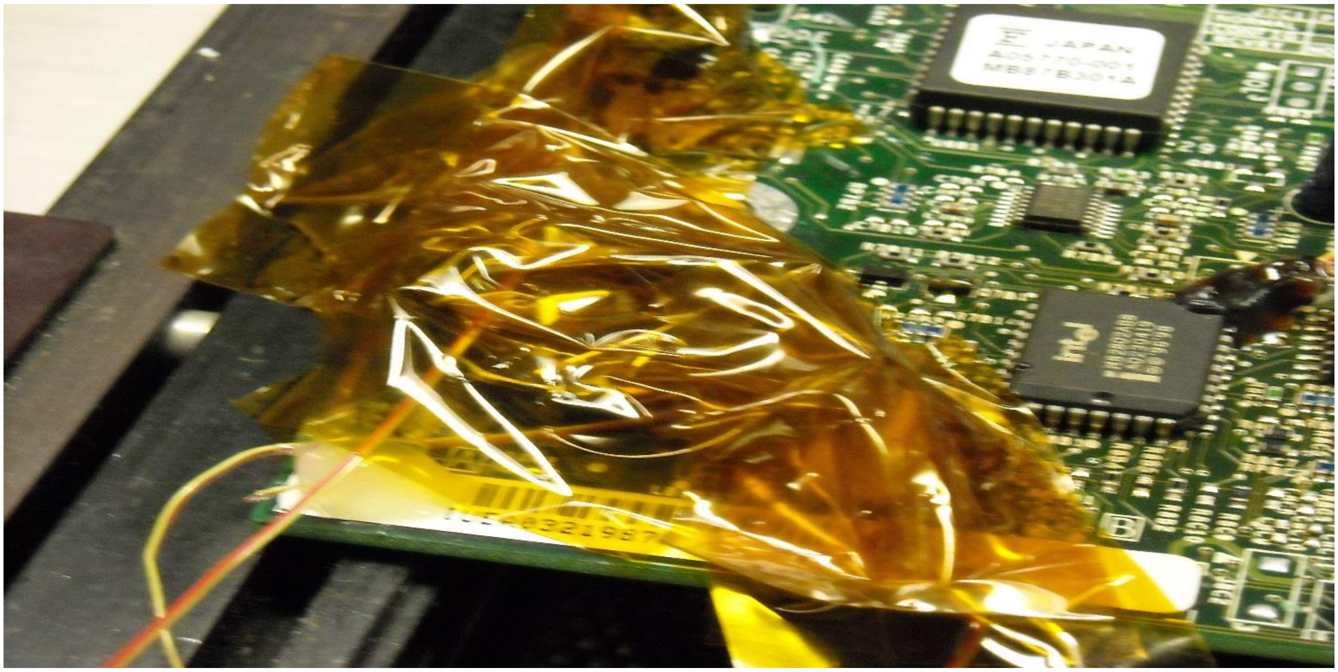


Figure #10 - Stainless steel sheet metal pieces, one coated in Kapton and one left bare, were used to shield components. The boundaries between the sheet and board allowed air to flow underneath easily.

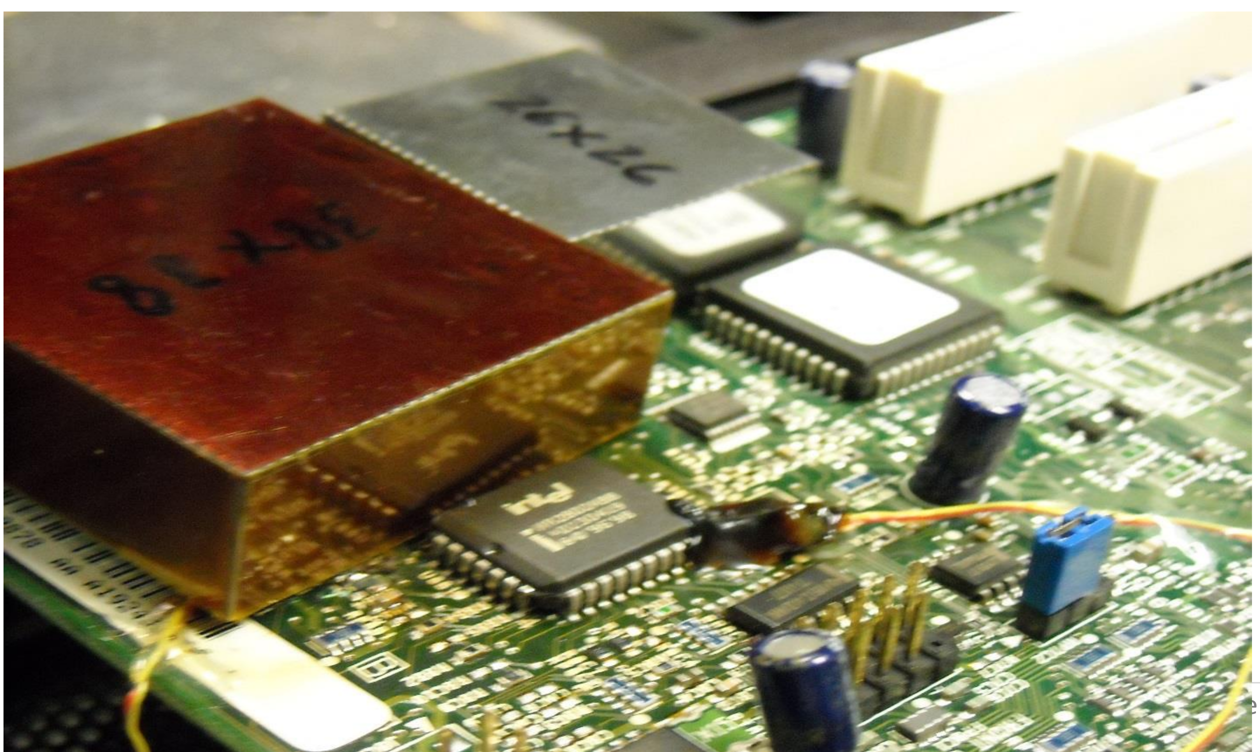


Figure #10 - A gel heat shield called HeatShieldGel™ performed best and was easiest to work into the board spaces

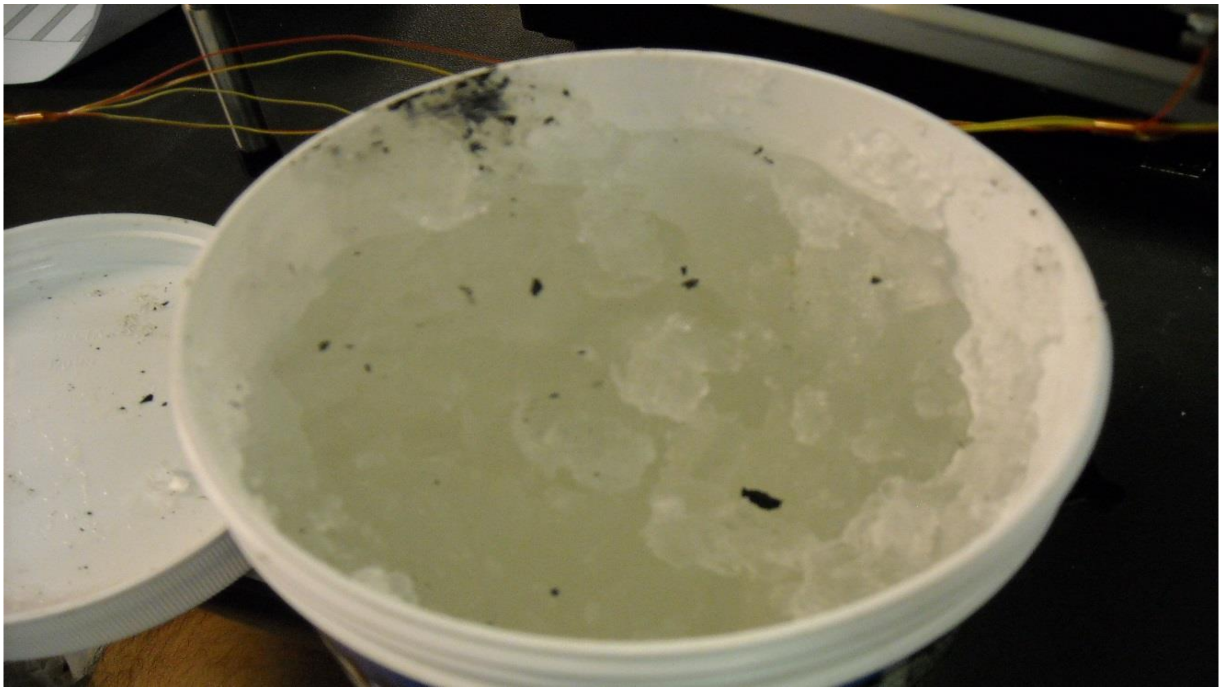


Figure #11 - View of HeatShieldGel™ applied to the board. It easily conforms to openings and gaps between components.

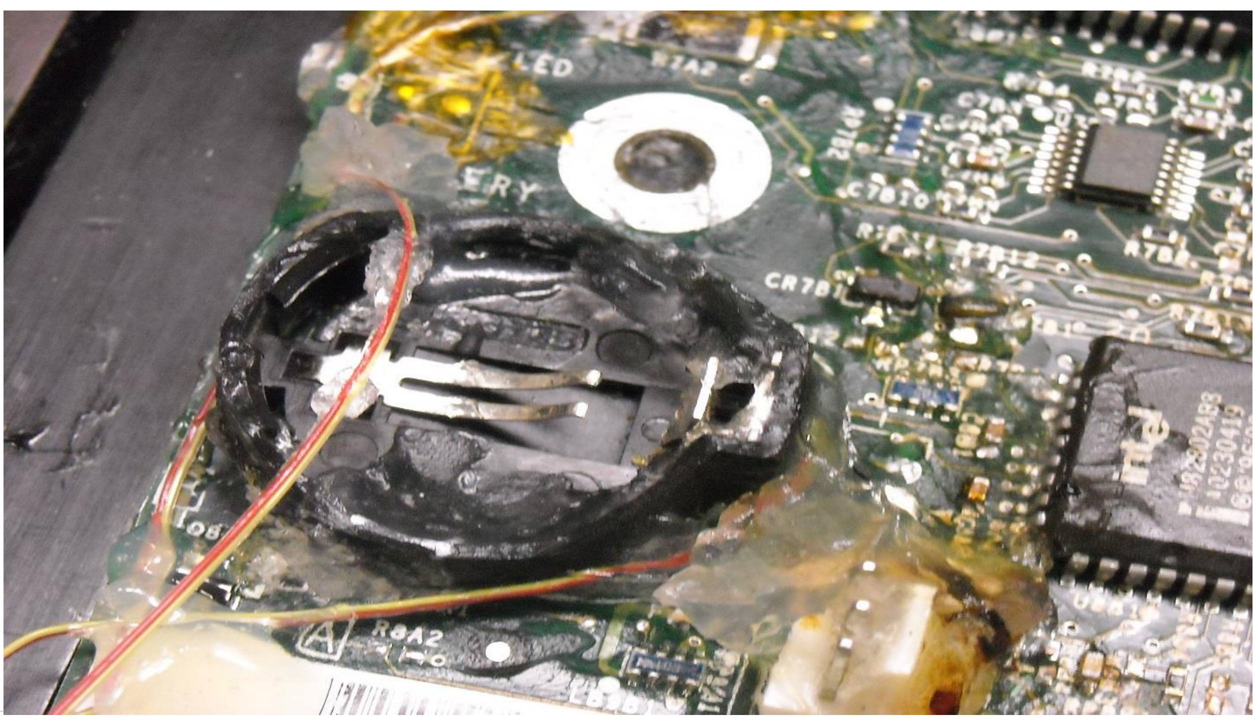


Figure #12 - After heating, this gel shield left a whitish, gray residue on the board. This was easily cleaned with alcohol and a brush, but ionic contamination and residual analysis is required prior to adoption to the electronics rework area

Results: The results below are the trials with the closest reference Test Site IC temperatures for an accurate comparison.

The distance from the IC reference temperature of each component is given below, in mm.

Speaker: 30.95mm

Battery: 9.73mm

Connector: 6.14mm

(Figure A) No Shield Control

Test Site	Speaker	Battery	Connector	Test Site IC
Max Temperature	123° C	227° C	173° C	232° C

(Figure B) Copper Tape

Test Site	Speaker	Battery	Connector	Test Site IC
Max Temperature	106° C	129° C	128° C	232° C

(Figure C) Sheet Metal

Test Site	Speaker	Battery	Connector	Test Site IC
Max Temperature	61° C	158° C	143° C	239° C

(Figure D) HeatShieldGel™

Test Site	Speaker	Battery	Connector	IC Test Site
Max Temperature	66° C	89° C	86° C	231° C

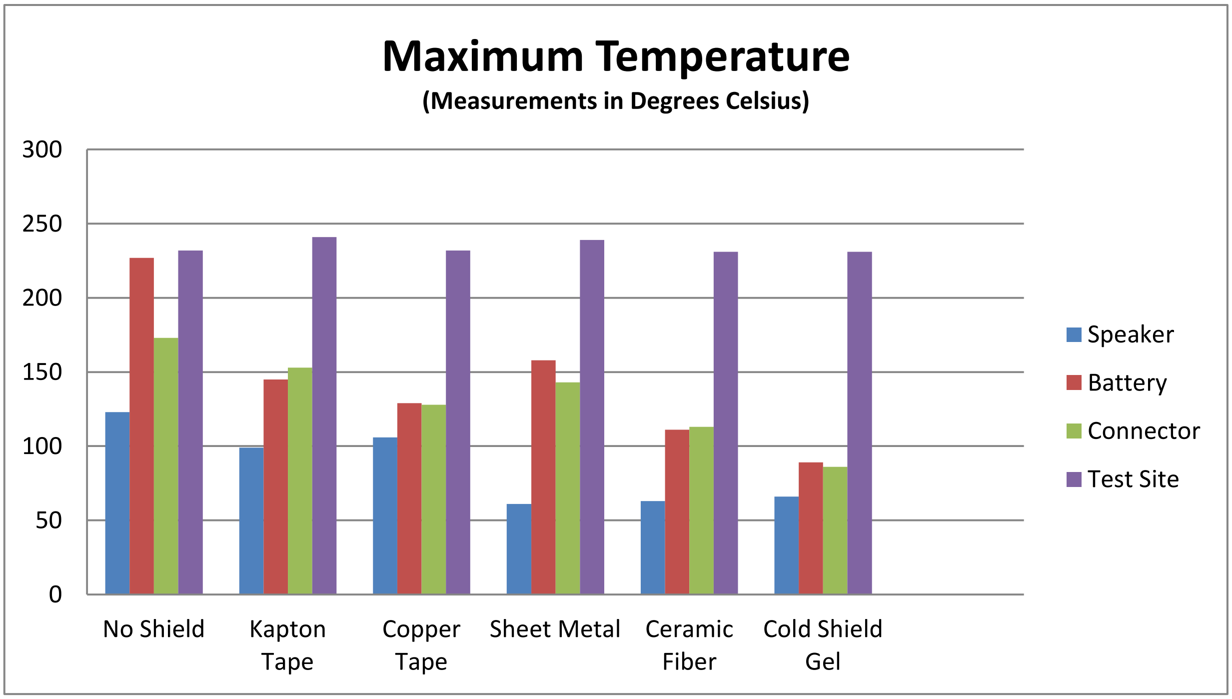
(Figure E)Kapton Tape

Test Site	Speaker	Battery	Connector	IC Test Site
Max Temperature	99° C	145° C	153° C	241° C

(Figure F) Ceramic Fiber

Test Site	Speaker	Battery	Connector	IC Test Site
Max Temperature	63° C	111° C	113° C	231° C

Graph (Figure G): Maximum Temperature for various shielding materials at select locations on a PCB



Result Anomalies: The sheet metal shields performed better than Kapton tape at the speaker and connector locations yet performed poorly at the battery site. This could be due to air being forced underneath the gap between the bottom of the metal and the circuit board surface. To combat this problem, Kapton™ tape could be used to seal this. The HeatShieldGel™ produced a gray residue on the surface of the PCB, possible due to the chemical makeup of the gel (clay and water).

Conclusion:

Through the repeated measurement of outlying component temperatures during the reflow process, the product HeatShieldGel™ was determined to be the best performing heat shield material. More testing, however, is needed to prove its effectiveness in the electronics industry as it is currently unknown if the residue left from the application and subsequent cleaning affects performance. The closest performing material to HeatShieldGel™ was the ceramic fiber pads. These have been used in the electronics industry for years and are known to be safe. The next closest performing materials in order were the copper tape, sheet metal, and kapton tape. The copper tape performed well and was able to adhere easily to surfaces. The sheet metal lacked in the ability to completely seal a board area as air could easily travel underneath the metal. Kapton tape simply lacked thickness and thermal resistance and was found to be the least effective material.

References

“Thermal Considerations for Surface Mount Layouts”, Charles Mauney, Texas Instruments
“Heat Management in Printed Circuit Boards, Jakob Dieterle Project Report 2010 MVK160 Mass Transit May 11, 2010.

“Thermal Considerations for Surface Mount Layouts” Charles Mauney, TI seminar