Effectiveness of Different Materials as Heat Shields during Reflow/Rework

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Abstract:

As device density continues to maximize the PCB real estate the reflowing of neighboring components or damaging of heat-sensitive components in the rework process continues to cause problems. Devices either have to be removed, thereby reducing rework throughput, or devices get damaged during the reflow process if not shielded from the heat generated during rework. The shielding solutions used most commonly 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 study documents the relative effectiveness of this ceramic nonwoven material as well as different shielding materials in protecting neighboring components during PCB rework.

Keywords: PCB rework, thermal heat shields, temperature resistant shields

There are a variety of temperature sensitive components that may be damaged during the rework process. In many cases this heating process not only sends the device to be reworked in to reflow but either softens up or reflows neighboring materials or can damage nearby components. These heat susceptible 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 compares and contrasts the 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 heat withstand requirements of 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 at 260°C for 40 seconds (though component body temperatures can reach 260°C during reflow). Little work has been done in the reliability of passive components while most work has been concentrated on the active components

Table 1 Thermal Conductivity Watt/m K @ 330C

Air	Kapton	304 stainless	Copper	Ceramic Fiber	Clay/Water Gel
0.03	0.37	≈18	379	0.14	Unknown

Radiant heat is one form of heat transfer to other areas of the PCB during the PCB rework process. This "heat energy" is transferred in the form of infrared waves. It travels at the speed of light and is either transmitted through, absorbed into, or reflected by any material it comes in contact with. A white surface, such as snow, reflects it while a black surface absorbs it. 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 (Figure 1).

Not only can heat be transmitted through air to components but heat can be transferred through the inner layers of the board either by directed rework heat or through the bottom side heating process. This process is known as conduction. The greater the surface area of the copper, the greater the ability to conduct heat through this 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.

There are a variety of materials, namely stainless steel, copper tape, Kapton tape, clay/water gel or a ceramic non-woven material which can shield the aforementioned heat energy from being transferred from the rework area to other areas of the PCB.

Stainless steel 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 options 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.

Copper tape allows the copper shield to be flexible and be easily applied to a PCB in the rework area. 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.

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 makes it an ideal "duct tape" for the PCB assembly industry. The ability to flexibly apply this tape by easily cutting it to size, it as well as the ability to be "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 of a PCB. The one drawback with this material is its relatively poor thermal insulation properties.

Clay/Water gel shielding material is a product which has been used in welding applications (particularly the automotive industry) due to its extreme resistance to heat. The gel contains 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 unknown. The product is easily applied and, due to its consistency, able to work its way into small spaces on a PCB. 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."

Ceramic fiber non woven shields, previously relegated to aerospace, nuclear energy and high temperature processing industrial environments, offer users several properties which makes it well-suited for PCB rework shielding. This material can be used at 1,100°C continuously with excursions to 1,650°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 and cut to shape. Since these materials are compressible, they can be easily fit in between components making it an ideal material for shielding. As an aside, the materials' low bio-persistence, meaning that if the fibers are inhaled, they're eliminated from the body within days makes them safe to use.

Experimental Procedure

In order to determine the thermal shielding effectiveness of various materials, a controlled heat source, simulating a rework process, was placed onto a IC reference site of a (10) layer mixed technology printed circuit board (Figure 1). The board was fabricated with a SAC305 solder alloy with a HASL finish. A reference site component (U3) was then chosen as the sample rework location. It was not connected to same copper layer as the components of interest. Various heat-sensitive components on the board were then identified, and the distance from the reference site to these locations was measured with a pair of calibrated calipers. Since the idea of a good thermal shield is to keep the temperatures below a point in which the component can be damaged or prevent underfill and glue from softening, a temperature well above the reflow point of solder was chosen as a target control temperature. A (5) minute reflow profile with a peak profile temperature of 230°C was applied at the reference site location.

Figure 1-Board used for testing fitted to board holder of hot air rework system

Four production type K thermocouples were attached to heat-sensitive components and at reference IC site using Kapton tape and production epoxy. The epoxy was cured in a production oven at 86°C for 45 minutes. The Kapton tape was removed afterwards. The thermocouples were connected to a production thermal profile scanning system. This was then connected via serial port to a computer. Production profiling software was used.

Figure 2-Materials used for shielding study -copper tape, ceramic non-woven, clay/water, stainless steel and Kapton(TM) (CW from upper left)

Five different materials (Figure 2) were chosen to test their shielding effectiveness. The first type was stainless steel 304 formed rectangular open box shields of sizes 38x38mm (Kapton coated) and 26x26mm. The second, , was a copper based shielding tape. Next, a ceramic fiber heat shield was used. Kapton tape was used to hold one 38x38mm and one 38x76 piece a ceramic material in place. Kapton tape of one inch in width and 3 mils in thickness was then used by itself as a shield. A control condition with no shielding followed. Each material including the control was heated five times for a total of twenty five heating cycles. A sample profile is found below (Figure 3).

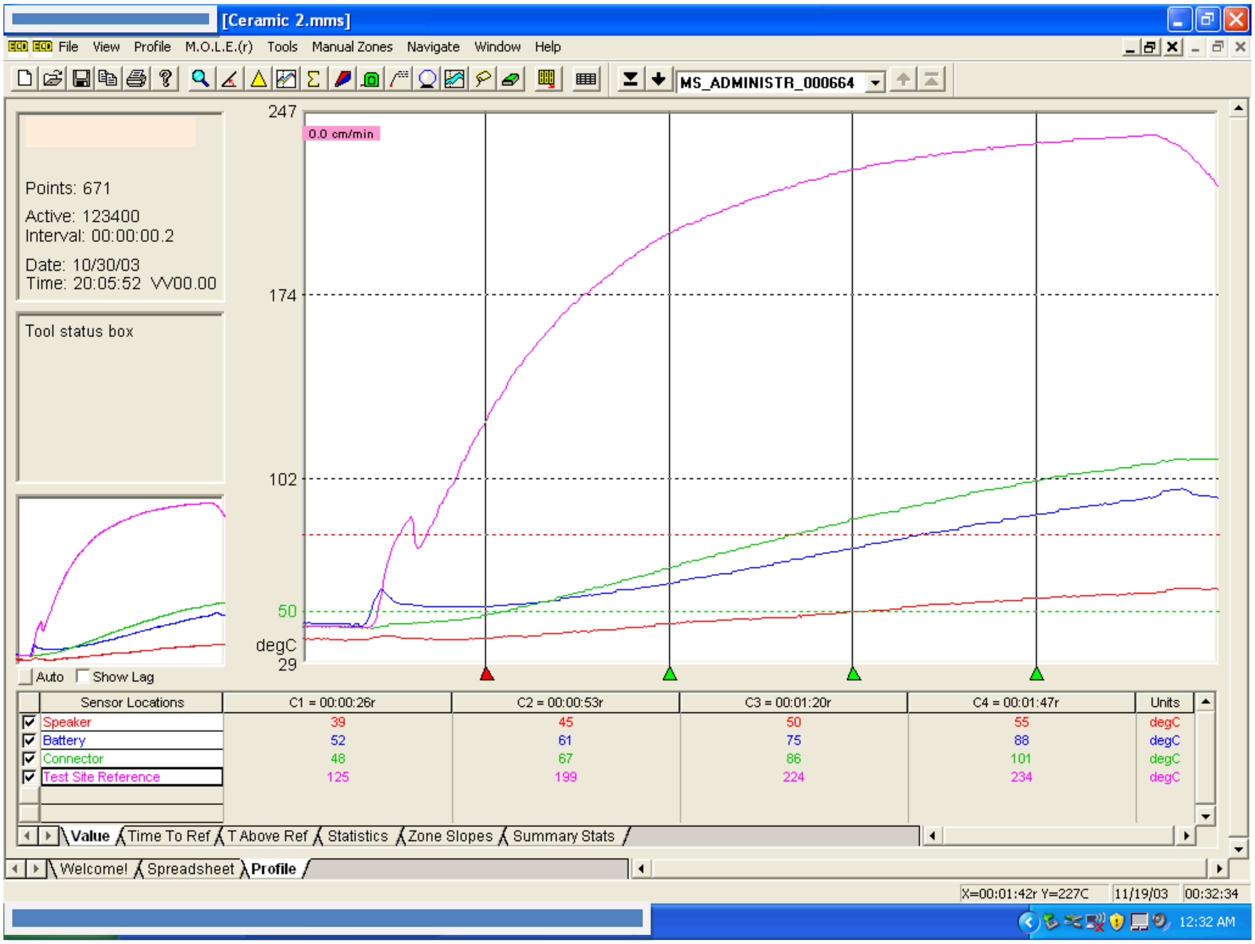

Figure 3-Sample output reflow profile

The board was first placed on a board holder as part of the production hot air system used for the trials (Figure 1). Kapton tape was used to hold four thermocouples in place until the epoxy was added. 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 the IC reference site location (Figure 4).

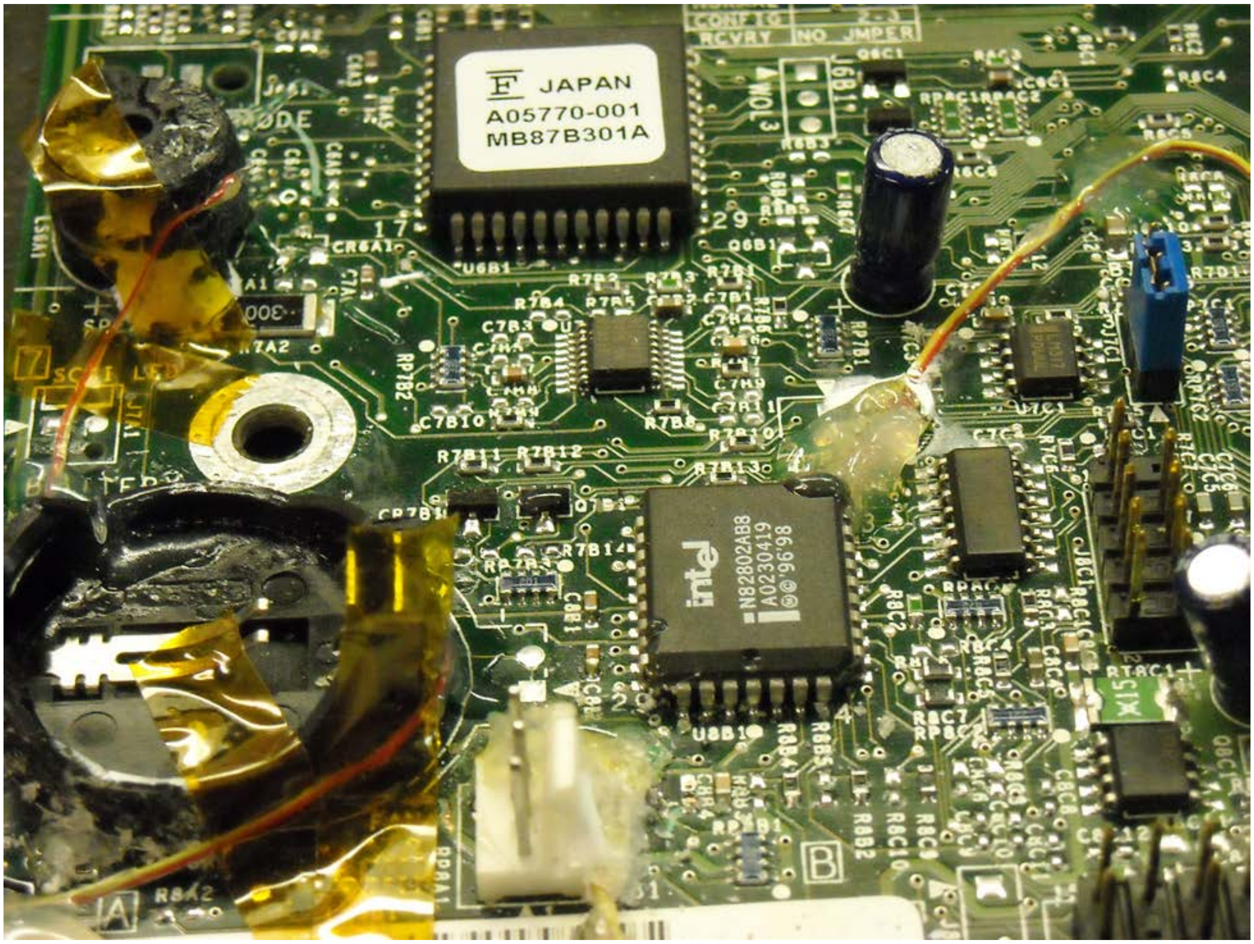

Figure 4-Locations on PCB where temperature measurements were taken

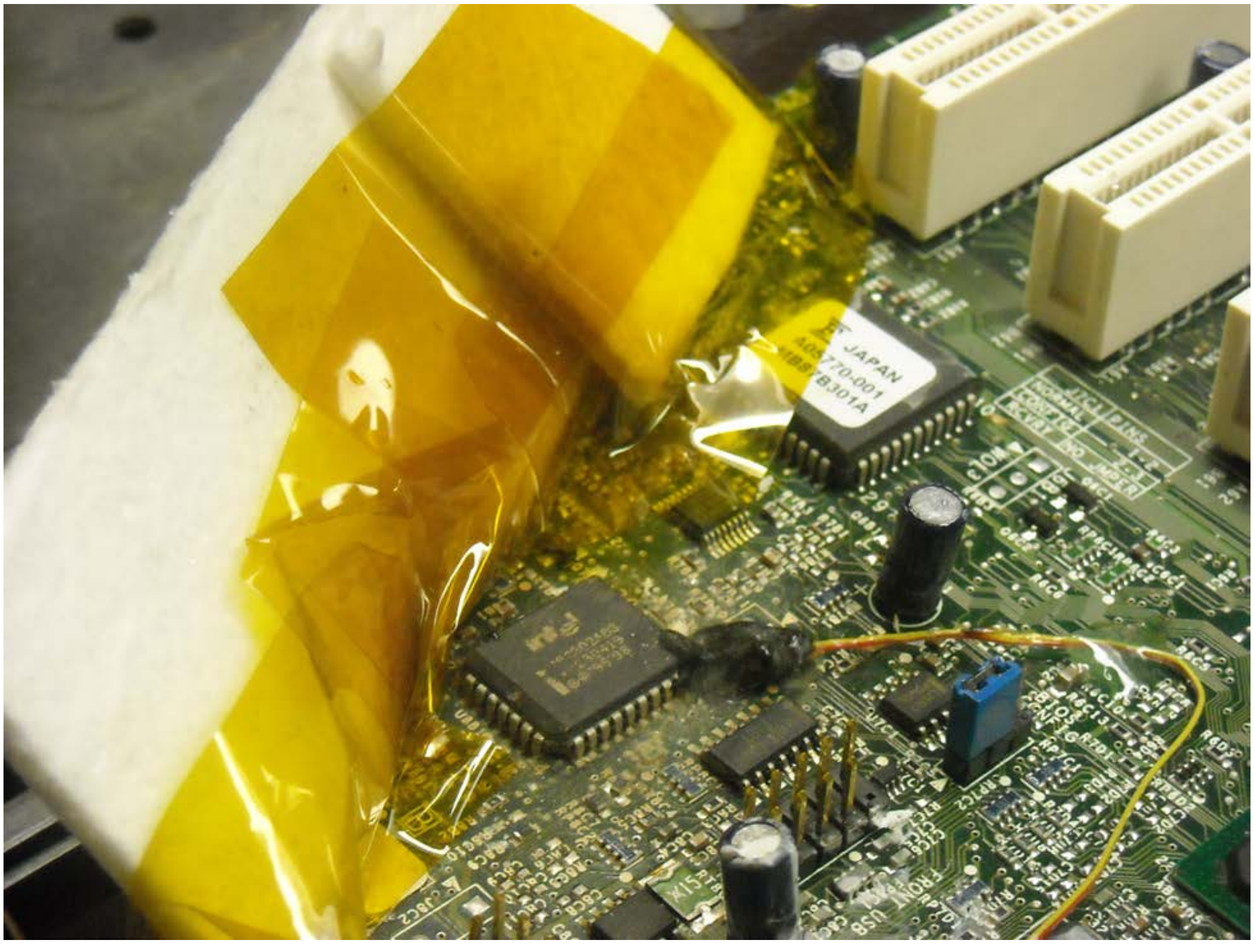

Figure 5-Ceramic non-woven fiber heat shields affixed to different board locations

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

The hot air nozzle heating system (Figure 6) was preheated with an output set at a temperature of 350° C for 2 minutes. This provided a high enough temperature in order to simulate a lead free reflow process. Heat measurements from the four components in five trials were gathered for each shielding material.

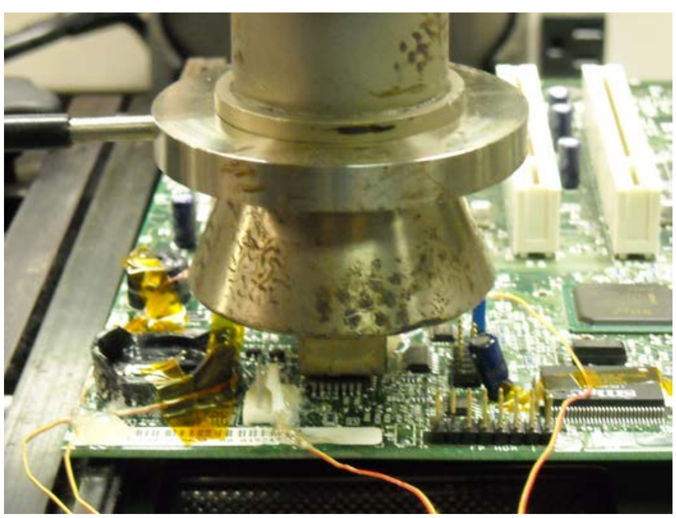

Figure 6- Hot air nozzle placed over reference location

Figure 7-Copper shielding tape

Copper tape was then applied. (Figure 7). After repeated heating, the copper also became discolored (Figure 8

). This discoloration did not affect performance. The epoxy holding the thermocouple became brown and eventually black with repeated heat cycles.

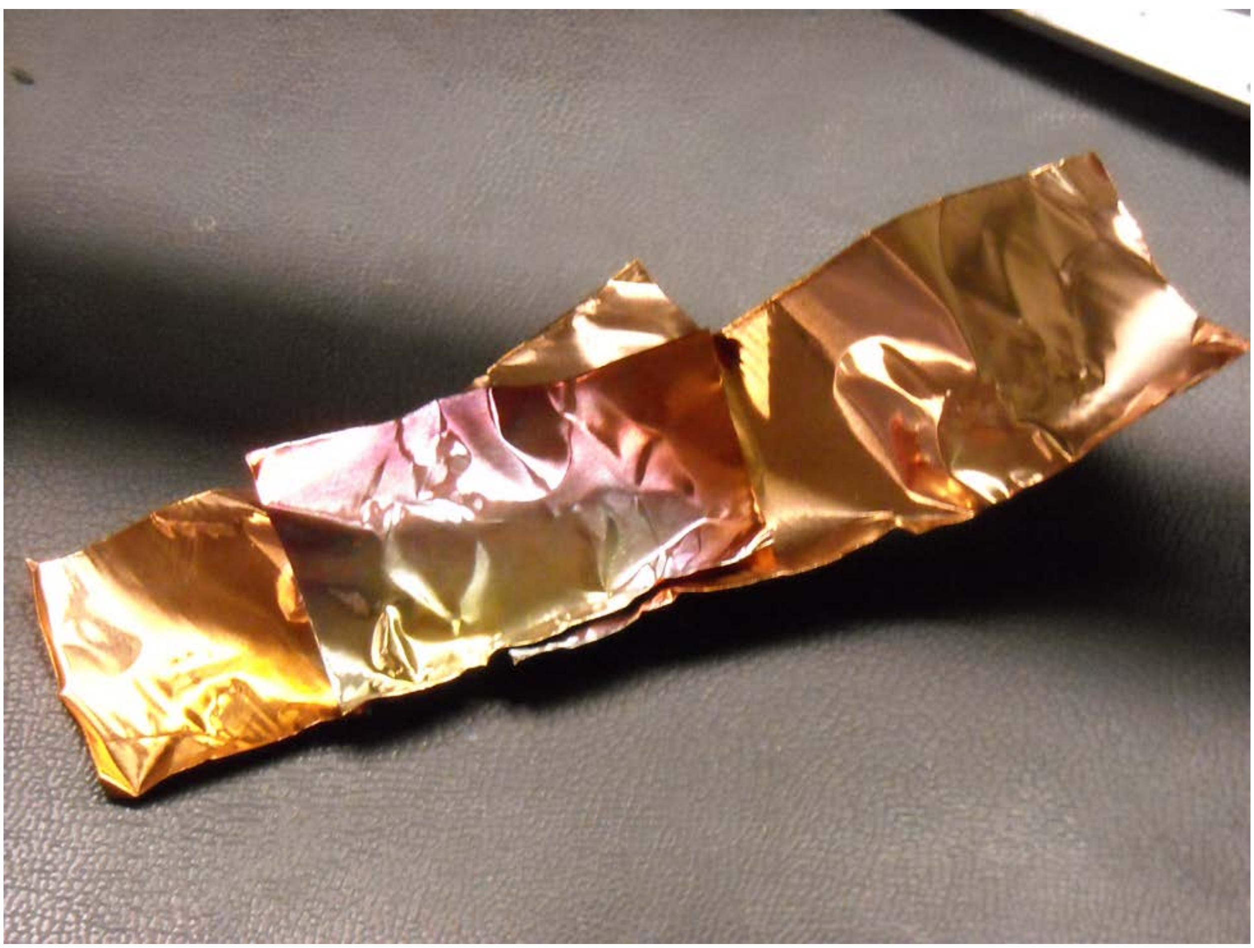

Figure 8-After repeated heat cycles copper tape discolors

Figure 9-Kapton tape used as a shielding material

Kapton tape alone was applied liberally and used as the only shielding material for on of the trials (Figure 9)

Stainless steel 304 open-ended “boxes” (Figure 10) were used to shield components. The boundaries between the boxes and board allowed hot air from the heat source to flow underneath easily.

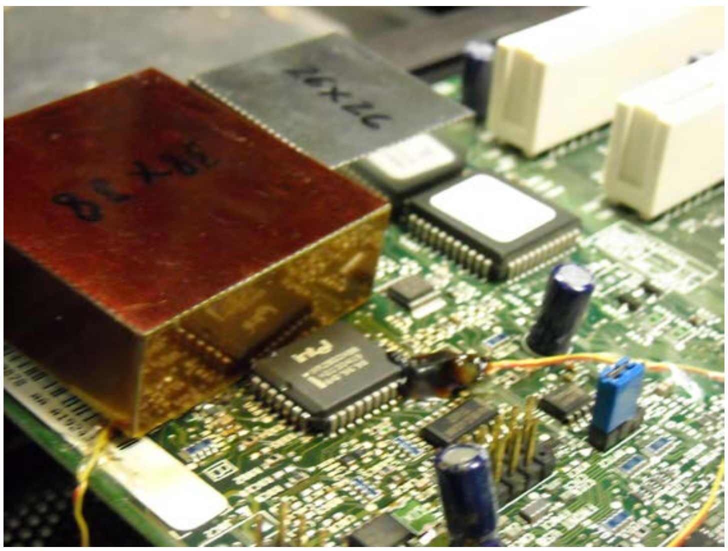

Figure 10-Stainless steel shields used in study

A gel type heat (Figure 11) shield made of clay and water was easiest to work into the board spaces.

Figure 11-Clay/water gel

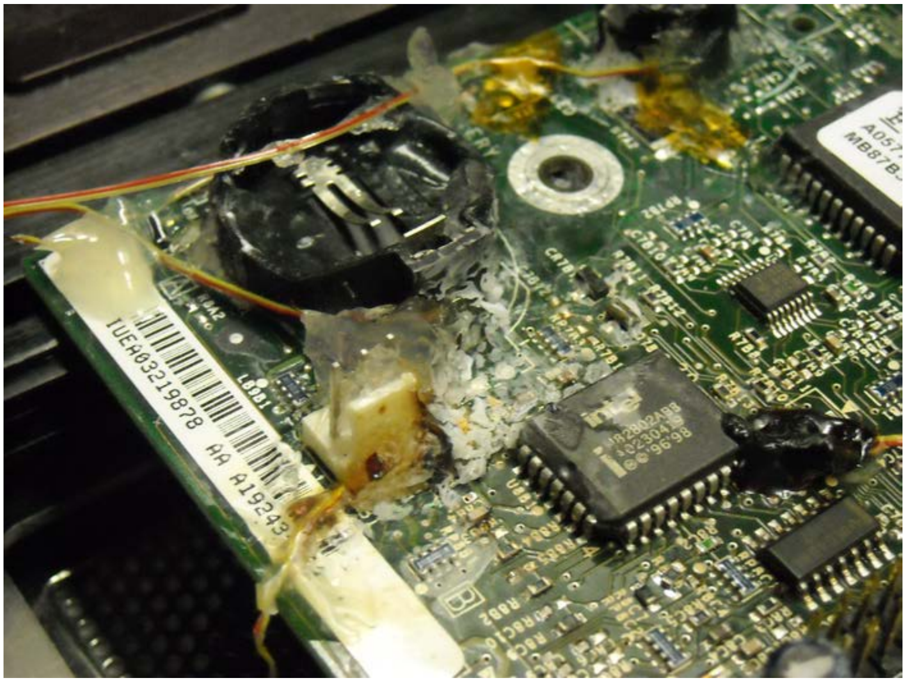

Figure 12-The gel easily conforms to openings and gaps. It discolors after being heated.

After heating, the gel left a whitish, gray residue on the board (Figure 12). This was easily cleaned with alcohol and a soft brush.

Results and Analysis

The temperature measurements below are for each of the shielding materials with the reference IC temperatures between 231-240ºC for an accurate comparison.

Table 2- Maximum temperature for various shielding materials at select locations on PCB

Test Site	Speaker	Battery	Connector	Test Site IC
Distance from test IC	30.95mm	9.73mm	6.14mm	
Control (no shields)				
Max Temperature	123° C	227° C	173° C	232° C
Copper Tape				
Max Temperature	106° C	129° C	128° C	232° C
Stainless Steel				
Max Temperature	61° C	158° C	143° C	239° C
Clay/Water Gel				
Max Temperature	66° C	89° C	86° C	231° C
Kapton Tape				
Max Temperature	99° C	145° C	153° C	241° C
Ceramic Fiber				
Max Temperature	63° C	111° C	113° C	231° C

The stainless steel shields performed better than Kapton tape at the speaker and connector locations yet performed poorly at the battery site (Table 2). 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 gap. The clay/water gel produced a gray residue on the surface of the PCB during the trials possibly due to the chemical makeup of the materials.

Conclusions:
Through the repeated measurement of outlying component temperatures during the reflow process, the clay/water gel was determined to be the best performing heat shield material. More testing, however, is needed to prove its impact on electronic materials as well as their reliability. The closest performing material to clay/water gel was the ceramic fiber material. The next closest performing materials in order were the copper tape, stainless steel, and Kapton tape. The copper tape performed well and was able to adhere easily to surfaces. The stainless steel lacked in the ability to completely seal to the PCB as air could easily travel underneath the metal shield. Kapton tape simply lacked the thickness and thermal resistance and was found to be the least effective shielding material. Therefore the most viable, flexible, effective, proven shield material for rework is the ceramic non-woven.

References:

[1] “Thermal Considerations for Surface Mount Layouts”, Charles Mauney, Texas Instruments

[2]“Heat Management in Printed Circuit Boards, Jakob Dieterle Project Report 2010 MVK160 Mass Transit May 11, 2010.
[3] “Thermal Considerations for Surface Mount Layouts” Charles Mauney, TI seminar
[4] Dytec Services, Inc. *Material Safety Data Sheet ColdShield Gel*. Greer, South Carolina: Dytec Services, Inc., 7 Aug. 2012. PDF.

Further Work:
Additional ionic contamination and materials capabilities testing as well as residual analysis is required prior adoption of the water and clay gel material in the PCB rework area.

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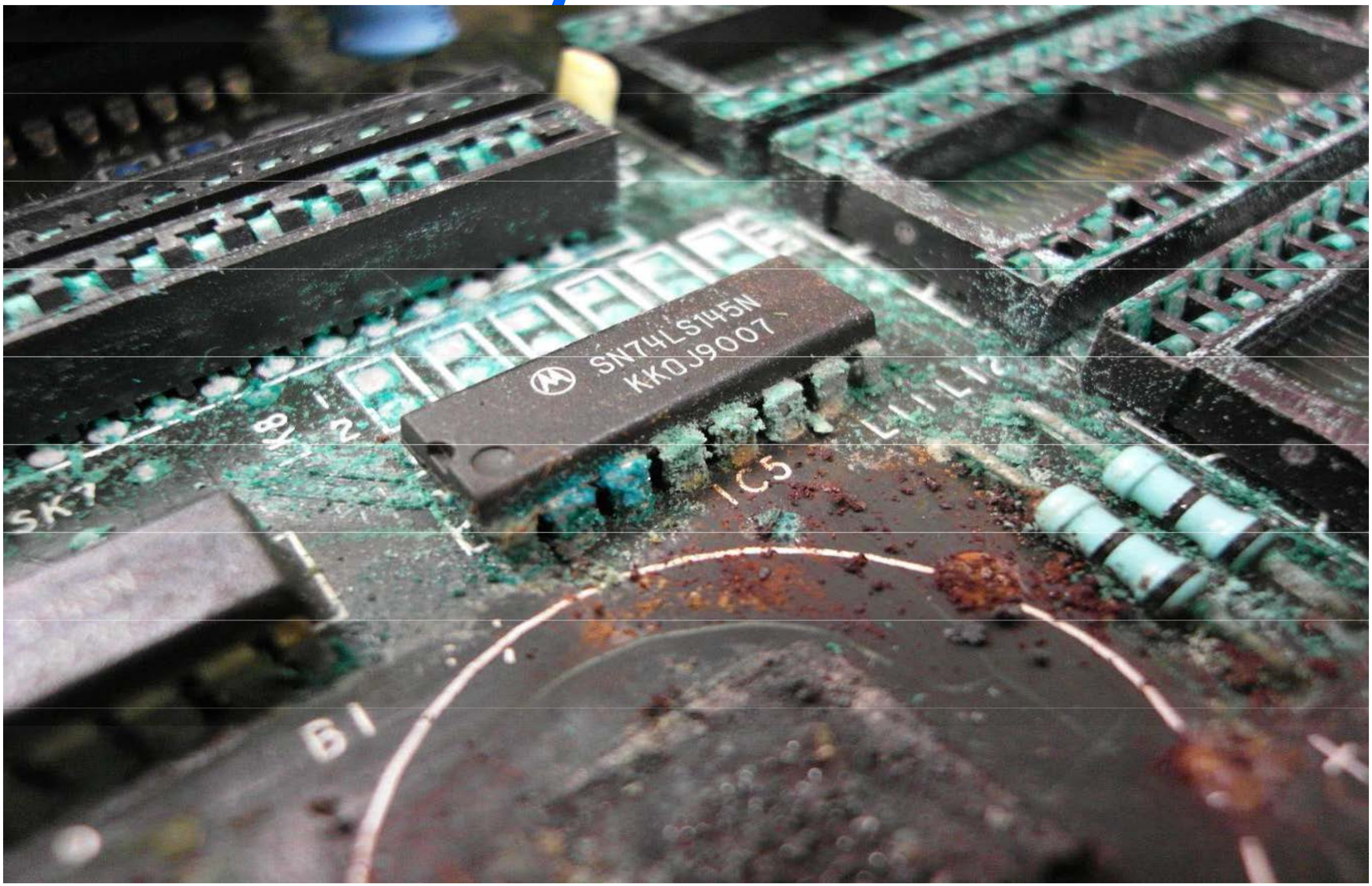
Outline/Agenda

- Myths and Problems with Current Shielding Methods
- Experimental Method
- Results
- Conclusions
- Q & A

Heat Sensitive Components

Aluminum and tantalum ceramic capacitors, crystals, oscillators, plastic-bodied components such as connectors

Battery Destruction

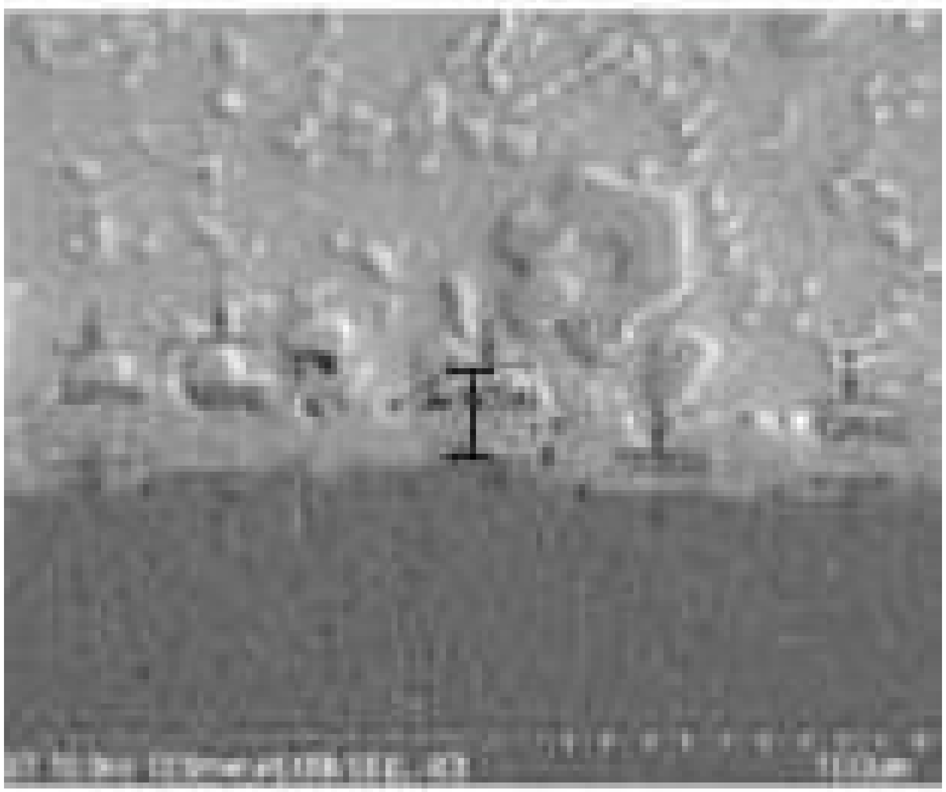


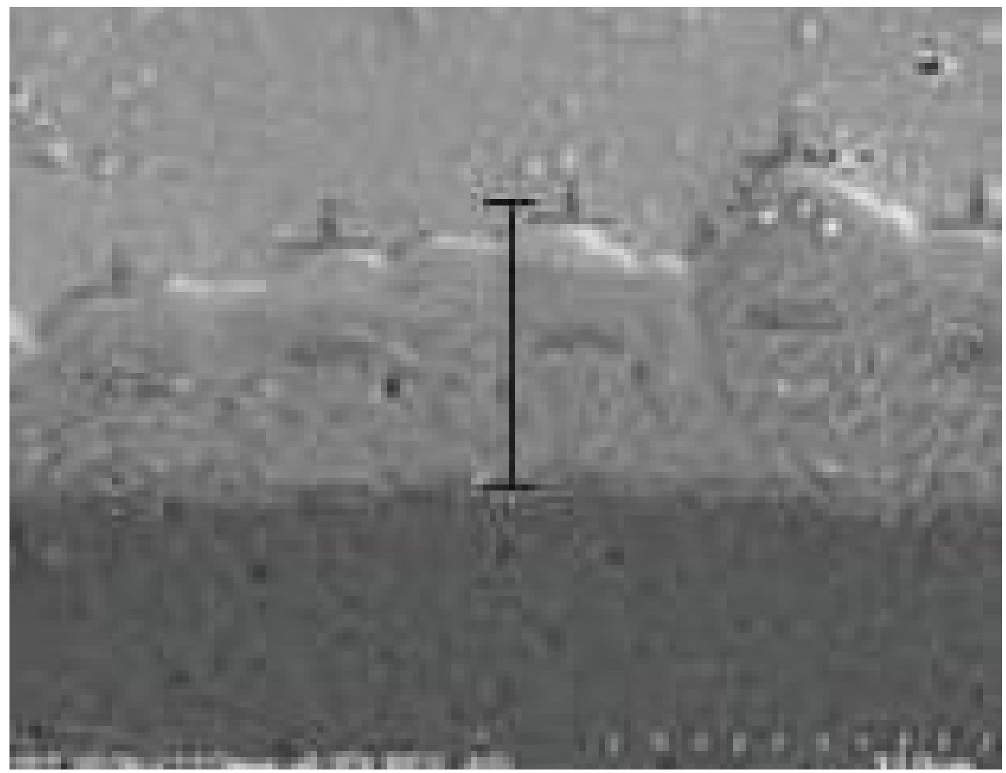
Introduction

Flow of underfill or adhesive in to unwanted areas

IMC Growth Impact Reliability

SAC305

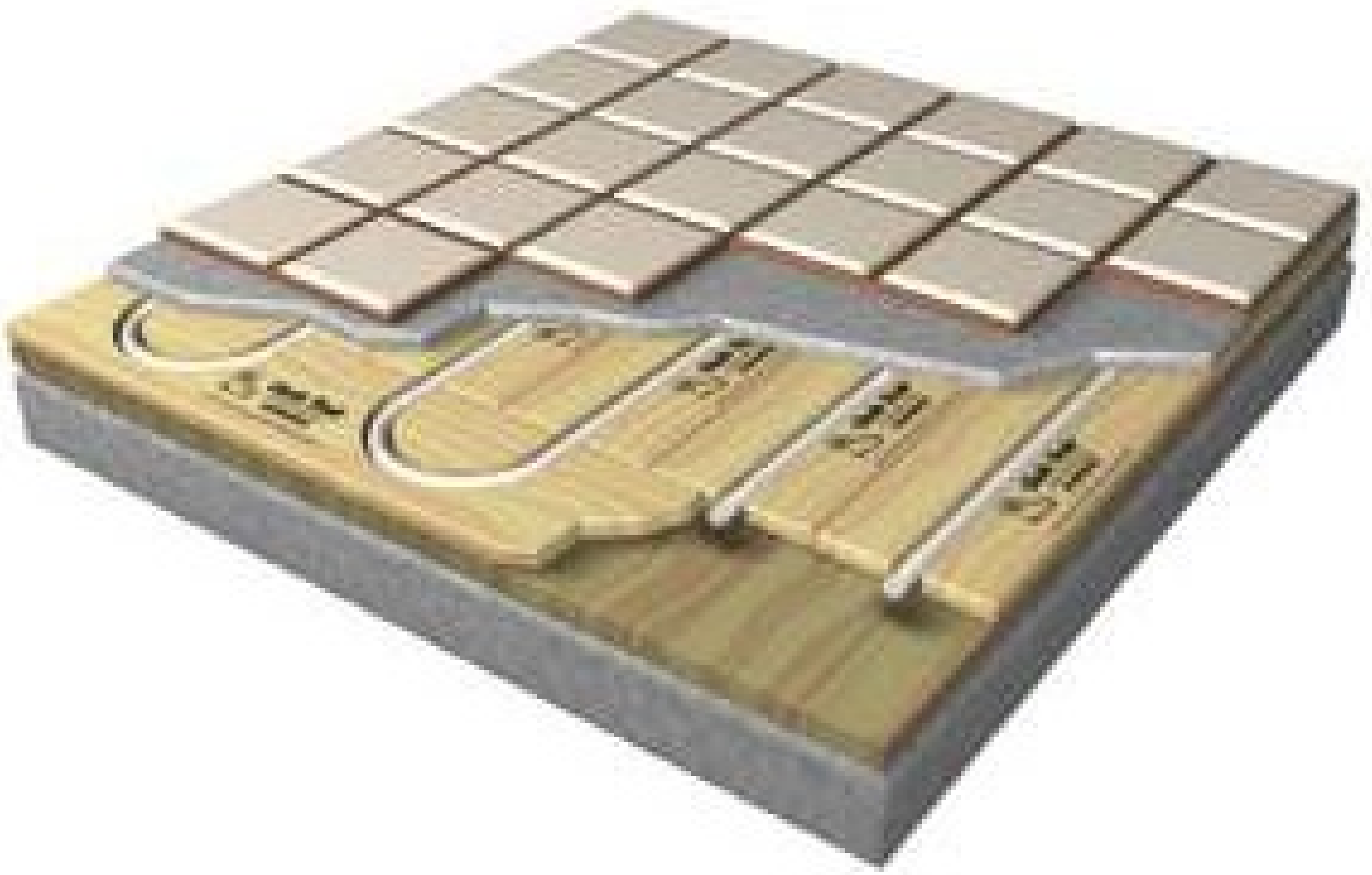




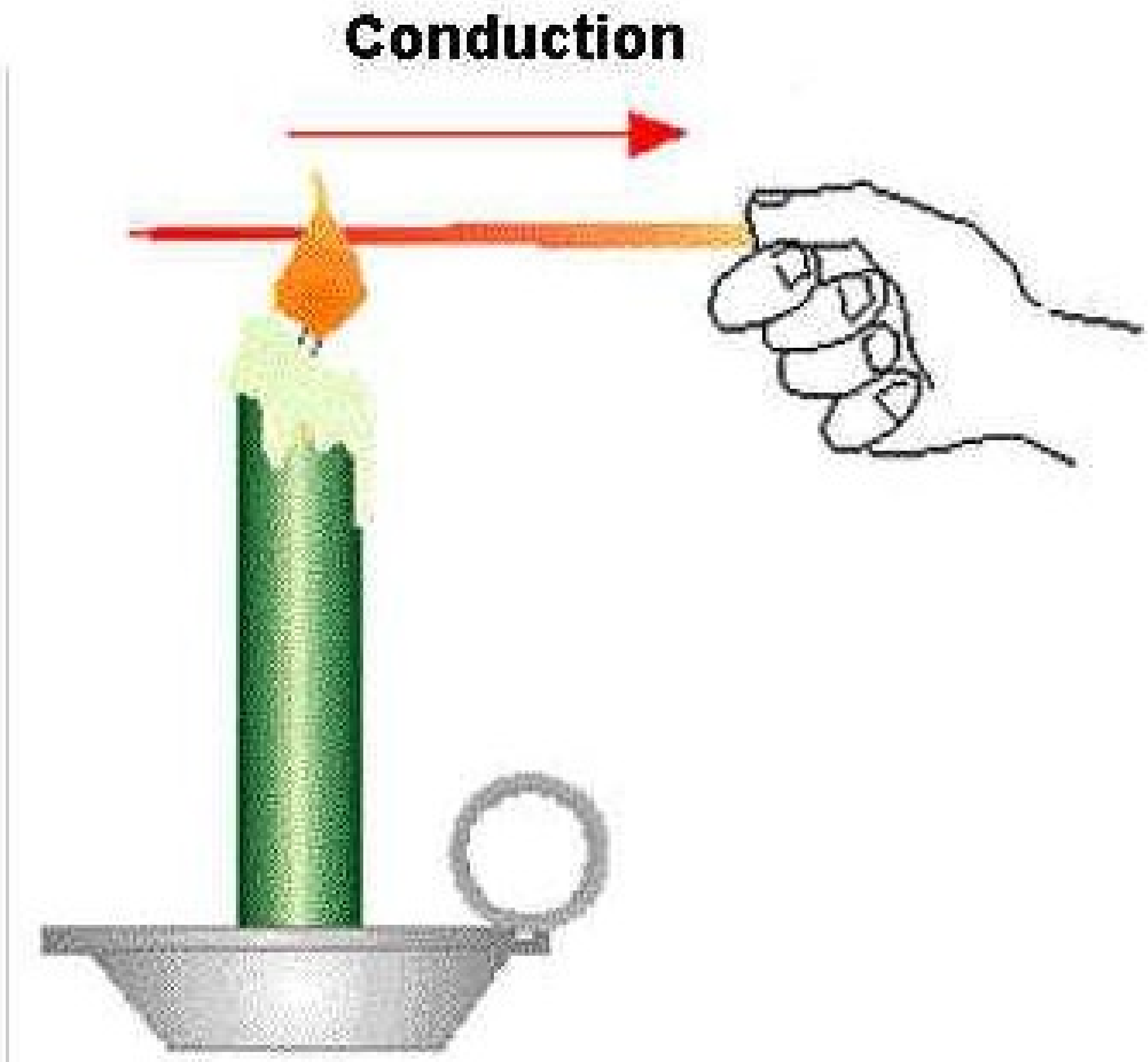
Thermal Conductivity

Material	Thermal Conductivity (Watts/m K @ 330°C)
Air	0.03
Kapton	0.37
304 Stainless	18
Copper	379
Ceramic Fiber	0.14
Clay/Water Gel	Unknown

Radiant Heat

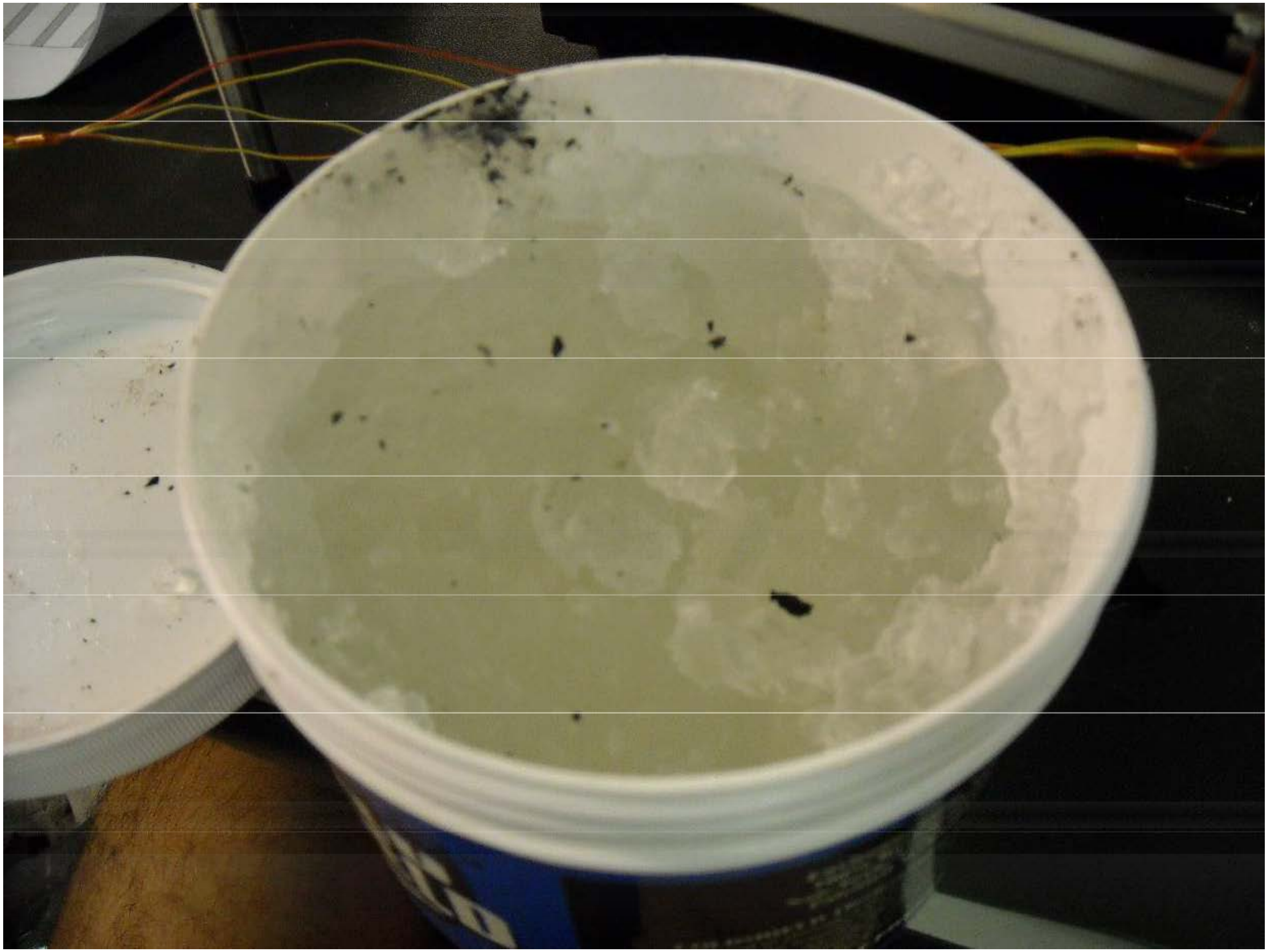


Conduction



Possible Materials for Heat Shielding

Clay Gel

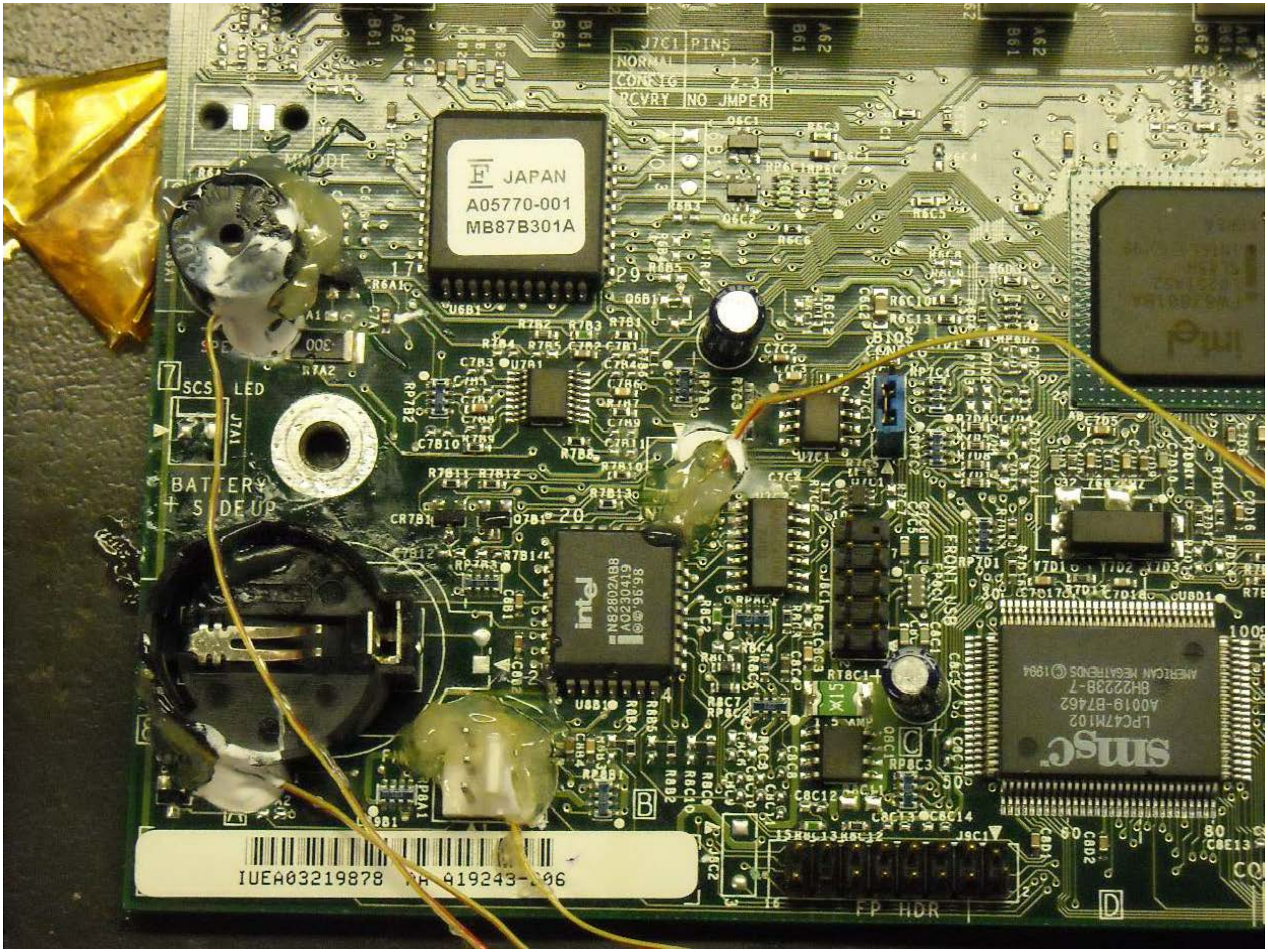


Experimental Method

Materials Used

- Stainless steel 304
- Copper with tape backing
- Ceramic non-woven fiber
- 3mil thick Kapton
- Clay/Water gel

Experimental Method



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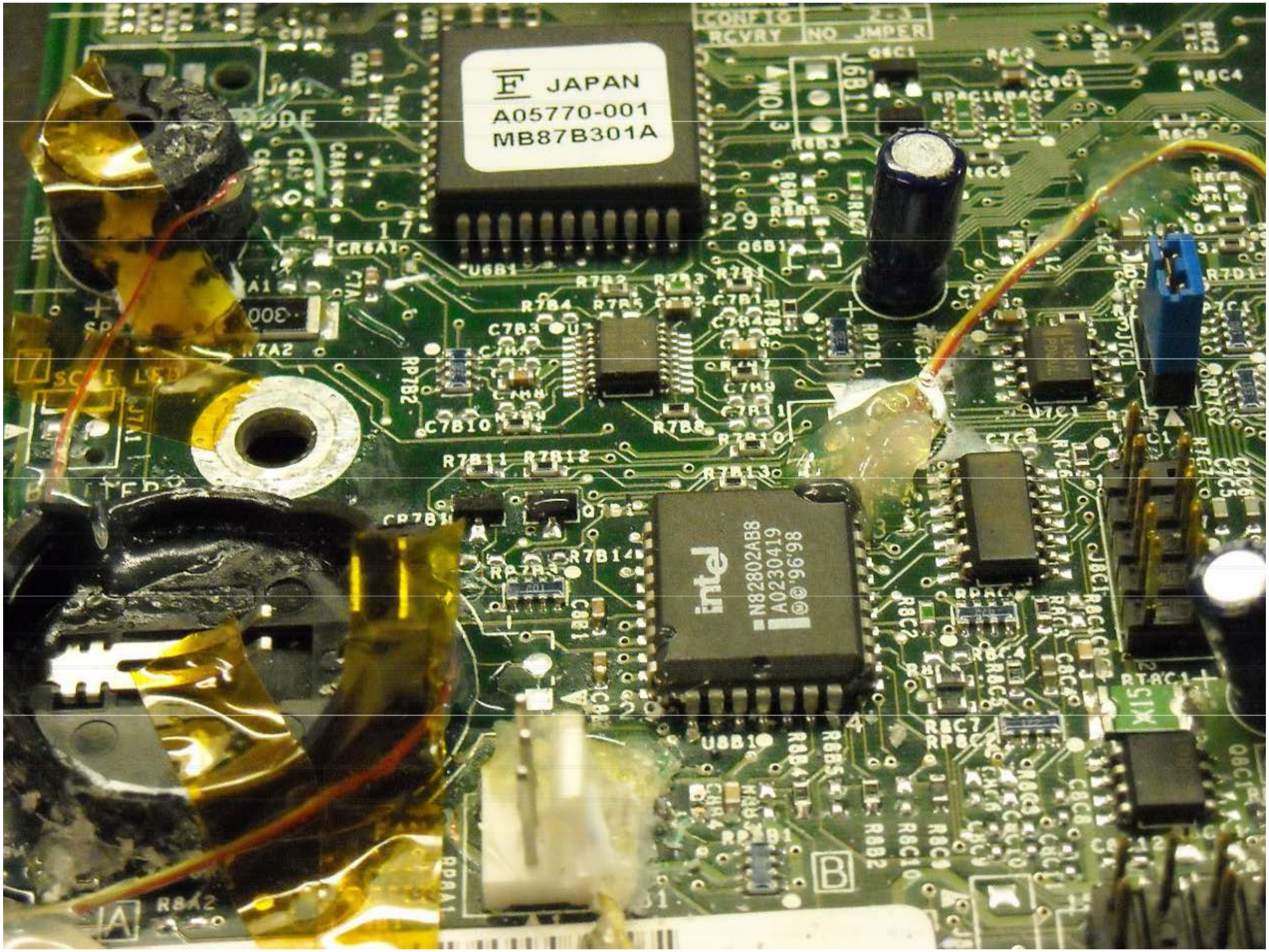

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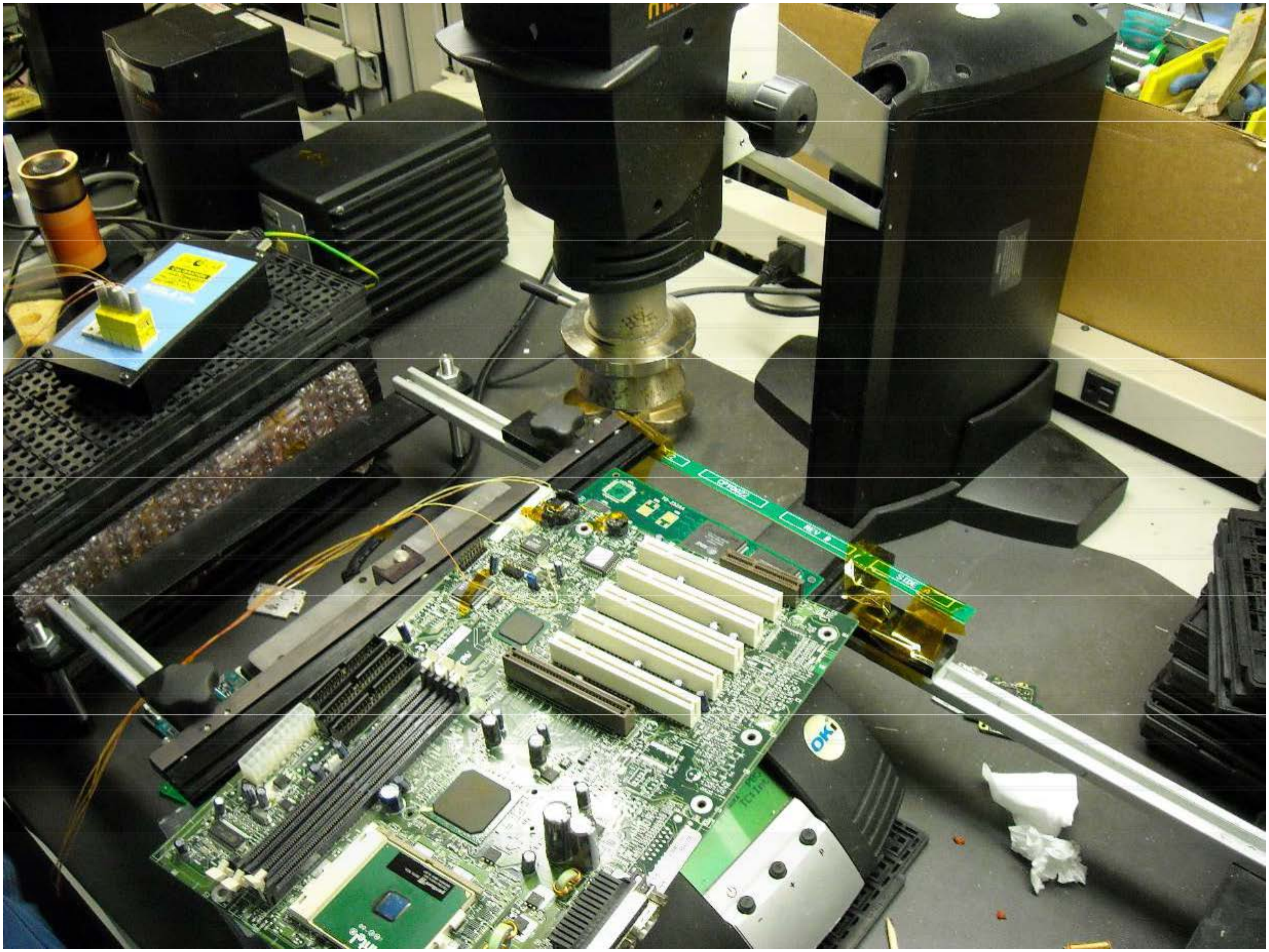

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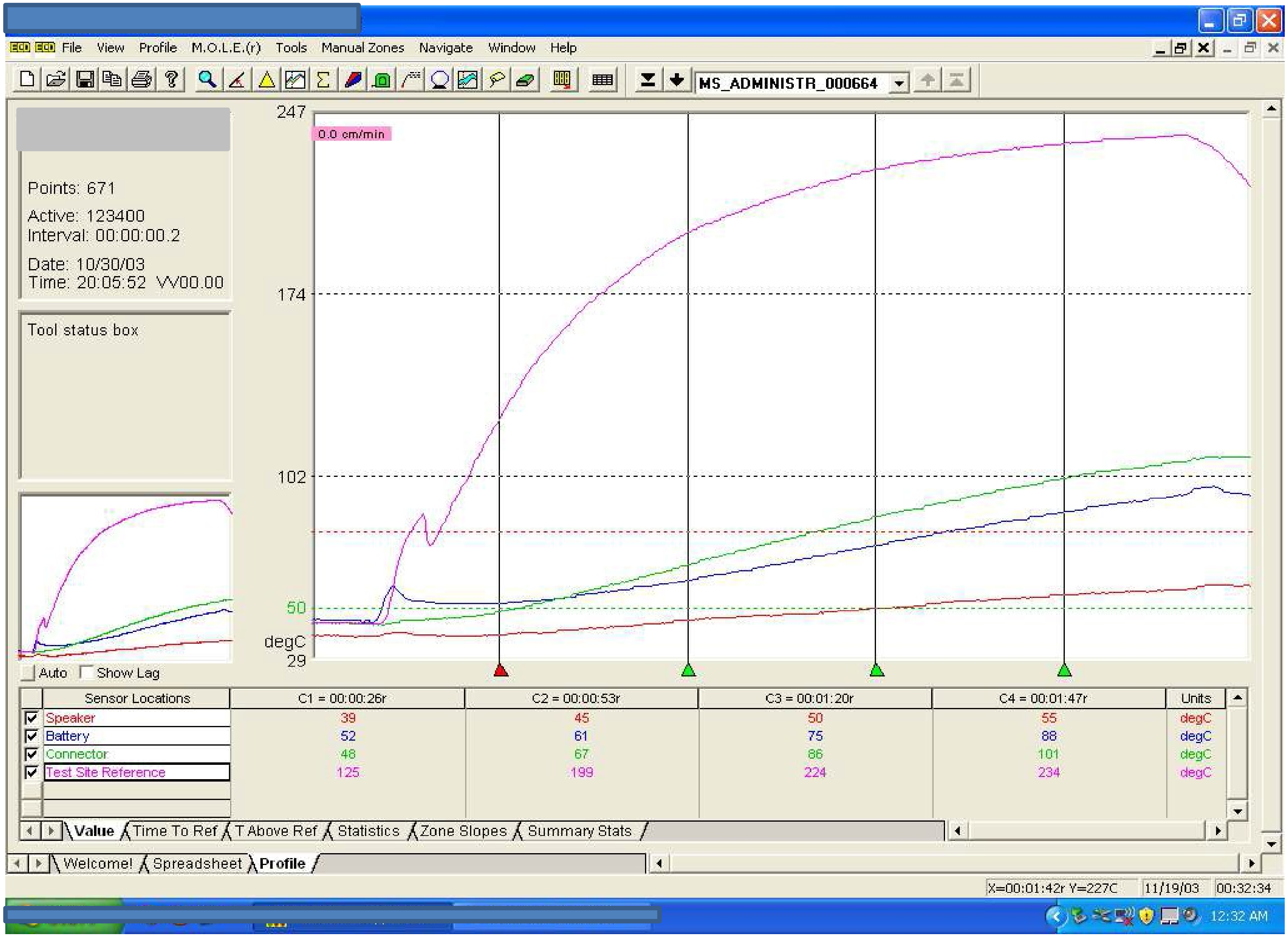

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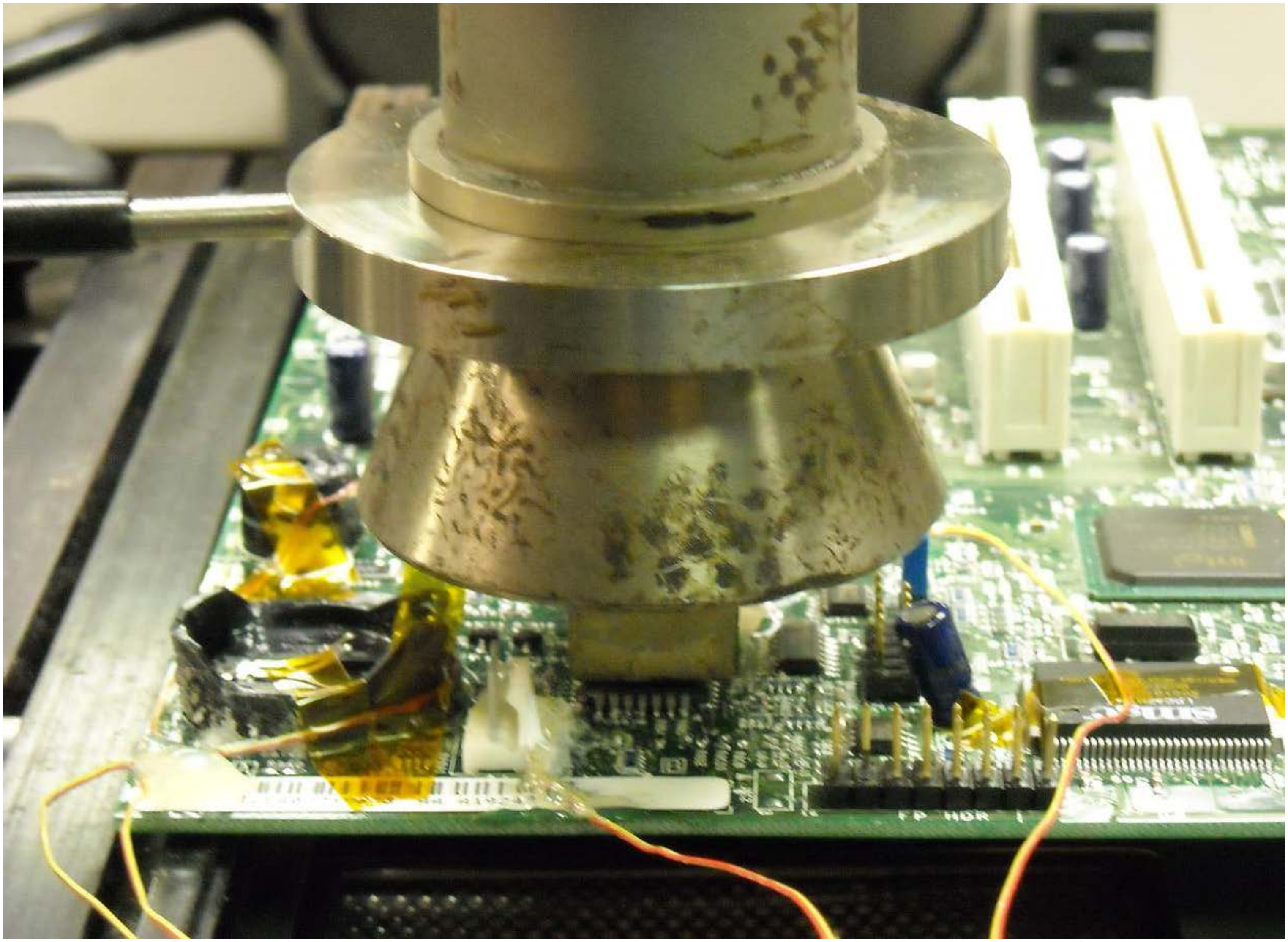

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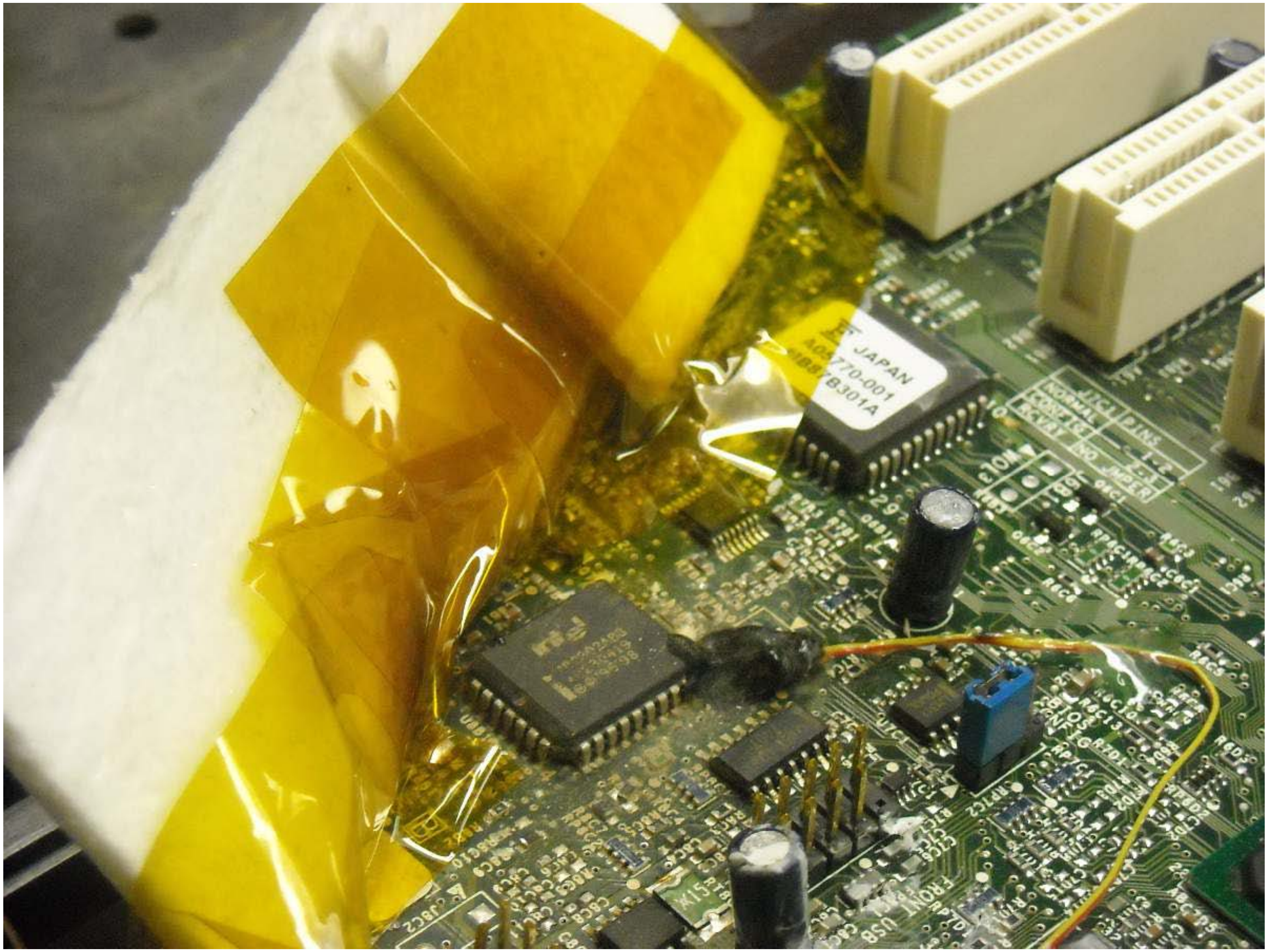

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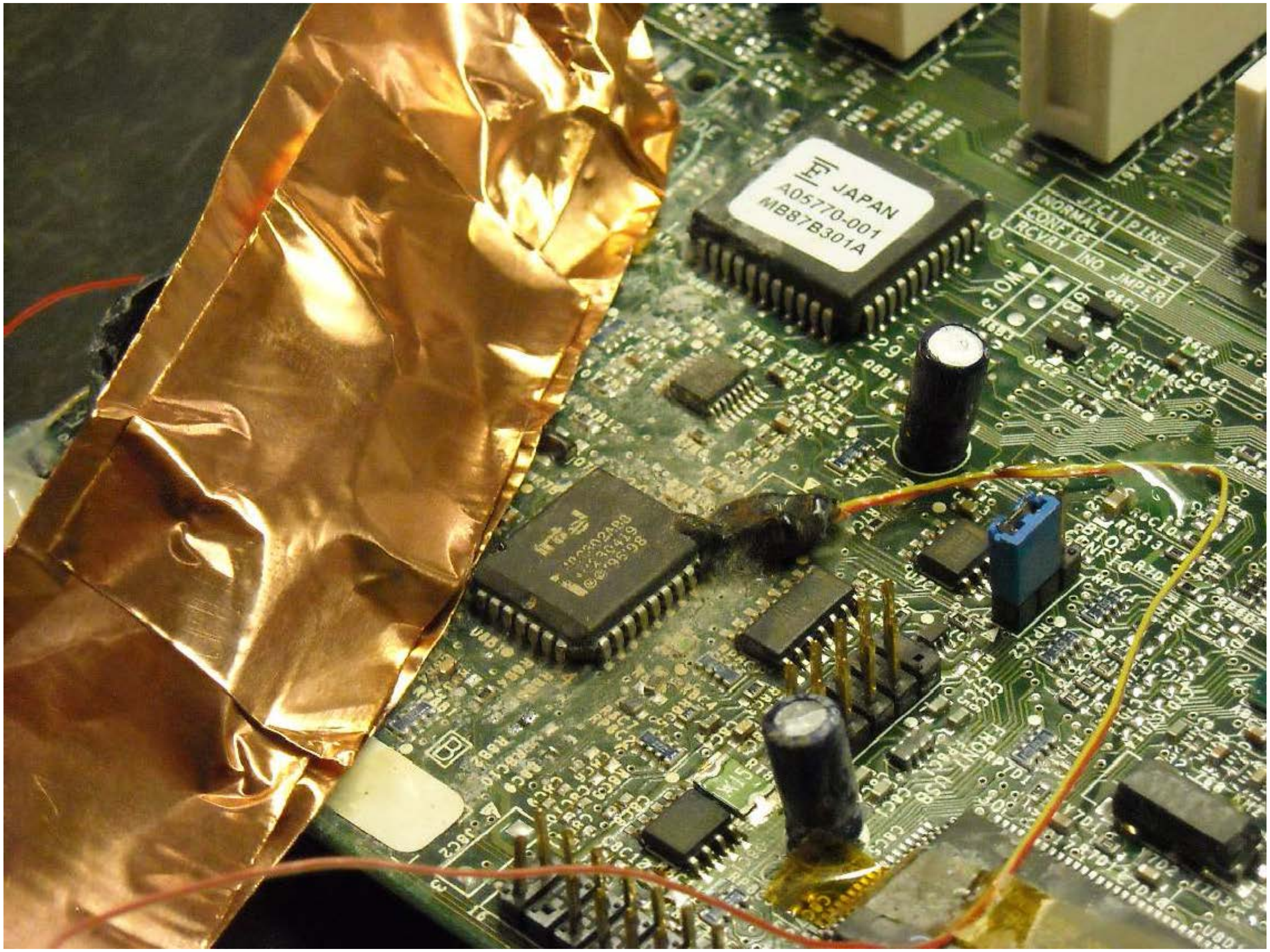

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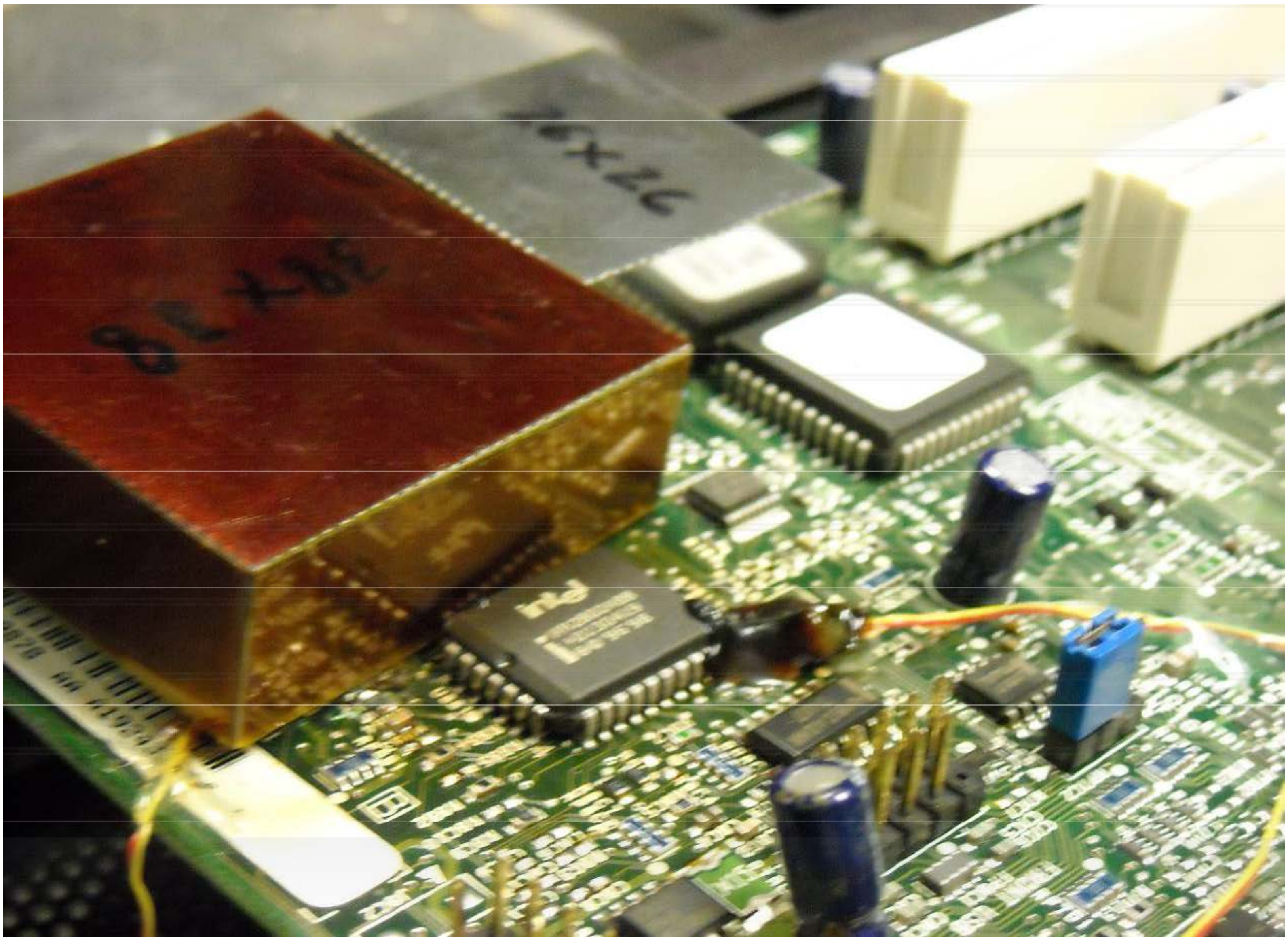

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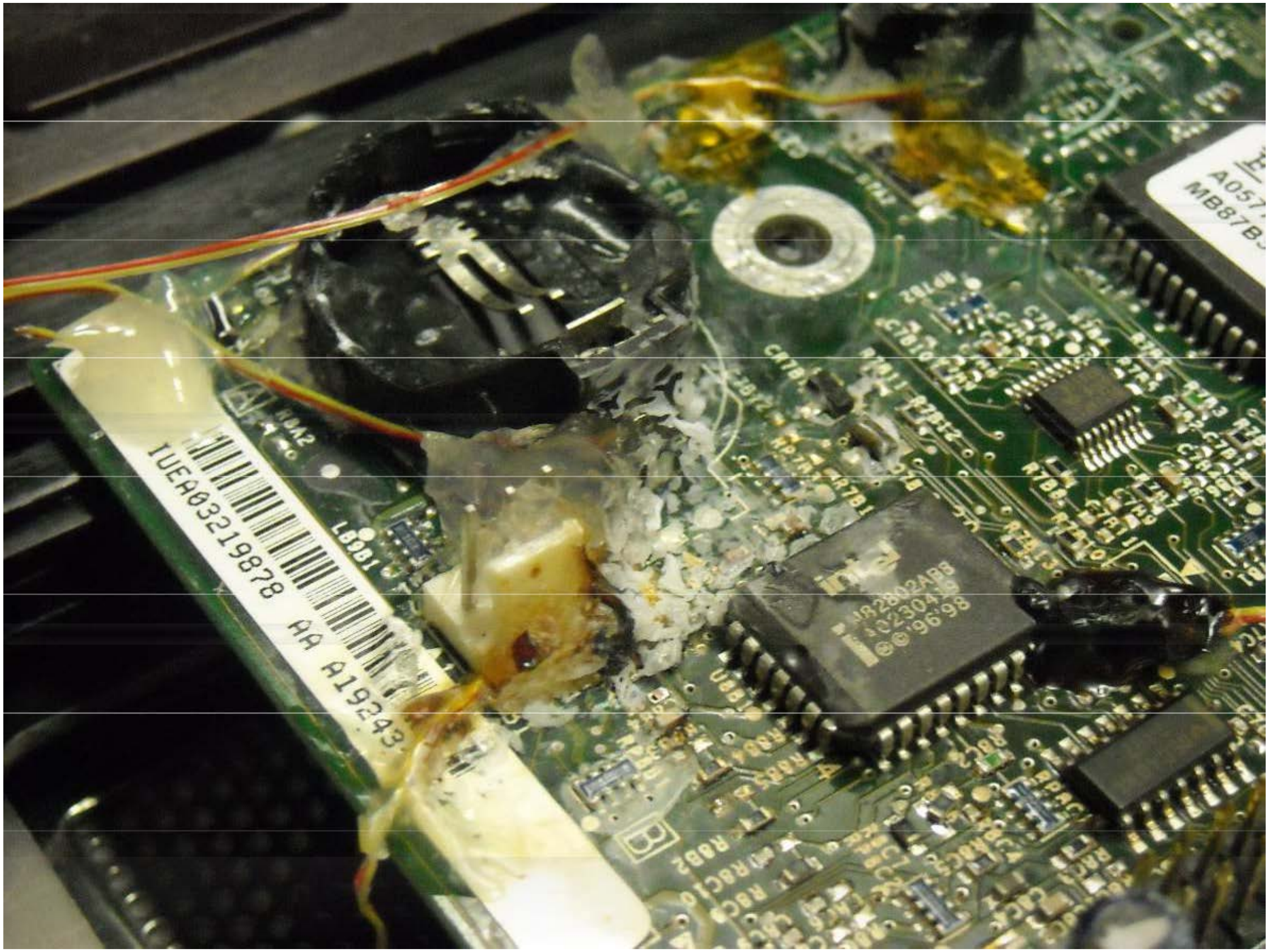

Results

Distance from test IC	Speaker 30.95mm	Battery 9.73mm	Connector 6.14mm	
Control (no shields)				
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Copper Tape				
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Max Temperature	63° C	111° C	113° C	231° C

Conclusions

- Clay/water gel best performer (needs further testing for impact)
- Ceramic fiber material best known tested material
- Kapton tape worst performing

Questions?