Advanced Rework Applications in a Shrinking World

Al Cabral, Finetech, Manchester, NH, USA
Dan Lilie, Finetech GmbH, Berlin, Germany

Abstract

As electronic assemblies continue to shrink in size, component population densities are increasing. Design engineers are forced to utilize all available board real estate and continuously push the limits of manufacturability. The next generation of board designs will incorporate even smaller passives than 01005 and tighter area array pitches than 0.3mm, while pushing design rules to reduce typical component spacing to less than 1mm. As limits are pushed, the need for advanced rework solutions is sure to increase from research organizations to volume manufacturing.

This paper will address some of today's most challenging rework applications and explore the demands of tomorrow including:

- Rework of 008004 micro passives
- LED rework as small as 0.5mm
- Micro Sensor Rework
- Assembly of Delicate Beam Lead Diodes
- Flip chip

Specific challenges of reworking these applications will be indentified and discussed, including process, material and equipment variables not common to 1mm plus rework.

Introduction

Some of the primary drivers for the rise in high-density electronic assemblies and smaller, lighter products stem from continued market demands and pressure for increased mobility, increased electrical performance, increased functionality and decreased costs, the proverbial "smaller, cheaper, faster". In order to remain competitive, many organizations have implemented aggressive material cost reduction programs that are touching all levels and have funneled down to board and component levels.

Lower cost consumer assemblies, commonly thought of as "scrap worthy" are being reconsidered for rework, and many incorporate high-density electronics. High value / high performance assemblies have always been candidates for rework. Many of these assemblies have implemented high-density interconnects, including those used in high-reliability applications. The "High-Rel" applications are no longer free from being reworked due to increased market and competitive pressures.

Reworking micro-passives

The days of "we will never design any boards with devices smaller than 0402" are long gone. Implementation of 0201 and 01005 micro-passives are common place, versus just being a check-mark on an equipment evaluation matrix. Manually reworking 0201 devices pushes the limits of most people, excluding of course, twenty-somethings with rock-solid hands and superb eye-sight. For most of us in this mature industry, manually reworking sub-millimeter devices is not a consideration, never mind reworking 01005 passives or 0.3mm pitch, bumped flip-chips that are exponentially more difficult.

Figure 1a and 1b – Illustrates the relative size of micro-passive devices

We applaud those who attempt to rework 01005s by hand and their one-in-a-row success, but reality has a way of kicking-in with practical demands for process control and thermal repeatability. This can be accomplished with advanced machinery and automation.

So how do you transfer enough energy through a surface area smaller than the tip of your pen to increase the temperature of a device's interconnections by 200C, without disturbing adjacent components less than 0.004" (100µm) away? Also once the alloy is liquid, how do you pick it up? Very carefully and with extreme accuracy, high resolution optics, thermal performance, and system control.

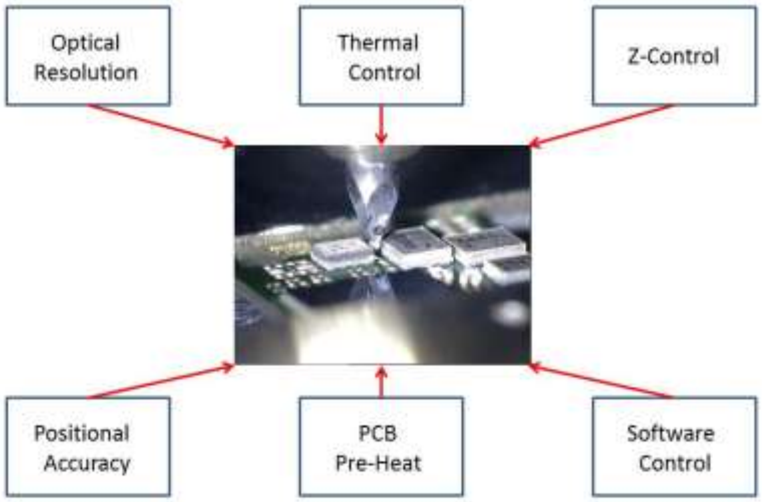


Figure 2 – Identifies critical aspects needed for successful sub-millimeter rework.

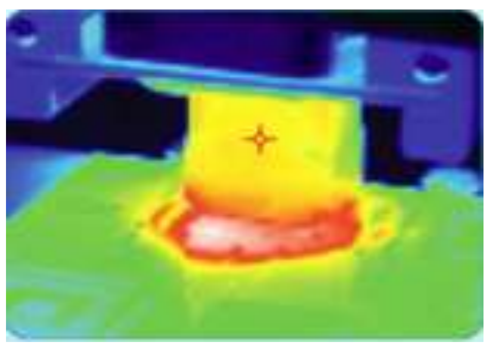


Figure 3 – Thermal image of a typical heating tool transferring energy to the targeted device.

Reworking 008004's

Our industry continues to downsize discrete components from the 0201s, which we have been using for more than 10 years, to 01005's. 01005's consume a quarter of the space needed by 0201's, extremely attractive for designers scrounging for board real estate on smart mobile devices and those stretching performance limits on high performance processors. The next step in an asymptotic curve of difficulty for micro-passives is the 008004 package, about ¾ the size of a 01005. If the introduction of this device in not ominous enough, there remains at least two different schools in nomenclature, continuing the confusion between US Imperial Standard and SI Metric units of measure.

Table 1 – Dimensions for micro-passives

Imperial [inch]	Metric [mm]
008004 (8 x 4 mils)	0201 (0.2 x 0.1 mm)
01005	0402
0201	0603
03015	0804
0402	1005

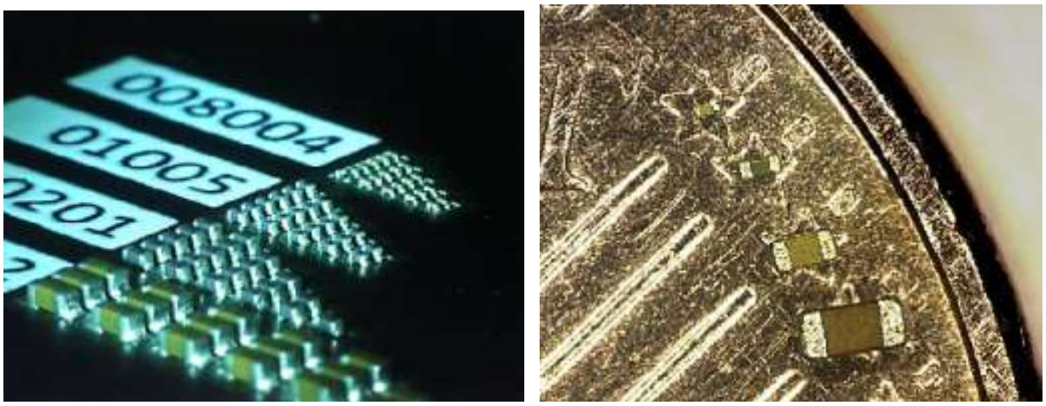


Figure 4a and 4b – 008004 devices about ¾ the size of a 01005

Additional considerations to be addressed include: The 008004 devices also exhibit geometric variations, resistors are adopting the traditional flat design, capacitors are higher in profile and vary vertically, and designs are being considered for coils and diodes as well as other devices.

Reworking 008004’s - Initial results are positive, but challenges exist:

- Vision - enhancements in magnification and resolution are required, but available from micro-assembly and packaging solutions
- Desoldering - non-issue, simultaneous evacuation of targeted device and residual solder is available
- Solder Re-deposition - dispensing challenges, need repeatable 60-80µm diameter homogenous dots
- Mechanical - systems require at least 10µm accuracy, presentation of materials for picking need refinement, electrostatic charges and vacuum detection need to be addressed

Figure 5 – Micro-passives housed in peel-away tape

- Soldering Challenges – very dependent on materials and surface finishes, considerations required for adequate control of atmosphere conditions including humidity, cleanliness and oxygen levels
- Clogging of <100µm vacuum holes in tooling require periodic cleaning (cleaning tools / methods not yet available)

LED Array Rework - Faulty Pixel Repair

LED assemblies hosting multiple, non-functional pixels of one or more colors become visually noticeable and are cause for quality rejection and /or scrap.

Figure 6a – assembly with >1000 RGB LED **Figure 6b - magnified view of LED assembly**

The physical attributes of super dense LED assemblies present extreme rework challenges. Reworking thermally sensitive optical components populated along a substrate's edge, or tangent to other devices with minimal component spacing, requires total system and process control with emphasis on thermal convective outputs to prevent "causalities of rework". This may include partial reflow of adjacent devices or discoloration of critical surface finishes, or delaminating of 24 layer or more PCBs. Success must be achieved while minimizing thermal exposure. For example, a time lined de-soldering step in just 120s. Further challenges are presented by lack of available real estate and zero free board space needed to properly mechanically support LED assemblies, not to mention limited process observation due to component topography.

Figure 7 – Single LED desoldered and removed

Mechanical attributes:

- RGB LED size - 1.5 x 1.5 x 0.8h mm (0.060 x 0.060 x 0.030")
- Component pitch - 1.9 mm with 0.2 mm component spacing (0.008")
- LED array - 104 x 78 (>8000 total)
- LED PCB assembly - 200 x 150 mm (8 x 6")
- LED PCB – 24 Layer, solid black finish with exposed solder terminations

Micro Sensor Rework

There is an overwhelming need today for miniature electronic sensors used in data collection and real-time analysis. Some applications include safety, security, environmental, human comfort or medical. Such devices must be tiny with low power consumption, due to in-situ power logistics. Many sub-millimeter micro sensors in development are targeted for low volume applications and are already being positioned for higher volume markets and high value products including integration with complex devices. Single micro sensors are adopting the form factors of micro passives.

Figure 8a - Relative sensor size

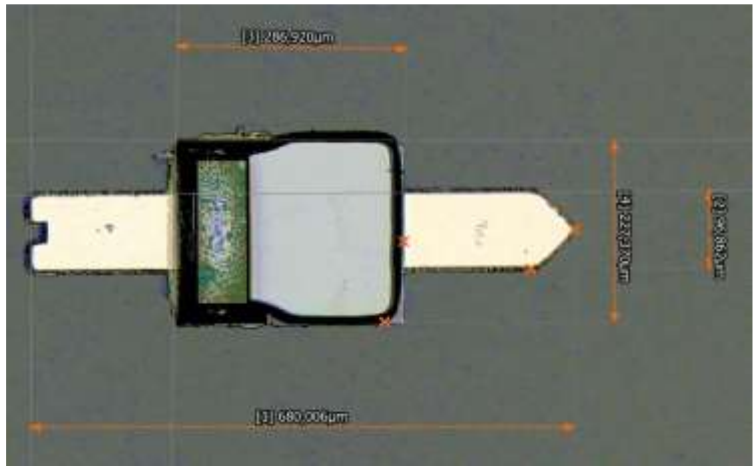


Figure 8b - Magnified view of sensor with dimensions

Assembly of Delicate Beam Lead Diodes

Rework is not just a non-value added recovery process, it can also present opportunities to organizations with its advanced capabilities that can be expanded and used in the world of micro assembly. The assembly of beam lead diodes serves as an example of how an advanced capabilities rework platform offers increased business opportunity and /or internal flexibility.

Figure 9 – Assembled beam lead diode

This application requires the soldering of a “sand grain” sized object to a substrate, without cracking it and with correct polarity. The substrate is brittle, utilizes no solder mask and is densely populated. It offers good thermal conductivity, has high thermal mass and is difficult to heat. Prior to assembly and reflow, requirements exist to apply fresh solder material via a uniform dispensing process, to deliver 120 micron (5 mil) diameter dots into an already densely populated neighborhood.

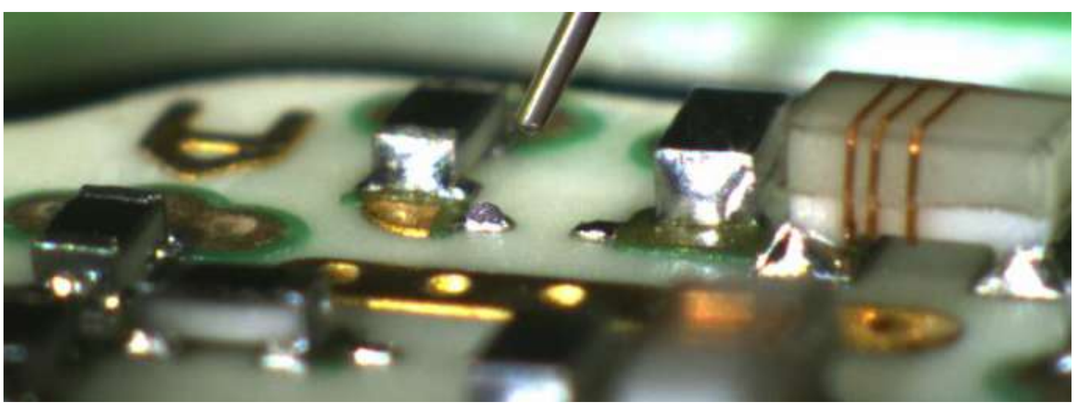


Figure 10 – Dispensing of 120um solder paste dot to rework a beam lead diode

The pick and handling of the beam lead diode needs nearly zero force, offers only a 250 micron (10mil) square termination free surface for tooling, and requires optimal component presentation onto a multi-up substrate consisting of 5 pieces housing

2 diodes each. Throughput requirements necessitate a 120µm dispensing rate of 10 dots per minute, followed by a 3 minute reflow process to conform to defined standards. During reflow, high magnification live process viewing provides real-time visual feedback and inspection.

Mechanical attributes:

- Beam lead diode – 0.68 x 0.23 mm (0.030 x 0.015")
- Ceramic-based substrate – 0.5 mm (0.020") thick

As the 008004 and other micro devices enter the electronic assembly arena, challenges associated with reworking extremely small devices are difficult to conceptualize. There is a steep learning curve unless familiarity of the sub-millimeter world exists - where all is discussed in terms of microns. Real limitations are unveiled, such as the actual 50-60 micron mechanical limit of machining a vacuum hole in a tool to secure a component. Availability of sensors with ranges fine enough to detect micro devices remains an issue. Heating and cooling temperature rates must remain in control and within specification to prevent change in electrical values of components, while applying sufficient energy to form proper solder interconnections. Remnants from the initial adoption of lead-free soldering exist. For example, reflow atmospheres need serious consideration, as they will impact surface tension of molten alloys. This will play a more significant role in the soldering process at micron levels, especially while trying to manage specific solder volumes with either fresh solder material or the reuse of residual solder alloys. In this shrinking world, we will be more dependent on the next generation of electronic assembly materials, including surface finishes, device coplanarity and geometric repeatability.

80 micron Flip Chip Soldering Flex Circuits

To visualize our shrinking world, compare the reduction in solder ball size and pitch. Main stream BGAs have been and continue to be configured with 760 micron (0.76mm) diameter solder spheres and populated with a pitch of 1.27mm. Figure X.0 below depicts the relative size of 500 micron (µm) diameter solder spheres at 1.0 mm pitch down to 50µm sphere at 100µm pitch.

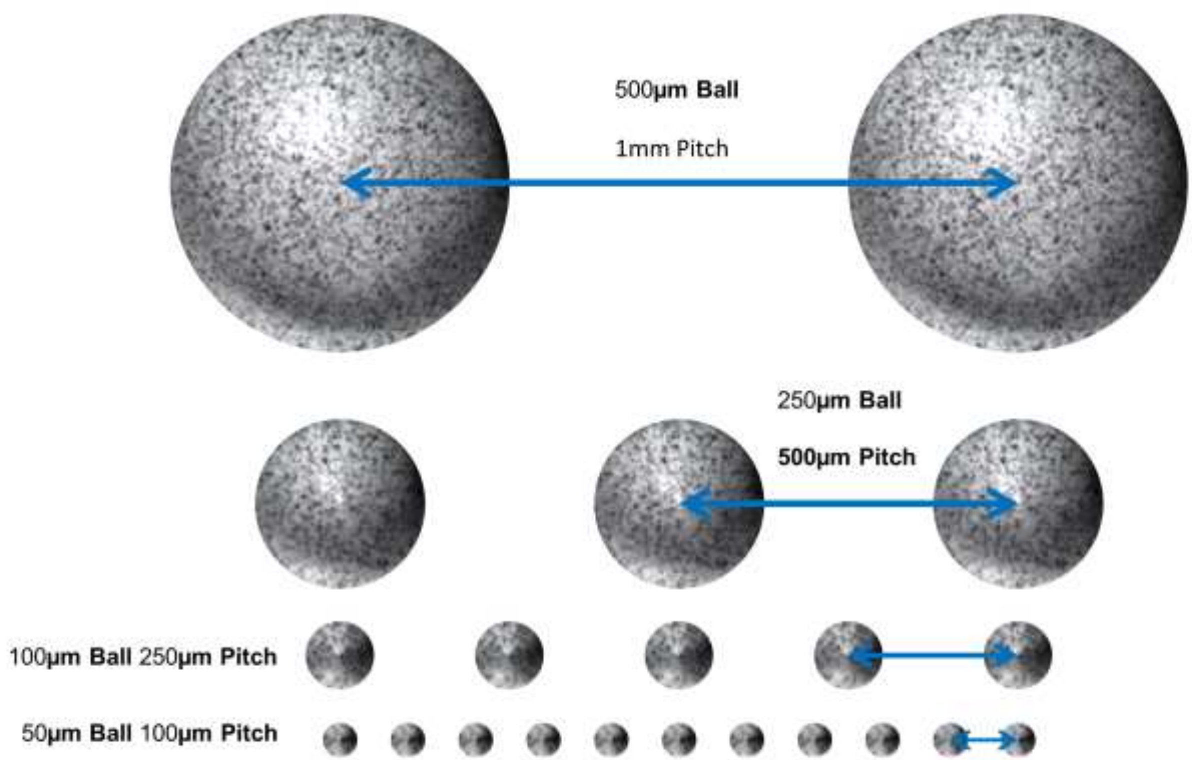
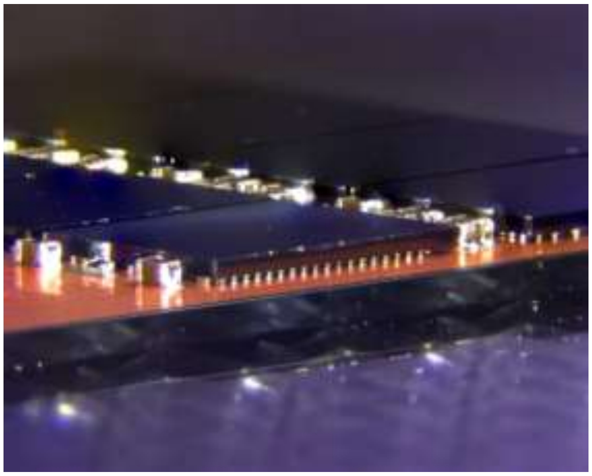


Figure 11 - Solder sphere size and pitch visual comparison

Sixty micron spheres are active in several applications in the C4 world. They are found in many handheld devices striving for increased performance and shorter signal paths. Their use in medical devices is increasing (intelligent implants, ingestible screening devices). Front-end test equipment utilizes these form factors during wafer manufacturing.

Area array flip chip sensors can be populated in dense configurations to minimize occupied real estate and maximize performance.



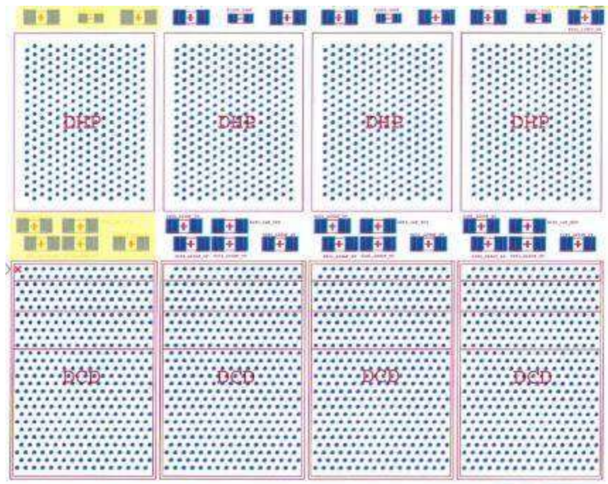
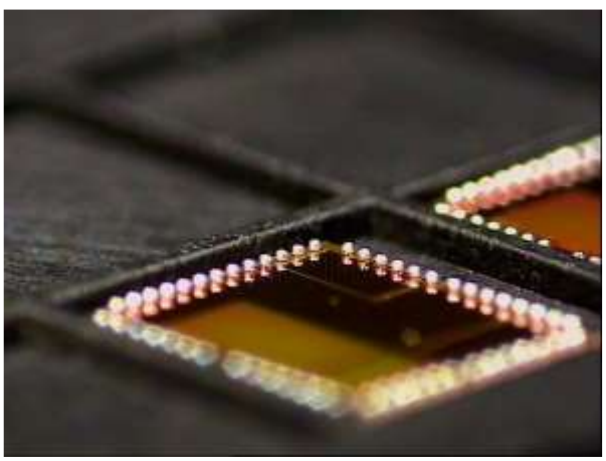


Figure 12a - Sensor with C4 Ball Array **Figure 12b - Sensor population**

In addition to area arrays, flip chips can also be configured as single outline packages (a.k.a. perimeter packages). Both versions are rework viable but present varying challenges in terms of necessary tooling, mechanical product support and component presentation.



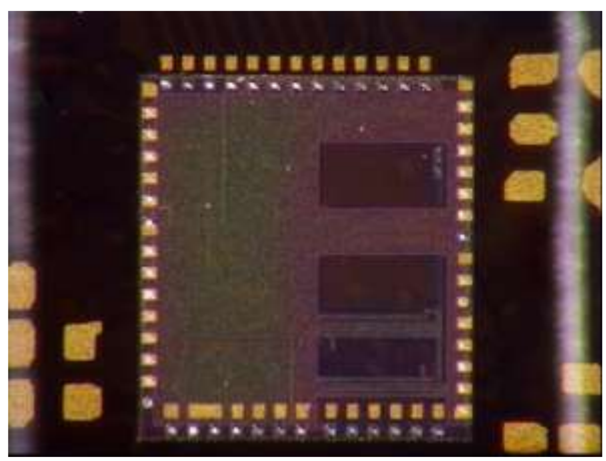


Fig13a – Flip chip with 75 micron solder balls **Fig 13b alignment view of the device on rework system**
populated at 100 micron pitch

Similar to micro-passive rework, C4 flip chip rework presents both equipment and process challenges. The system needs to be able to resolve the flip chip and site adequately. Enhanced optics and illumination are needed. Mechanical accuracy of 5 microns is required and tooling intended to properly present and handle bare die. Thermal considerations are needed for the die, tooling, substrate and product holder to ensure compatible thermal expansion. The highest control of gas flow and heat transfer management is required to ensure proper soldering without component displacement. Additionally, the application of soldering materials like flux is paramount along with supporting various atmospheres.

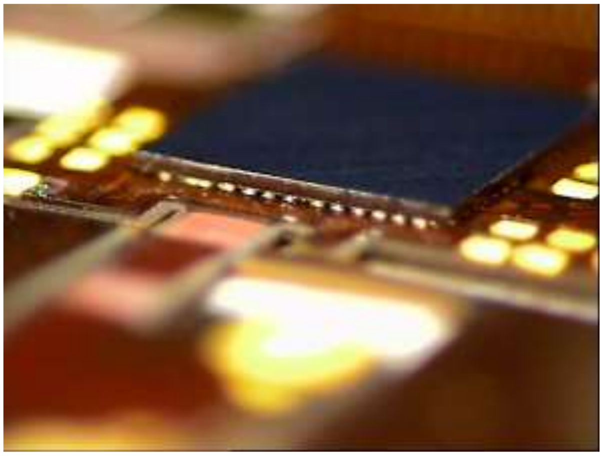


Figure 14 - C4 Flip chip soldered to a flex circuit

The image above illustrates a flip chip configured with 54 perimeter solder balls with a diameter of 75µm and populated at a pitch of 100µm. Each of the 20 individual flex circuits populates a common pallet. Each flex circuit is about 20x20mm, has asymmetrical features, is multi-layer and utilizes gold (Au) terminations.

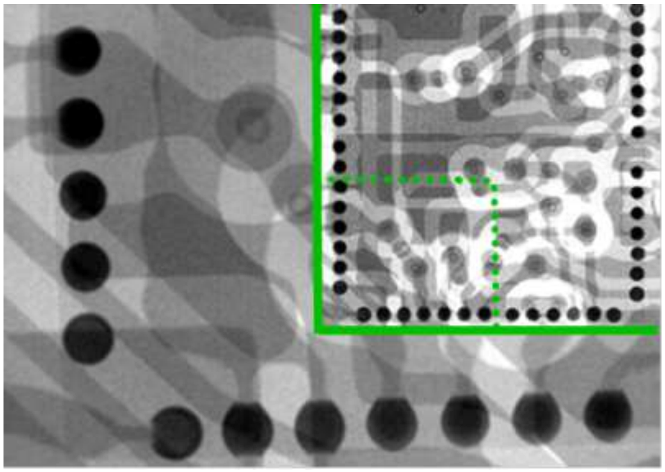


Fig 15 - X-Ray image of C4 flip chip soldered to flex illustrates solder interconnects at high magnification of the lower left corner of the device

Advanced Rework Applications in a Shrinking World

Dan Lilie – Finetech GmbH, Germany
Al Cabral – Finetech, USA

IPC APEX – Las Vegas, NV, USA
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Electronics with Micro-Passives

Wearable Electronics

- Sportswear
- Work clothing, protection wear

Consumer Electronics

- Smart phones, tablets and phablets
- Notebooks, handheld devices

Health Care Electronics

- Hearing aids
- Cardiac pacemakers
- Insulin injection

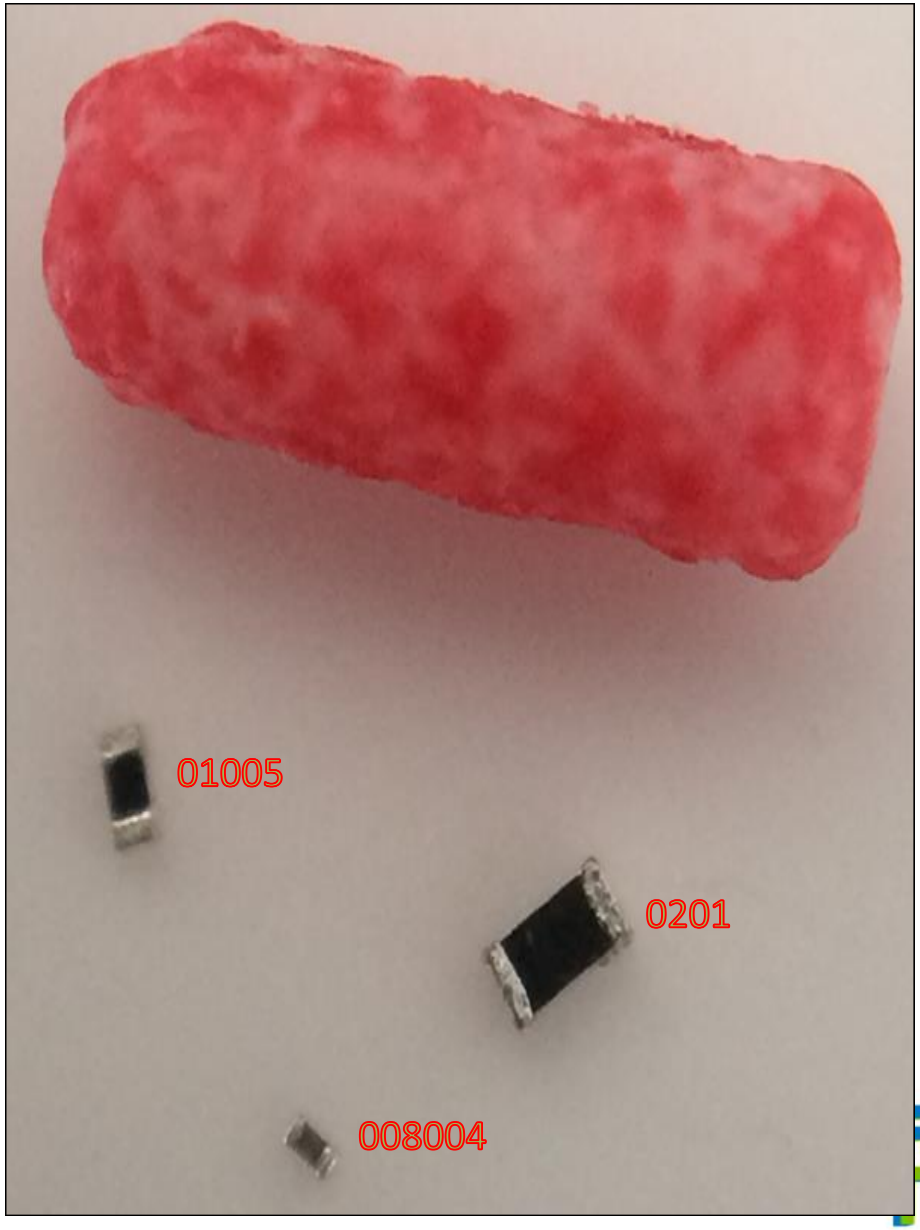
Micro-Passives vs. Sprinkles

Everybody knows “sprinkles”

- Small pieces of sweet decoration
- Mostly made of sugar or chocolate
- On cupcakes, cookies or ice cream

- 2 - 4mm long
- Diameter ~ 1.5mm

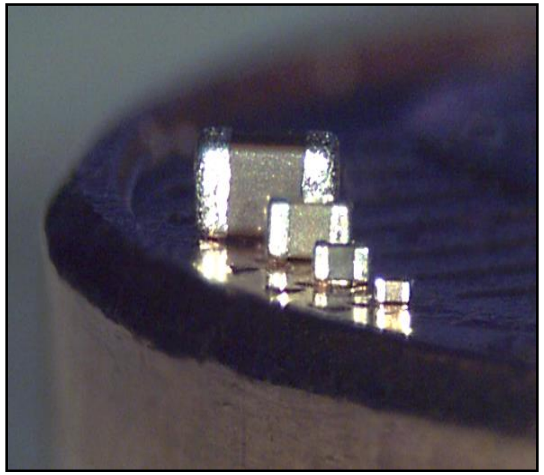
- Compare with 008004, 01005 and 0201



Micro-Passives Dimensions

Active & Passive Components

- Resistors (flat design)
- Capacitors
- Coils and diodes



Component Sizes (nomenclature issue)

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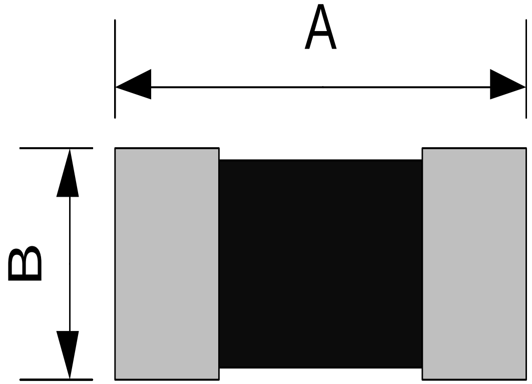
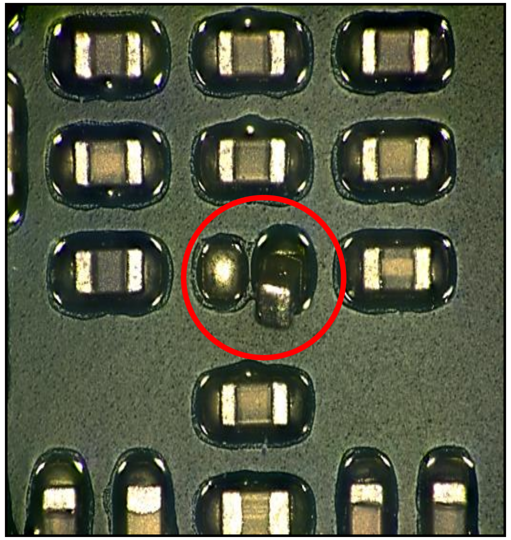
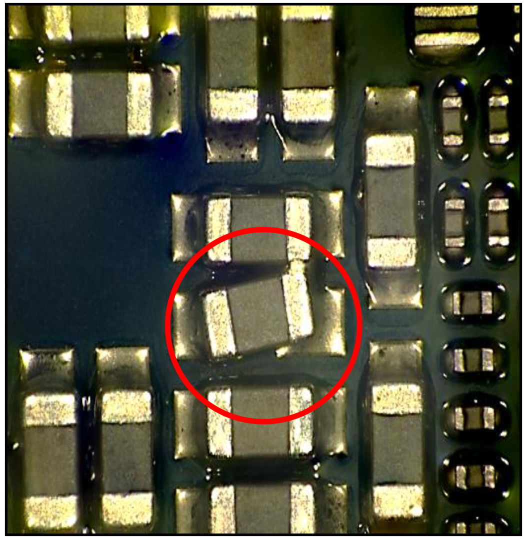


Micro-Passive Rework Drivers

- Low volume Research & Development
- Defect or wrong components (e.g. resistor value)
- Tombstone effect
- Shifted / twisted components / shorts
- Missing or unequal amount of solder
- Cold solder joints





Micro-Passive Typical Tooling (008004)

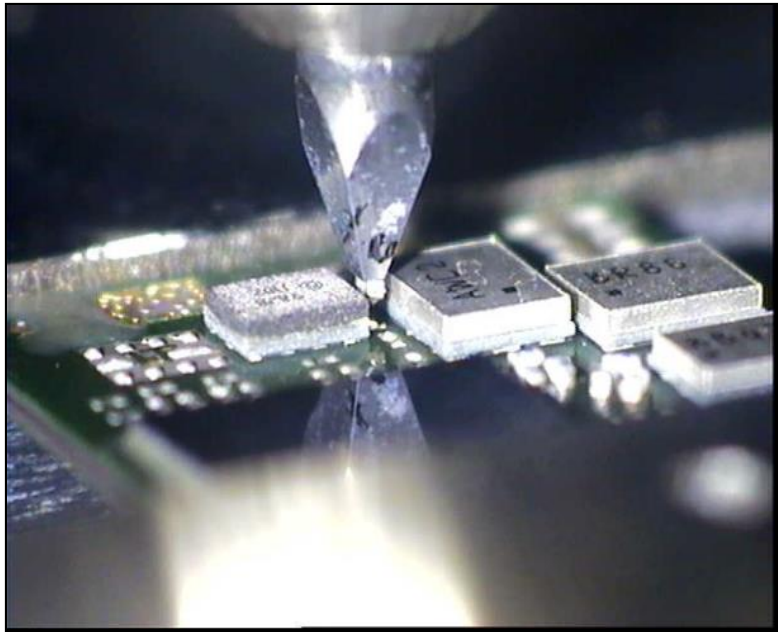
Soldering Head / Nozzle

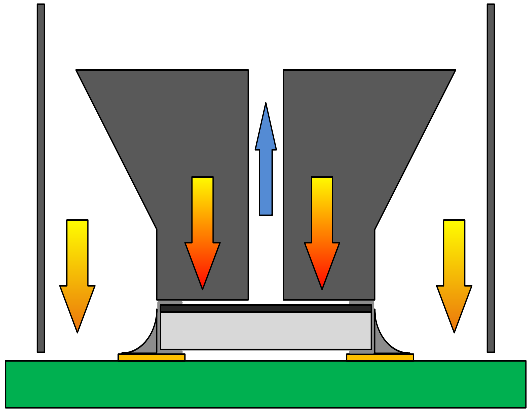
- Similar design to 01005 tooling, but …
  … smaller outer dimensions
  … smaller vacuum hole diameter

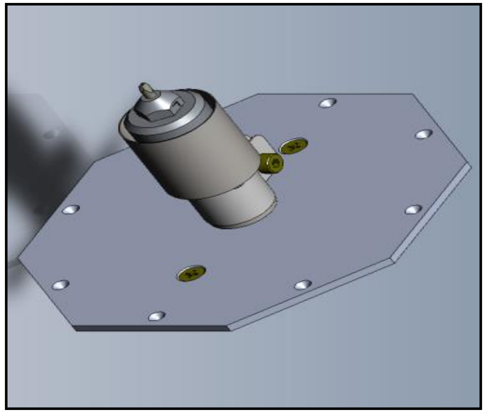
- Thermode Tip (conductive heating)

- Throttle Cap for heat regulation (side warming)

- Short or long tools depending topography







Vision, Vacuum and Force Considerations

Vision Systems

- Brighter Lighting / Illumination
- Higher Resolution Optics
- Higher Magnification

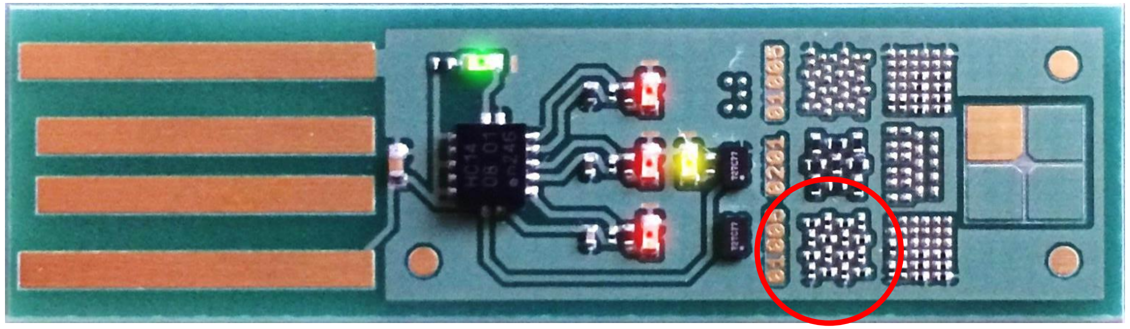
Vacuum Systems

- Finer Vacuum Detection and Resolution

Force Systems

- Increased Force Sensitivity <50g

Micro-Passive Materials & Equipment Considerations



Solder Paste
- Type 6 or 7
- Flux With Long Activation Times
- Increased Material Consistency

Dispensing
- Small / Short Needles For Very Small Volumes
- Prevent Flux Separation From Alloys
- Require <100 um Dots

PCB
- Increased Feature Fabrication Accuracies

Initial 008004 Rework Results

Vision challenges

- Available Higher Resolution Vision Applied from Bonding Solutions

Dispensing challenges

- Homogenous and Uniform Dot Diameters (50 - 100 µm) Required

Pick and Place Challenges

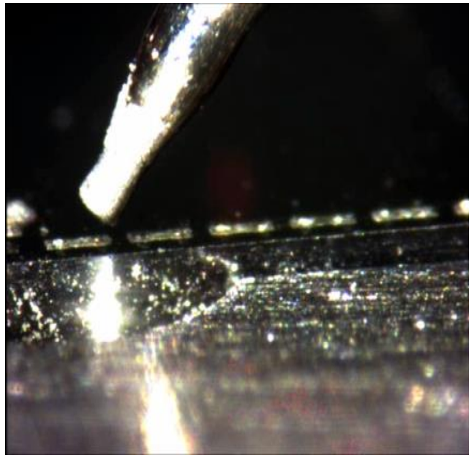
- Electrostatic Charge and Vacuum Detection Needs Improvement
- Clogging of Vacuum Holes, Cleaning Tools Not Yet Available

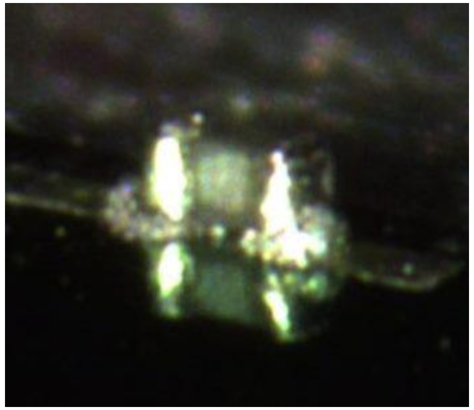
Soldering Challenges

- Material and Surface Dependant, Improved Surface Conditions Needed

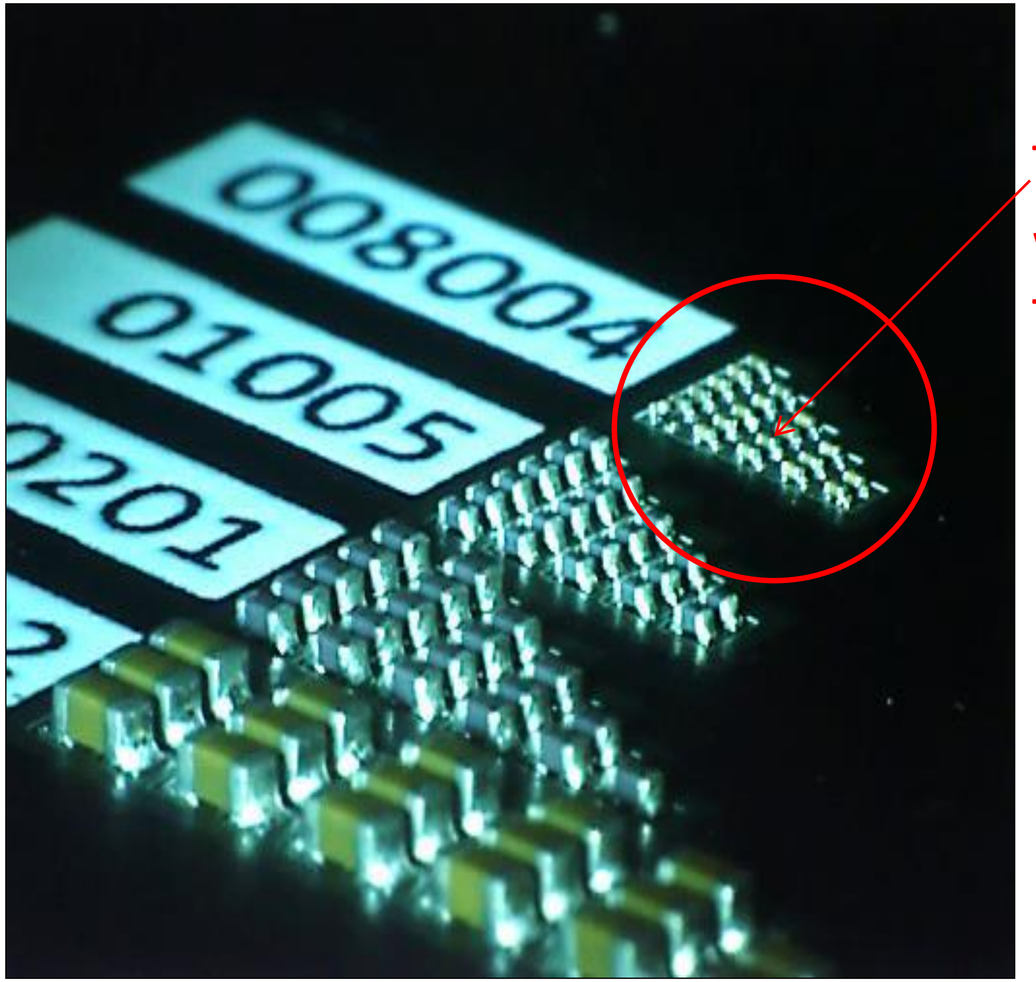
Desoldering Challenges

- Devices and Solder Removed Simultaneously



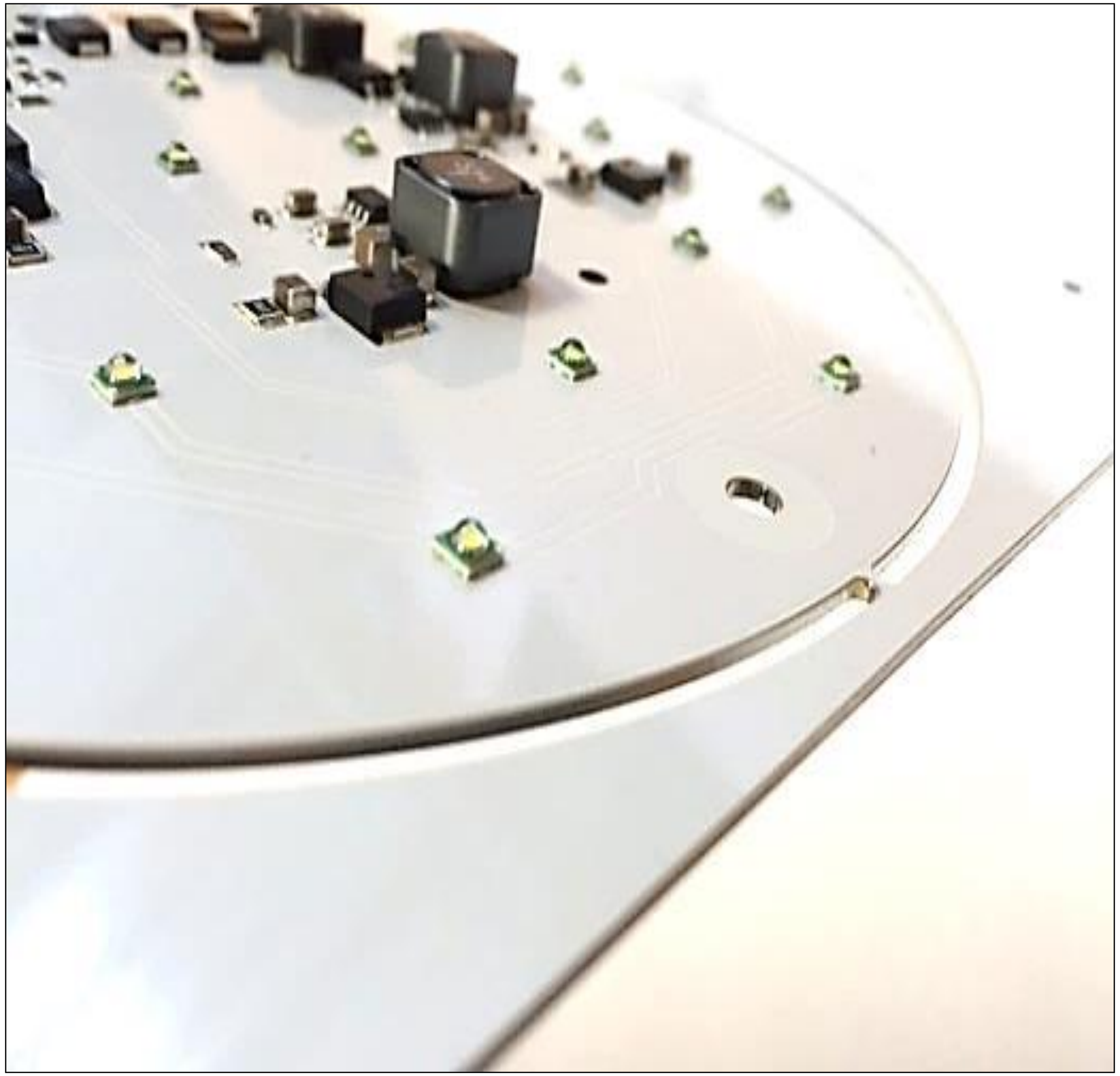


Micro-Passive Rework



Try reworking this with a Heat Gun & Tweezers!

LED Rework

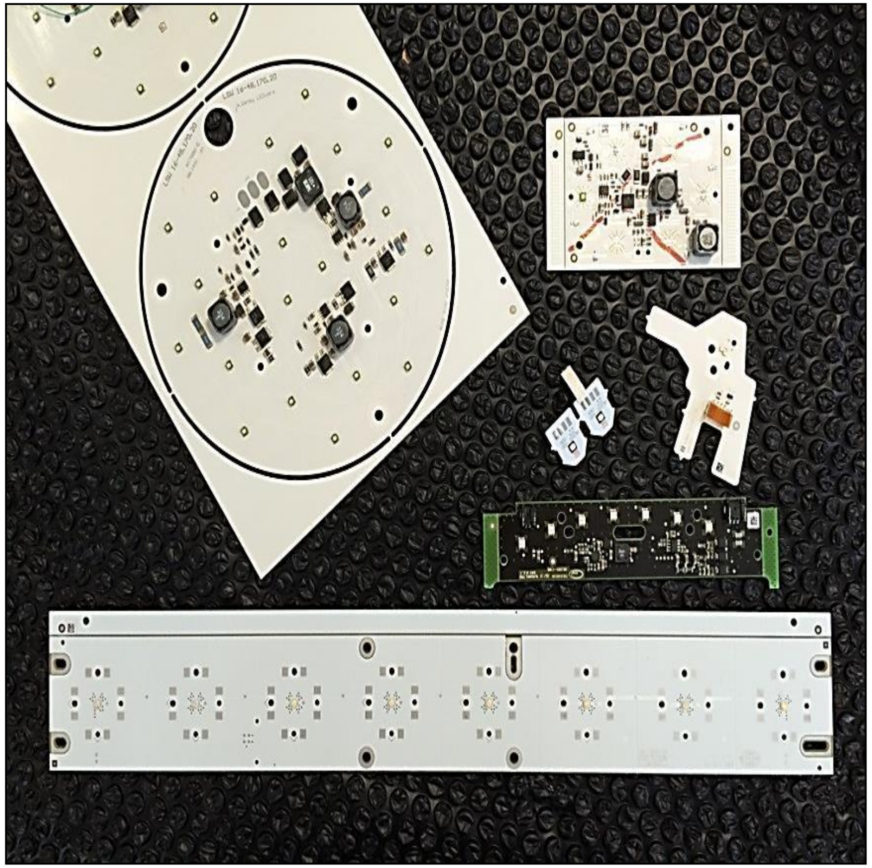


LED Substrates

Substrate Materials
- Mostly aluminum
- FR4 PCB
- Ceramic

Substrate Sizes
- Small / Very Small → e.g. Medical Apps.
- Mid Size → e.g. Automotive Apps.
- Large → e.g. Displays, Big Spotlights
- Very Large → e.g. Marketing Display Walls

Substrate Shapes, Weight and Thickness
- Always different!!!

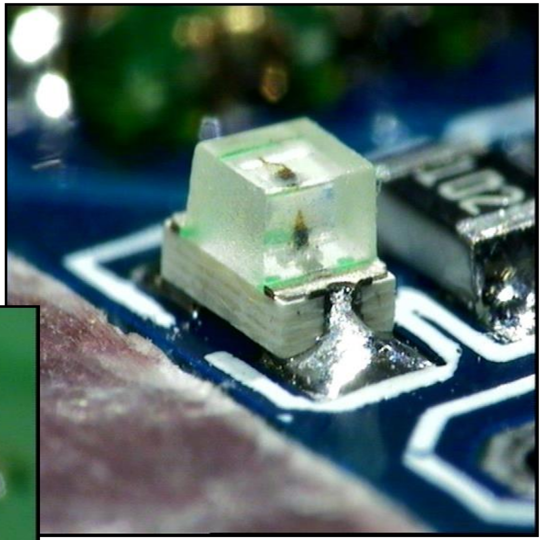


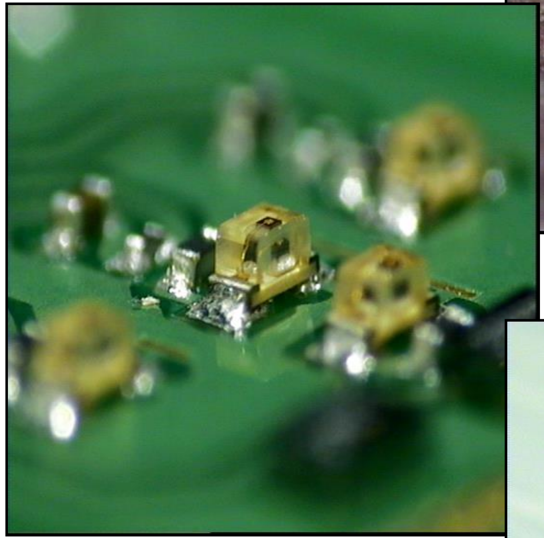
LED Designs

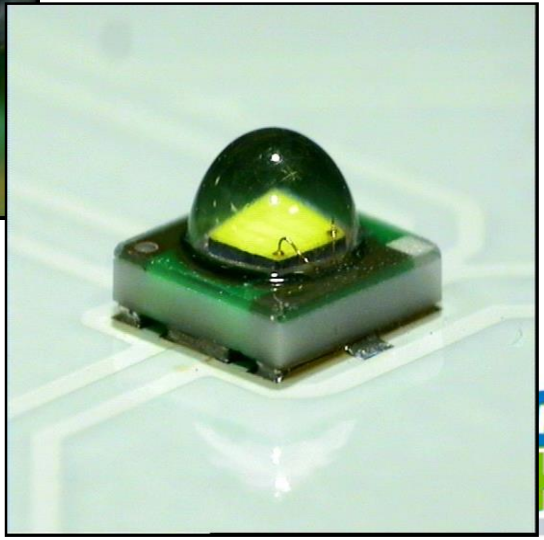
- Small: Mostly 0402, 0603, 0804 Sizes
- Big: Up to 15 x 15 mm

- Sensitive Plastic / Silicone Bodies
  - Risk of Deformation
  - Risk of Changing Light Spectrum
  - Shortening Durability

- Difficult Handling
  - Various Surfaces
  - Big Pads with High Surface Tension



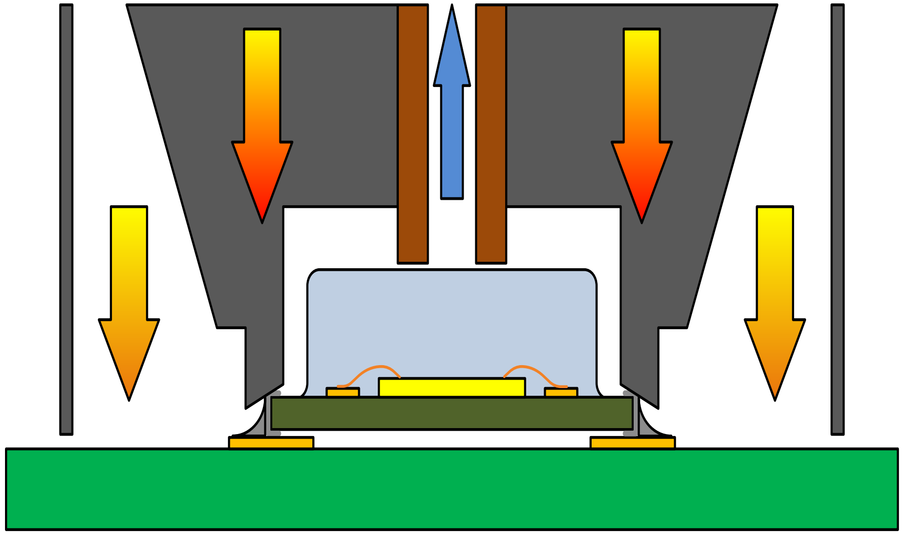


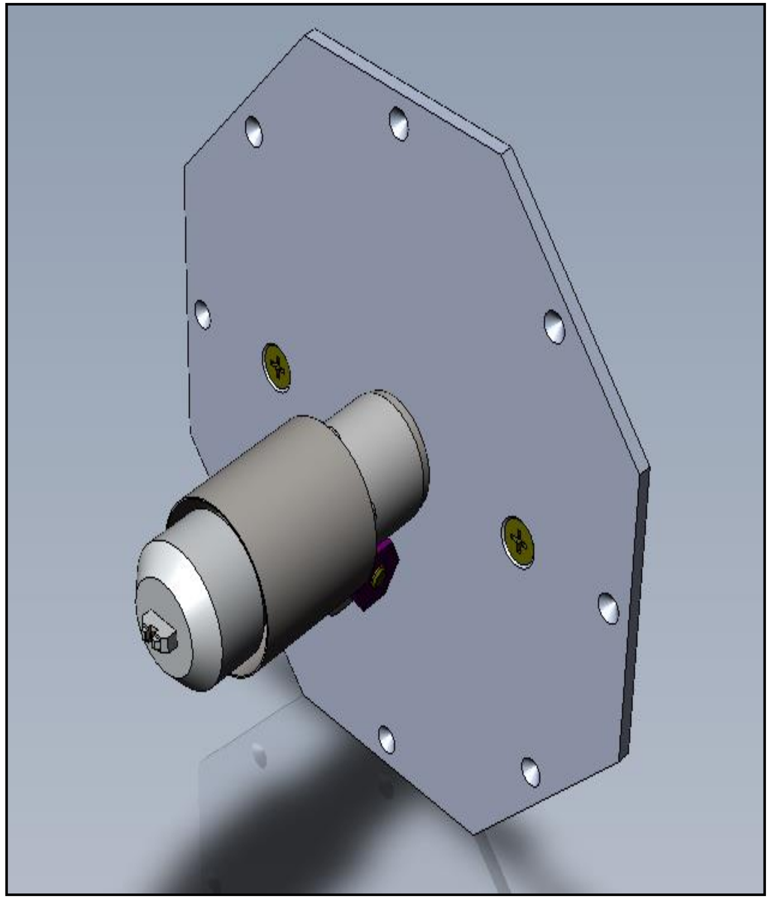


LED (e.g. 0402)

Solution:

- Contact heating / Conductive Thermode
- Heat Resistant Plastic Material
- Adjacent Heating Throttling

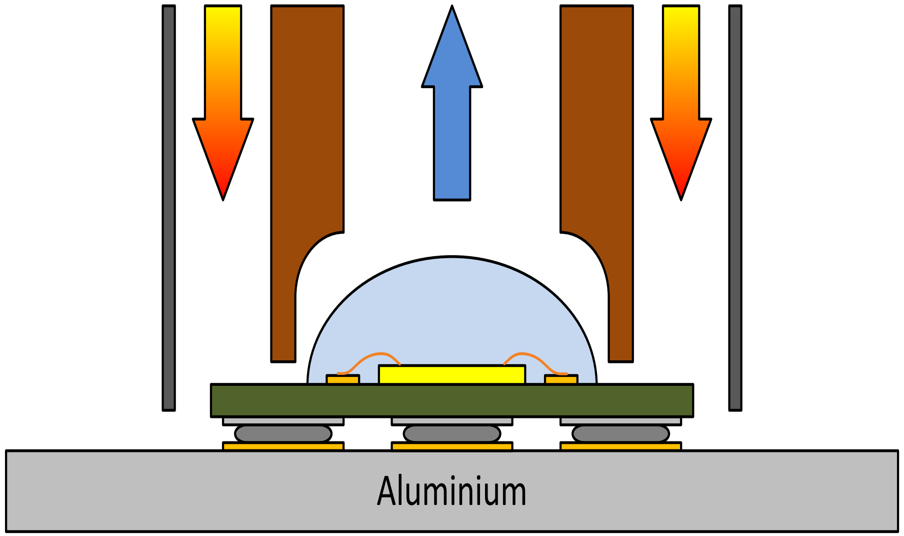


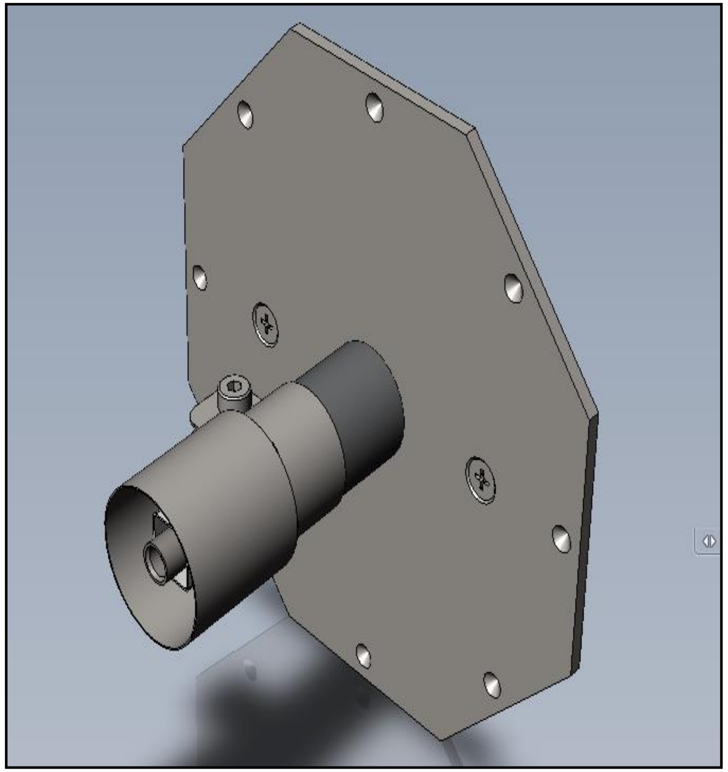


LED (e.g. 3x3 [mm])

Solution:

- Heat Resistant Plastic Material
- Heat Protection via Thermal Isolation
- Adjacent Heating Throttling

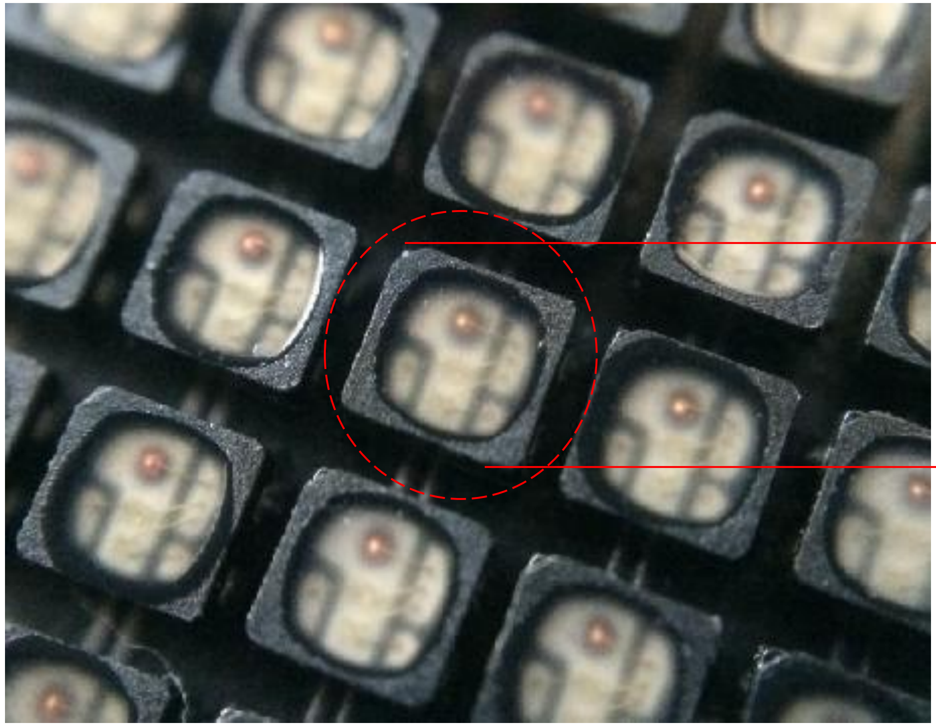




LED Array Rework - Faulty Pixel Repair

Assembly With >1000 RGB LEDs

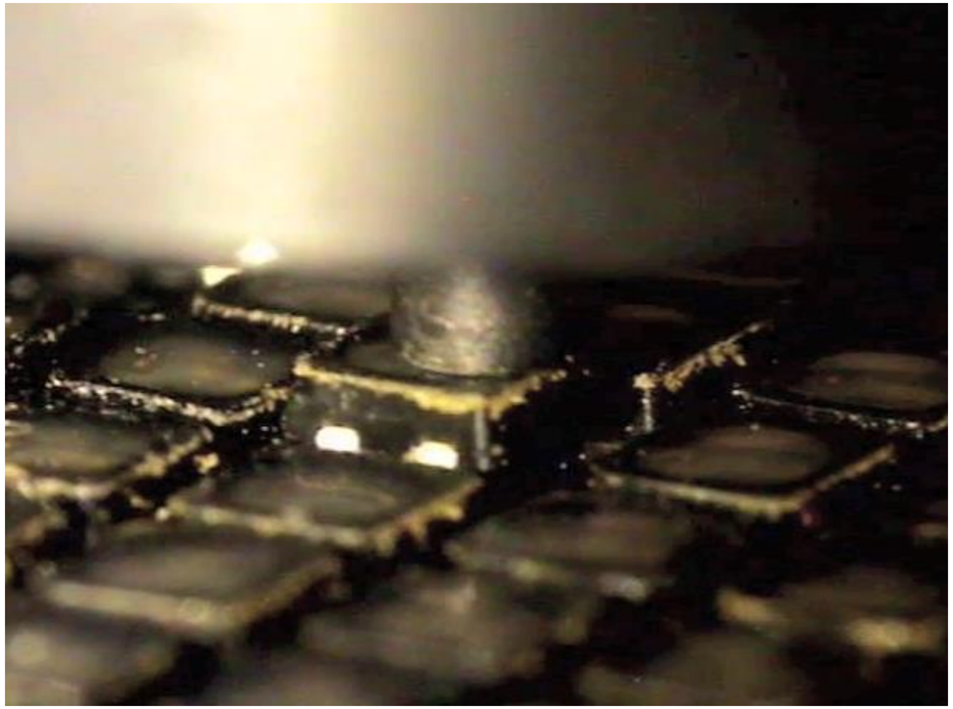
LED Array Rework - Faulty Pixel Repair



1.5mm (0.060”)

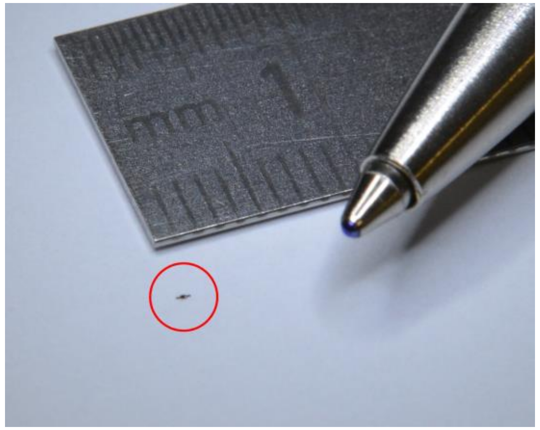
- RGB LED Size: 1.5 x 1.5 x 0.8h mm (0.060 x 0.060 x 0.030“)
- **Component Pitch: 1.9 mm with 0.2 mm component spacing (0.008“)**
- LED Array Configuration: 104 x 78 (>8000 total)
- LED PCB: 200 x 150 mm (~8 x 6“), 24 Layers, Solid Black Finish with Exposed Terminations

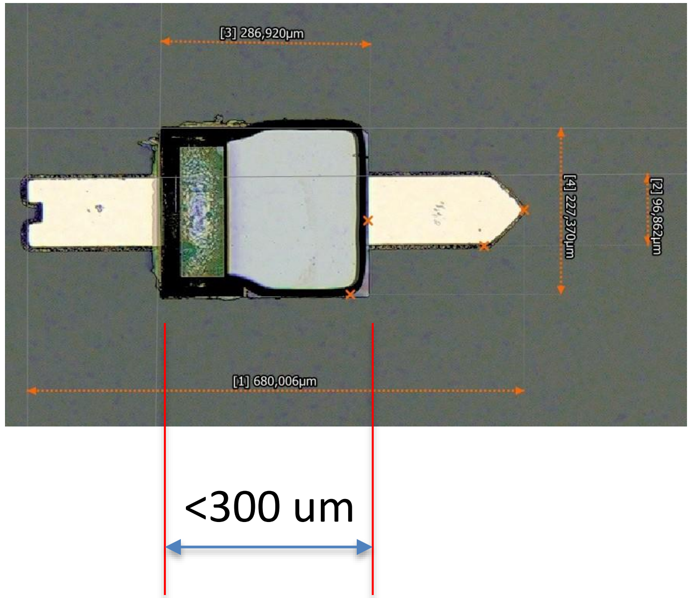
LED Array Rework - Faulty Pixel Repair



Single LED Desoldered and Removed

Micro Sensor Rework

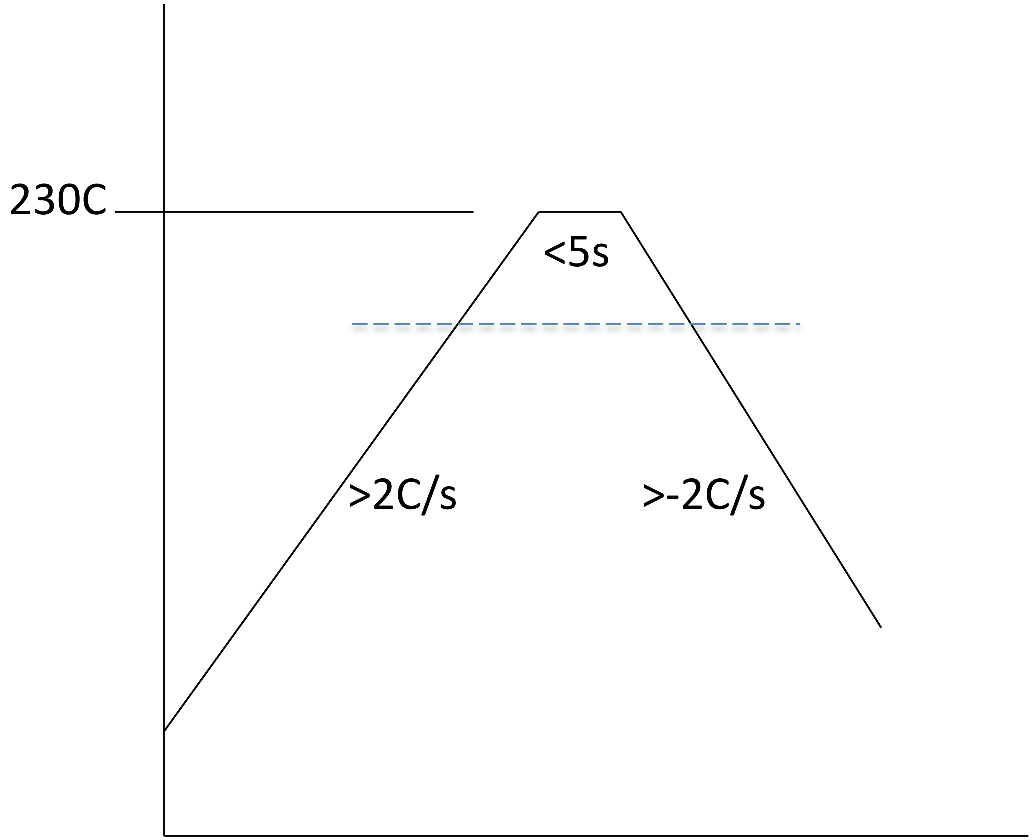




Rework Challenges:

- Physical Size
- Temperature Sensitivity
- Fragile Devices, Minimal Force

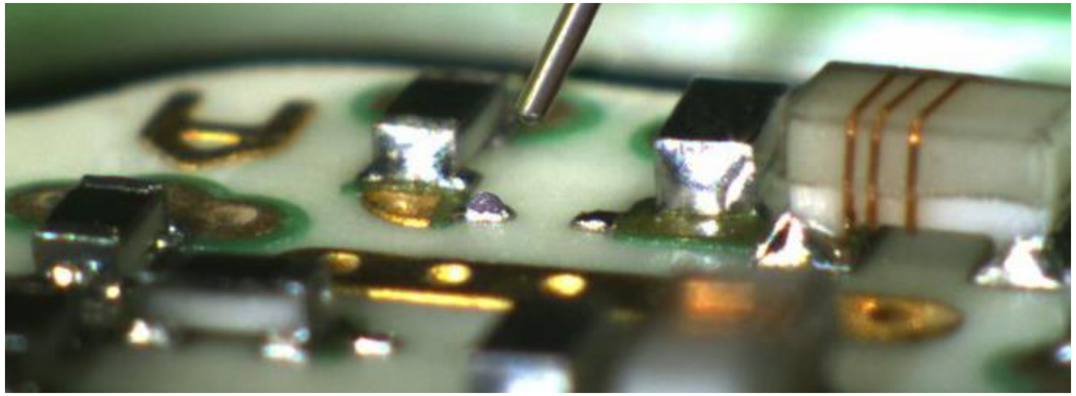
Micro Sensor Rework



Typical SAC 305 Micro Sensor Rework Profile

Beam Lead Diode Rework

Delicate Placement

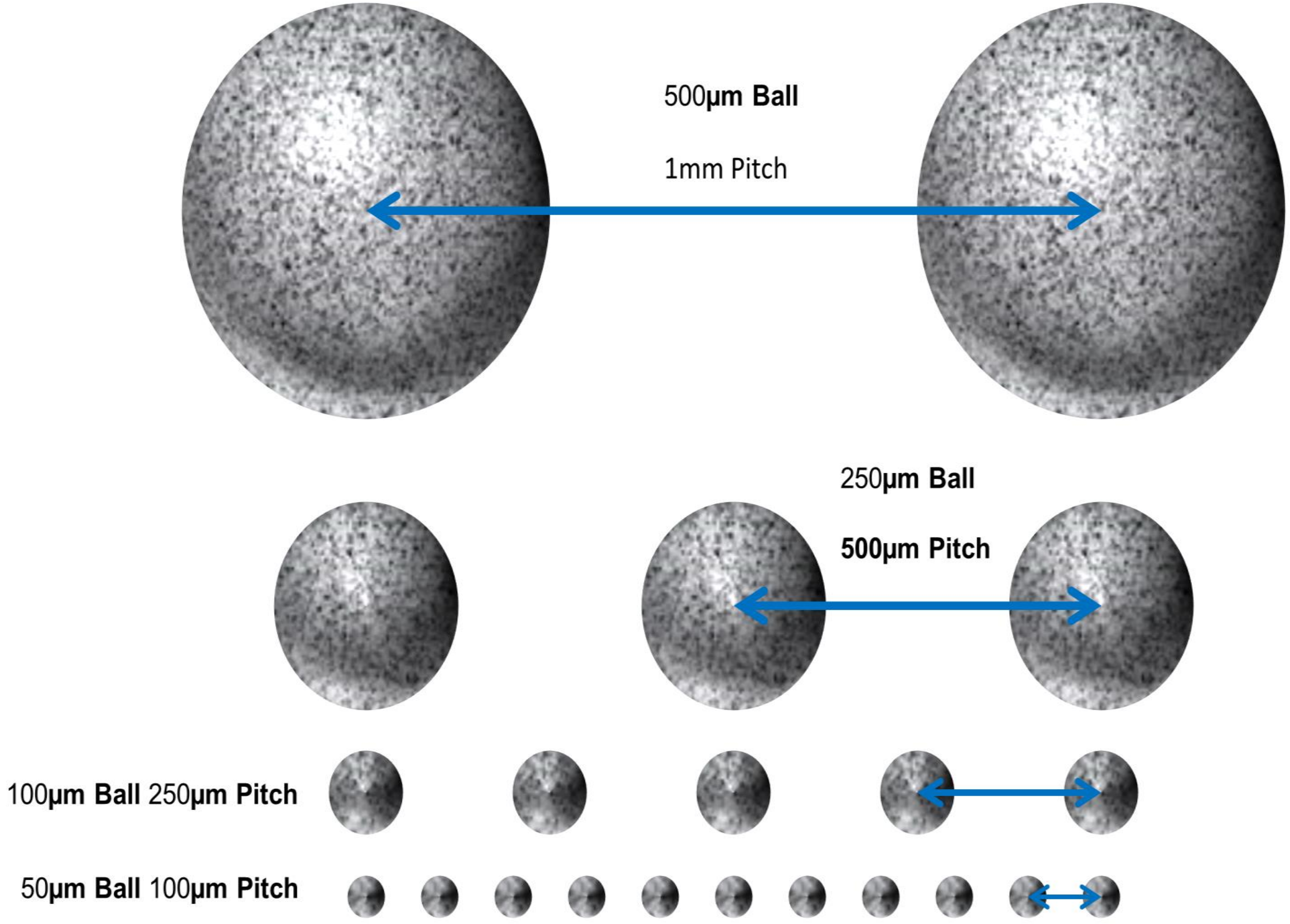


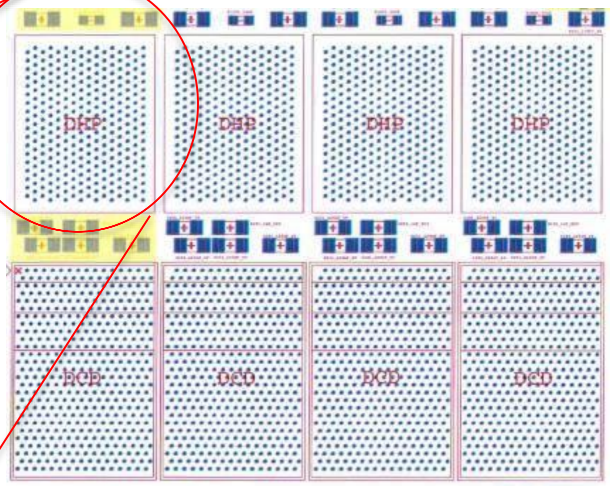
Dispensing of 120um Solder Paste Dots

- Device: Beam Lead Diode 0.68 x 0.23 mm (0.030 x 0.015“)
- Substrate: Ceramic 0.5 mm (0.020”) thick

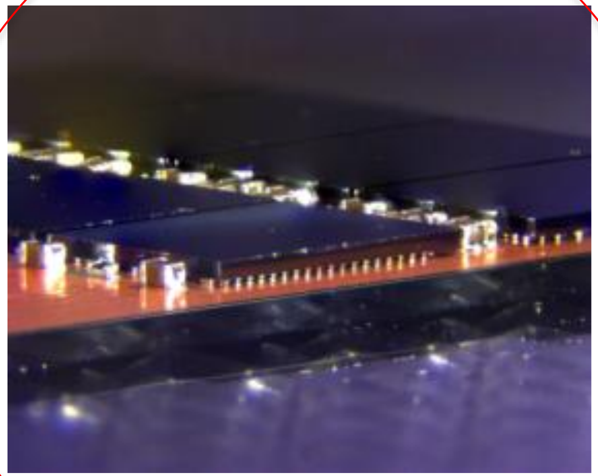
Flip Chip Soldering to Flex

Relative Solder Sphere Size and Pitch

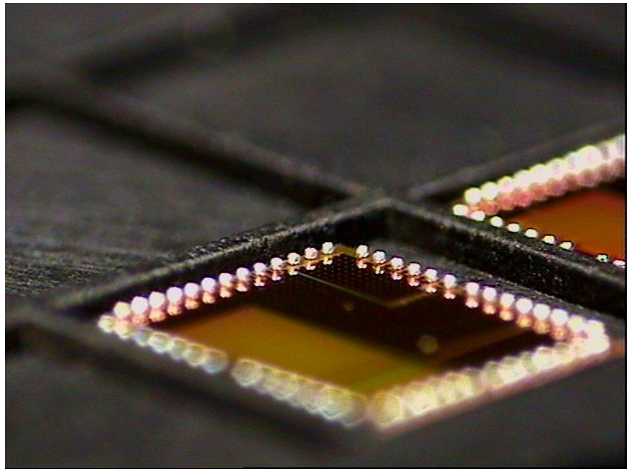


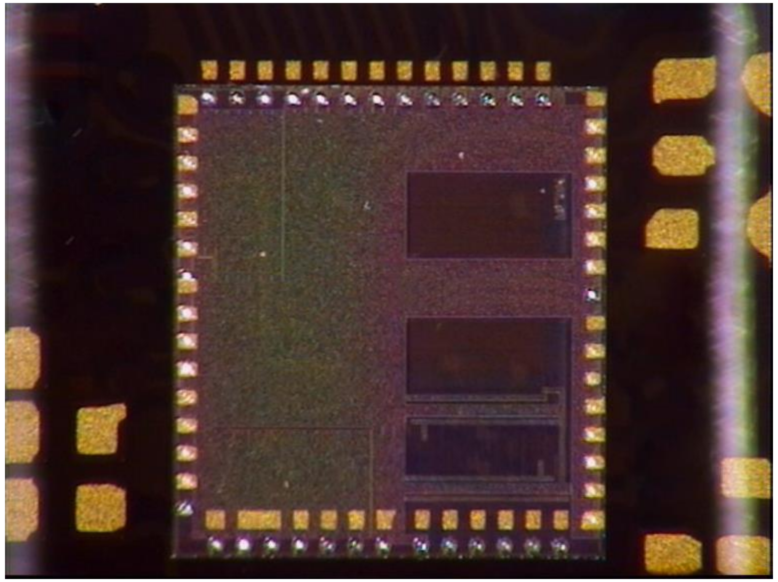


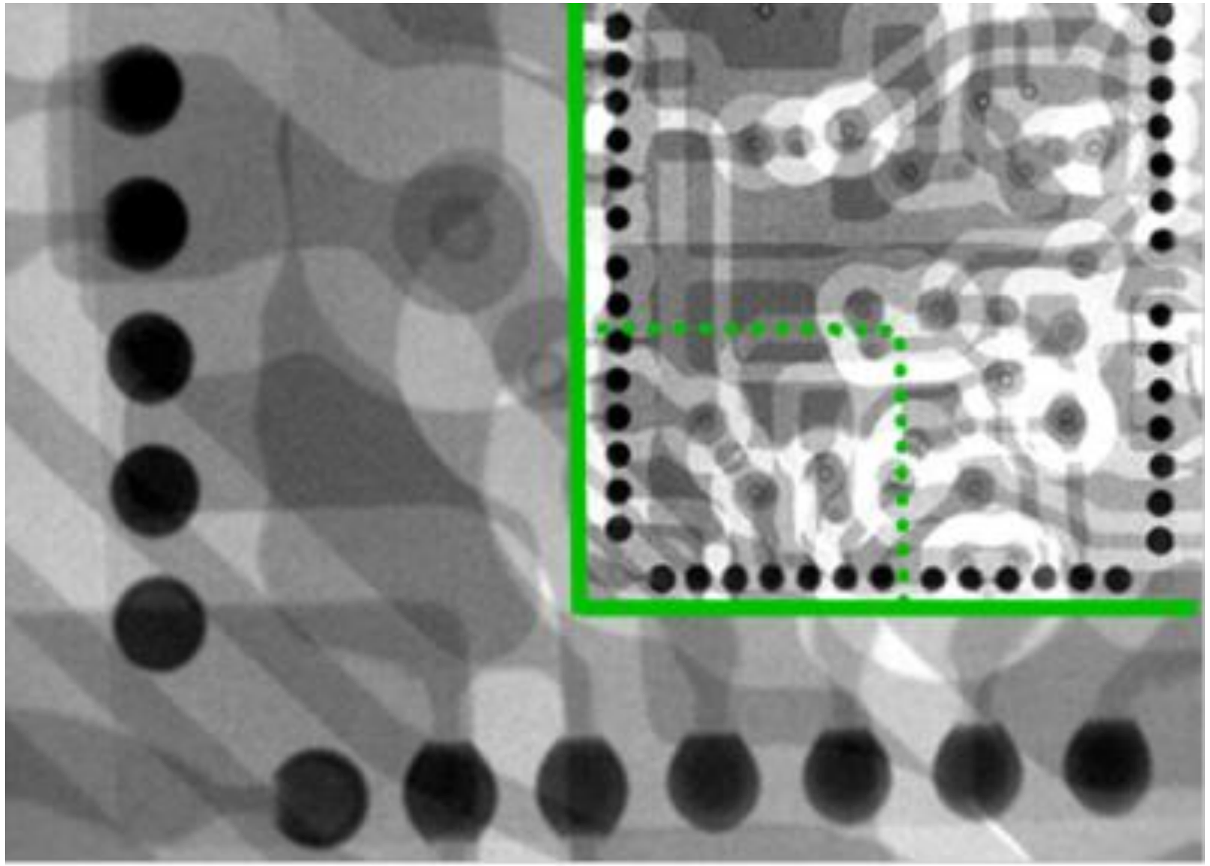
Sensor Population



Flip Chip Sensor with C4 Ball Array

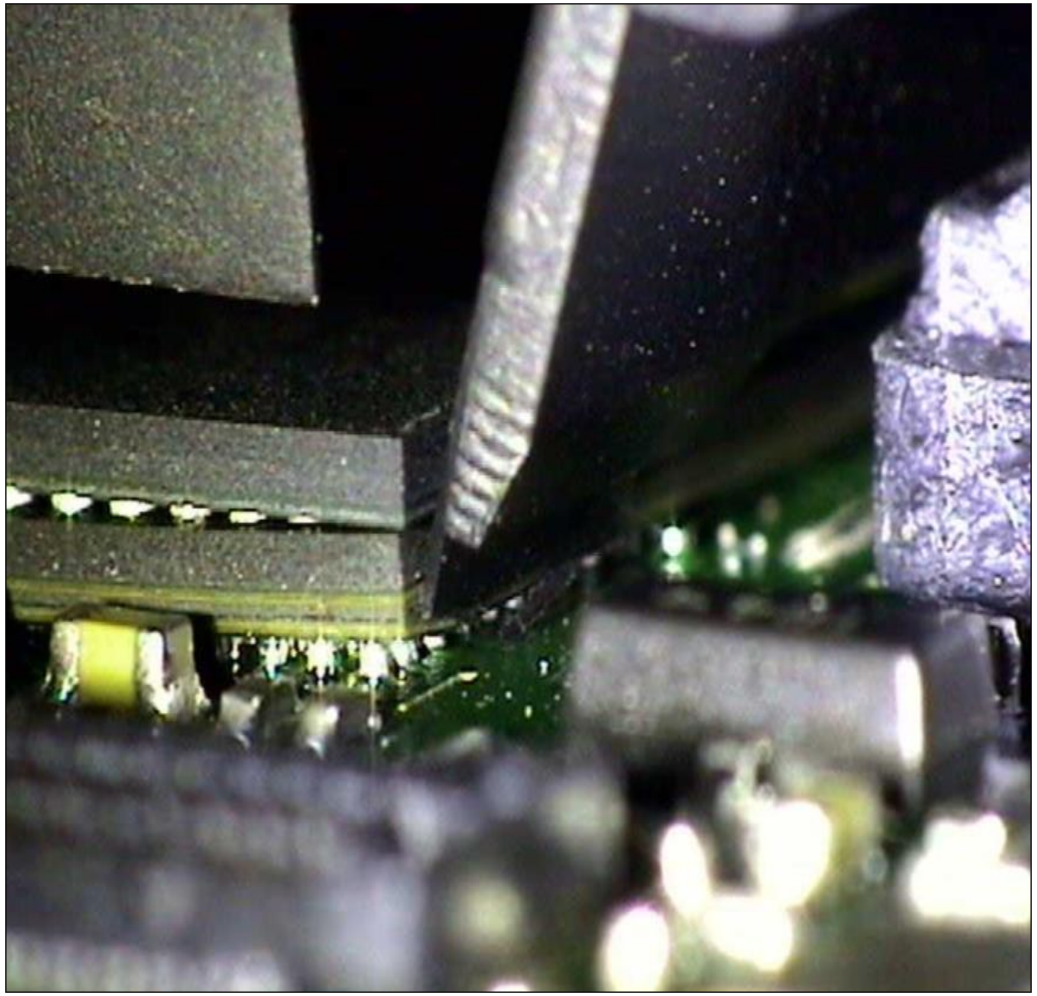

Flip Chip with 75 um Solder Balls at 100 um pitch


Alignment View of Flip Chip on Rework System



X-Ray Image of Flip Chip Soldered to Flex
Illustrates Solder Interconnects at High Mag.
of Lower Left Corner of Device

Underfill Rework



Underfill Applications

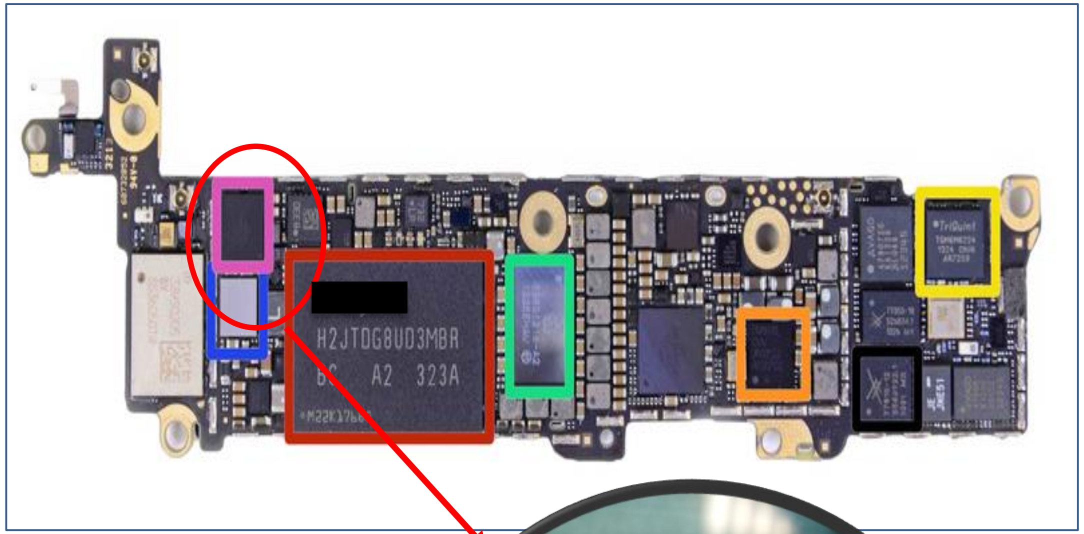
Demands

- Chip
- Substrate
- Whole device

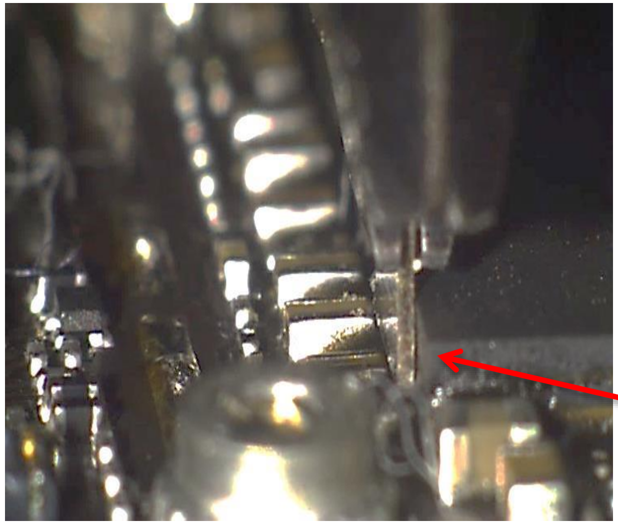
Markets

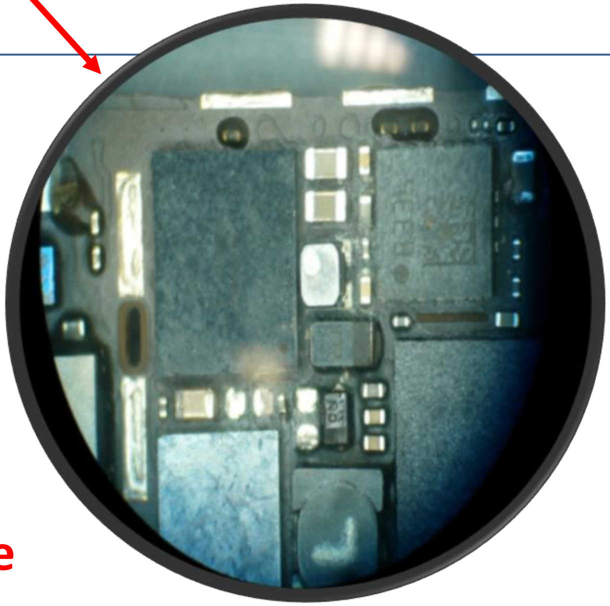
- Automotive
- Data Recovery
- Forensic
- Mobile Service Contractors

Underfill Challenges



- Component Size
- Thickness
- Distance to Surface
- **Distance to Adjacent Devices**

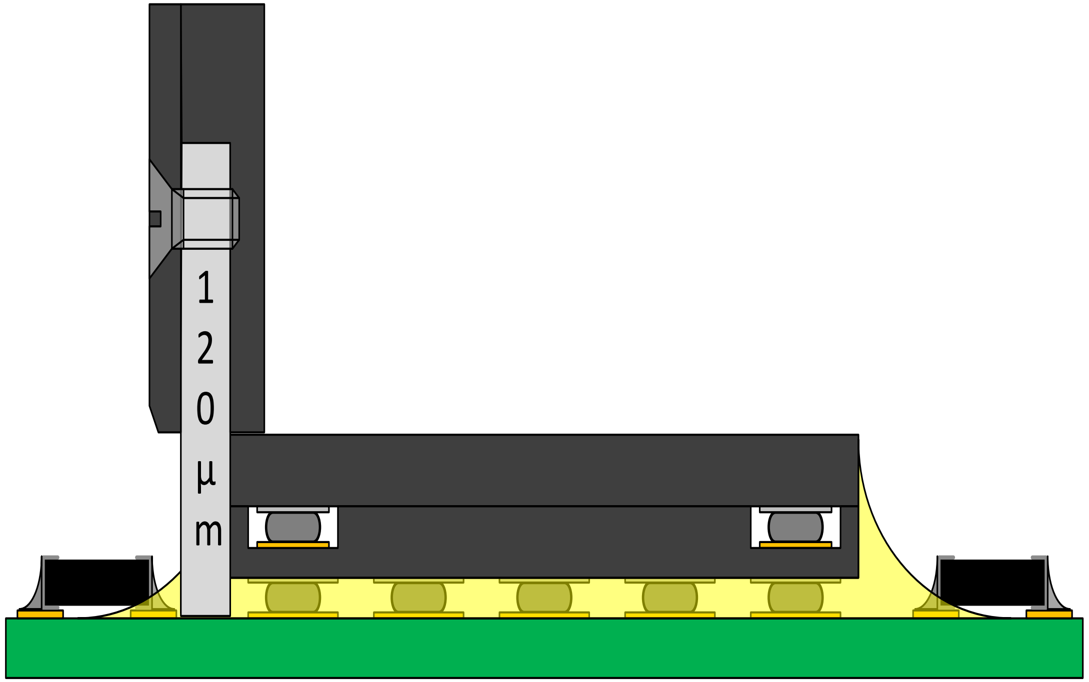




Adjacent Device

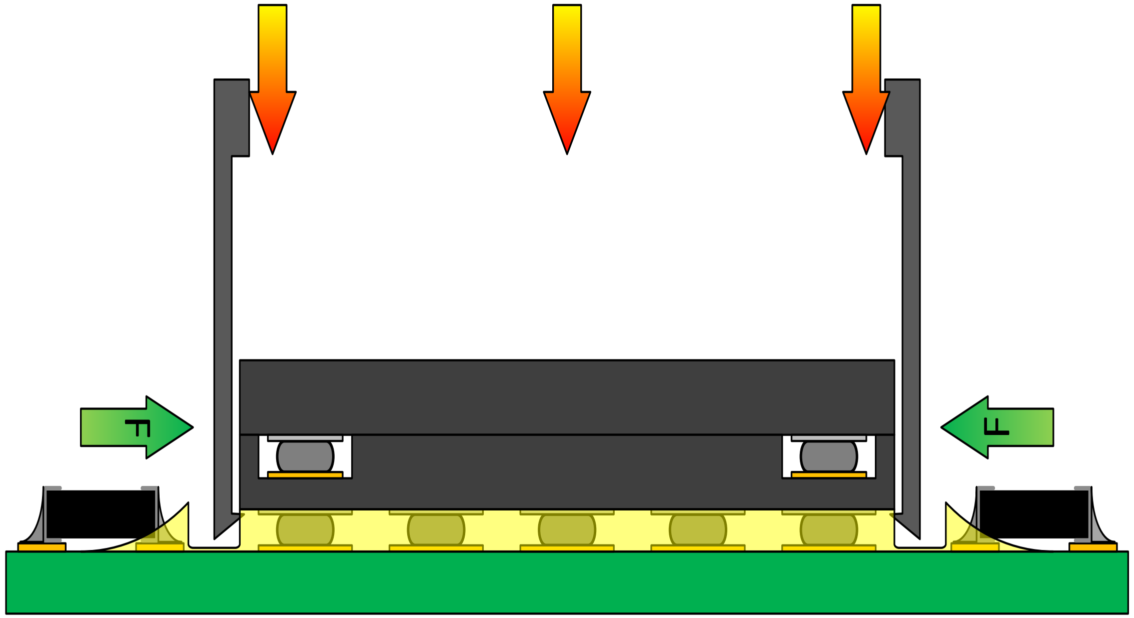
Distance 0.2mm!

Underfill Slicing



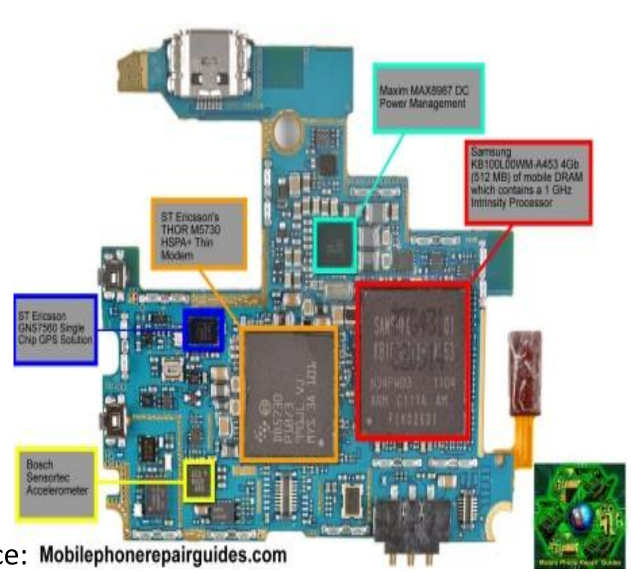
120µm Knife with Positive Component Contact Enables Safe Underfill Cuts

Underfill Heating

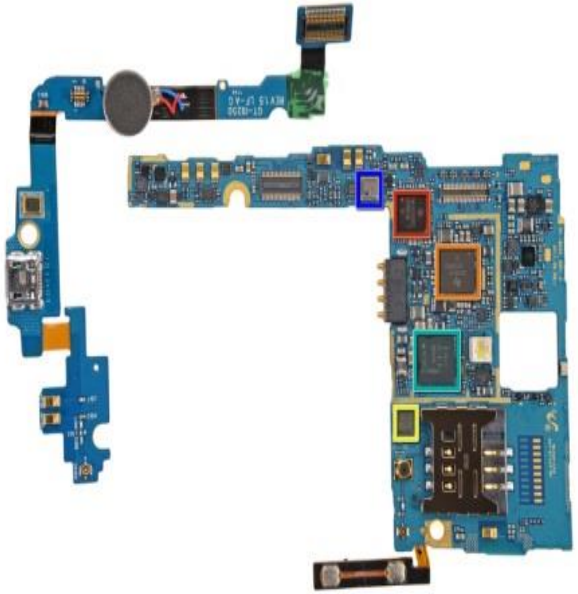


Underfill Solder Nozzle with Gripper

Current Underfill Rework Limitations



Reference:



- Underfill **MUST** Be Reworkable!!!
- 0.2mm minimum Distance to Adjacent Devices
- Minimum Component Size 8 x 8mm
- Minimum Component to PCB Height (Gap) >0.2mm
- Quality PCB Material
- Rigidity Fixtures for Asymmetrical and Thin PCBS

Advanced Rework Equipment Requirements

- Accurate, 5um or less – <u>no</u> specmanship!
- Repeatable, able to rework more than 1 in a row
- Powerful, requires significant heat transfer (heating & cooling)
- Control, cannot displace adjacent components
- Thermal Isolation, protect sensitive devices
- Vision, high resolution vision with high magnification
- Innovative Tooling, not everything is symmetrical and uniform
- Solder Replenishment, cannot always rely on enough residual

Questions?

dan.lilie@finetech.de

ac@finetechusa.com

Thank you