REWORK PRACTICES FOR MICROLEDS AND OTHER HIGHLY MINIATURIZED SMT COMPONENTS

Neil O'Brien
Robert Avila
Finetech
Gilbert, AZ, USA
neil@finetechusa.com
robert@finetechusa.com

ABSTRACT
Miniaturization of SMT components has been a continuing trend in all marketplaces, but probably most notable in consumer electronics. Smartphones and the rapid advances in the display market have implemented various microLED's, as well as small passive devices such as 01005 and 008004 devices.

Packing more miniature devices into less space, results in very challenging rework conditions. Repairing these sites should not create more rework by damaging neighboring components or the substrate. The use of glue and foil shields are not reliable high-yield methods. This challenge requires novel solutions for tooling, site preparation, paste deposition, precise thermal management, as well as high accuracy and optical resolution. This paper will focus on practices and innovative solutions to successfully repair these miniaturized, sensitive and often fragile components. For the general purposes of this paper, miniaturized components are those below 1mm in length and width.

Key words: microLED, rework, 01005 devices, 008004 devices, miniaturized components

INTRODUCTION
Smartphones, tablets and other mobile devices have seen rapid advances in display technology. Users enjoy better resolution and brightness all in a thinner product. The use of discreet components is now in mainstream production. The newest in these markets include microLEDs, in addition to the growing adoption of small passive components in mass production down to 01005 and 008004 (see Figures 1 and 2). Even with extremely good production yield, these small components in a high-volume manufacturing process will still create a rework need.

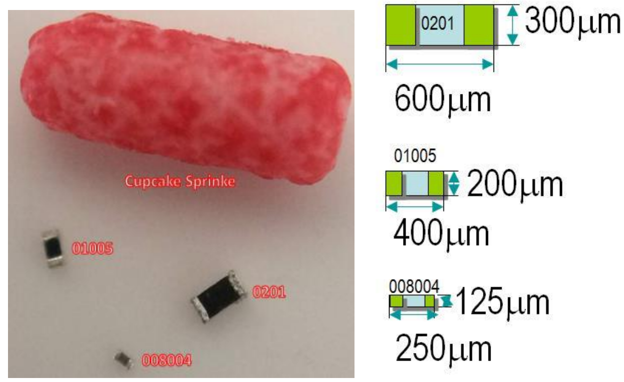

Figure 1. Small passive size comparison

To help put this in perspective, a 42mm Apple watch has roughly 120,000 pixels, each one of three colors, so that would mean up to 360,000 microLED's. [1] Because of the scale here, most manufacturers have targeted this smaller "near eye" market first. But the large display market is the second market that is rapidly advancing. The Yole Development group forecasts the market for microLED displays could reach 330 million units by 2025. [2] Final assembly yield will be the biggest obstacle to volume production adoption. With this forecast of microLED production demands, rework is a significant consideration, even at greater than 99.99% yield.

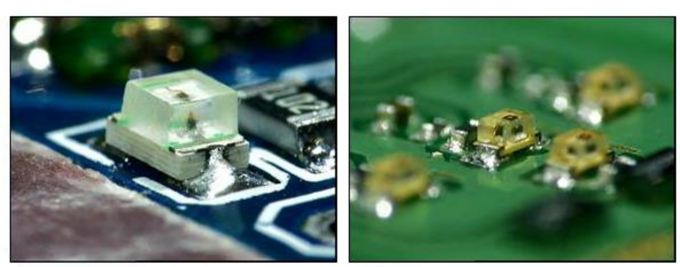

Figure 2. MicroLED examples viewed with a process camera

TYPICAL PRODUCTION FAILURES
Failures that generally occur in the assembly and reflow of miniaturized devices include: tombstoning (one side of a component flips up), bookending (component stands up on its shorter side), as well as broken, misplaced, or bridged parts (see Figures 3a and 3b).

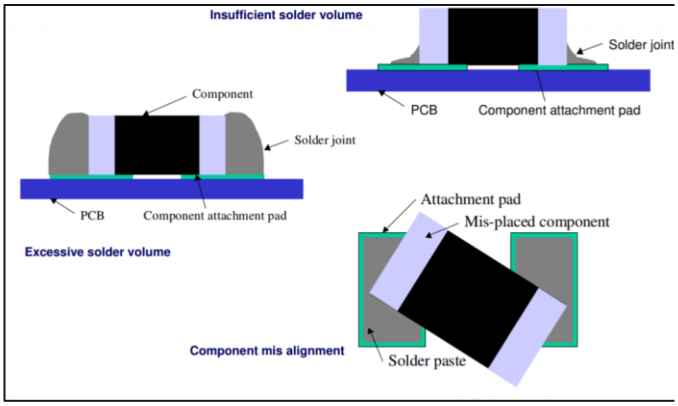

Figure 3a. Failure examples of passive components (Courtesy of Universal Instruments)

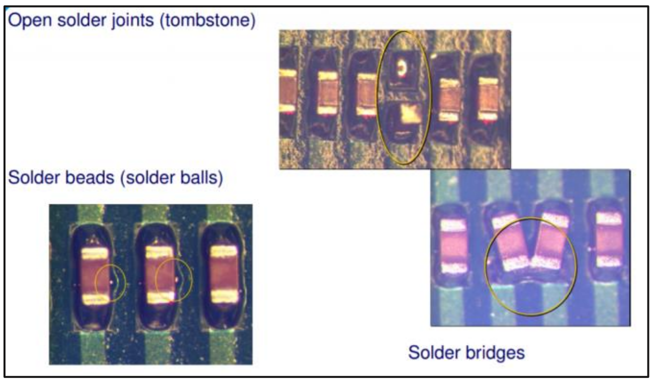

Figure 3b. Failure examples of passive components (Courtesy of Universal Instruments.

Repairing components on densely populated substrates must be done in such a way that neighboring devices are not disturbed. This challenge requires novel solutions. Foremost, this type of rework requires excellent placement accuracy and optical resolution. Reworking miniature devices using a microscope and hand soldering tools is nearly impossible and yields will be low. Furthermore, tooling, site preparation, paste disposition, and precise thermal management are all critical aspects of reworking µSMD components. Within these aspects, there are important conditions to consider.

Miniaturized component rework challenges:

» Safe handling of the component: from pick-up to placement, handling of highly fragile components with low mass
» Avoidance of electrostatic charge
» Reliable force control during handling and placement throughout the entire repair process
» Reliable vacuum component recognition on the tool
» Reliable protection of vacuum openings on the tool against clogging
» Compensation for thermal expansion to meet placement accuracy requirements
» Editing target components without endangering surrounding components
» Finding a tool design that allows access even to densely packed boards with short distances
» Reproducible solder paste dispensing or solder paste transfer
» Replacement of LEDs in large arrays
» Different and heavy substrate materials such as aluminium with a high thermal conductivity

HIGH ACCURACY AND OPTICAL RESOLUTION
Because of pad size and some self-aligning properties of components in molten solder, placement accuracy is sometimes overlooked in rework. However, it is essential to consider in this miniature component range. Placement accuracies, even in some high-end rework systems, can be in the 50 micron range. The systems used in the rework cited in this paper, are specified at 5 to 25 microns. [3] When working with miniature components that are only in the hundreds of microns or less, this specification becomes very relevant. Placement accuracy is a limited specification, defined by the machine's mechanical capabilities and not by optical magnification. It's easy to increase magnification and the cost to do so is relatively low.

However, without coupling better optical resolution, the equipment will simply be magnifying "noise" which will result in a blurry image. And the higher the magnification, the blurrier the image. Figure 4 shows a simple example.

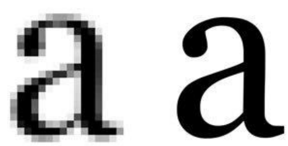

Figure 4. Same magnification at different resolutions

Optical resolution is typically defined as the ability to determine the spacing between a line pair (see Figure 5). If a rework system placement specification is +/- 0.05mm, it begs the question, what is the optical resolution of that system?

Figure 5. Line spacing 0.5mm, 0.25mm, 0.1mm spacing, etc.

If you cannot resolve what you are seeing, for example pad edges, vacuum holes, or component edges, then reworking the component is not possible. One way to look at the significance of placement accuracy relative to optical resolution is this: A miniLED or microLED will typically have a physical size of 0.1 – 0.2mm, or sometimes even smaller than 0.1mm. As these small, two-lead devices continue to shrink, so will the properties of self-alignment. Larger and more traditional SMT devices like Ball Grid Arrays (BGA), CSP, etc., do have some self-alignment properties during solder reflow. Placement accuracy is still an important consideration, but not nearly as critical in comparison to small passives, and microLEDs. As shown in subsequent examples, tooling designs may require that it stay in contact with the component throughout a heating profile. Therefore, where you place the LED or passive is where it will stay.

PREPARATION

Efficient Tooling

In rework, tooling is the method of energy transfer, whether the source is based on Infrared (IR) or convection heat (hot gas). Tooling must be able to remove a known defective component as well as replace it with a new one. Site preparation of residual solder is also a possible need. This all must be done without disturbing adjacent components (as shown in Figure 6).

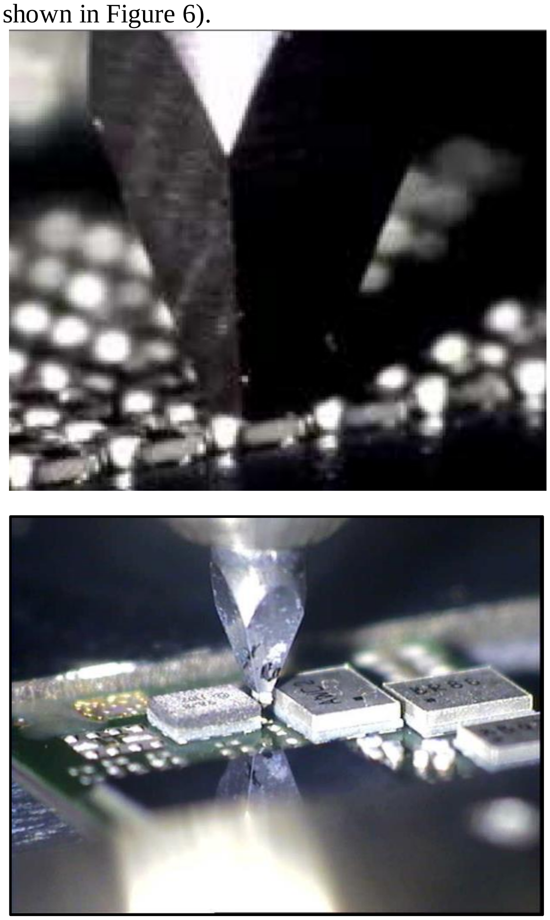

Figure 6. Micro tooling for miniaturized parts

Soldering heads must be specially designed for small passive and microLED components. For the latter, a soldering head is designed to conduct heat around the plastic housing to avoid discoloration or deformation of the microLED. See Figure 7.

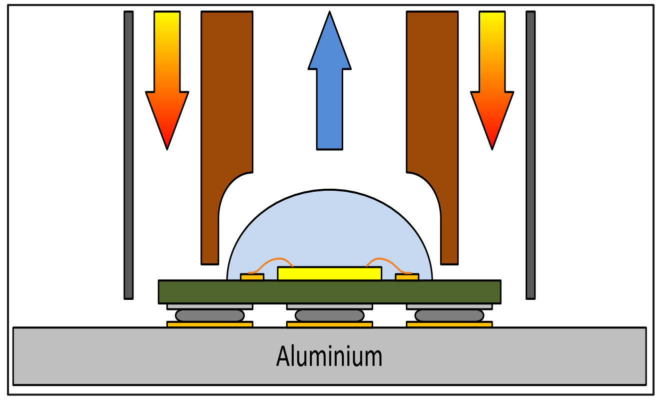

Figure 7. LED solder head design

Inert Environment

Having the capability to induce Nitrogen (N^2) into the repair area almost always provides an advantage. There are numerous studies to show the benefits of N^2 in such a process. Soldering quality is certainly improved [4,5]. The surface area of the component being reworked in comparison to the surface area of the solder pads must be considered when designing the tooling. Because of the physical limitations of how much vacuum can be put on the small device, the aspect ratio of the vacuum hole relative to the size of the component is critical. The surface tension of the solder will be significant when dealing with this scale of component. Inducing N^2 will help relieve the surface tension and allow the tooling to be more forgiving. This will allow a more consistent removal of the component during the desoldering process. Introducing N^2 to the rework area is easily done with most convection systems (see Figure 8). IR based systems will have more challenges to create an inert atmosphere.

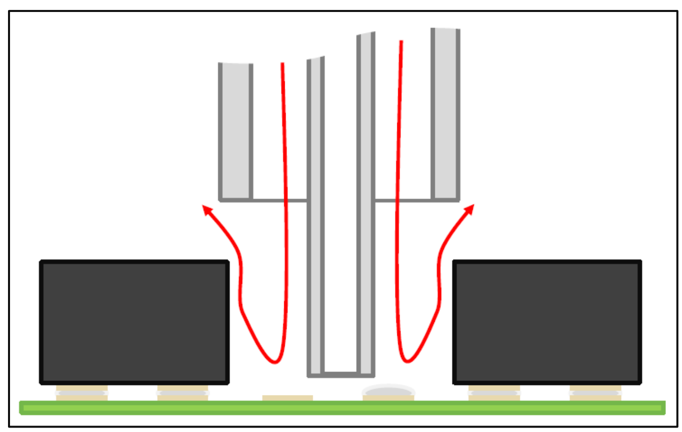

Figure 8a. Showing N^2 flow during site cleaning

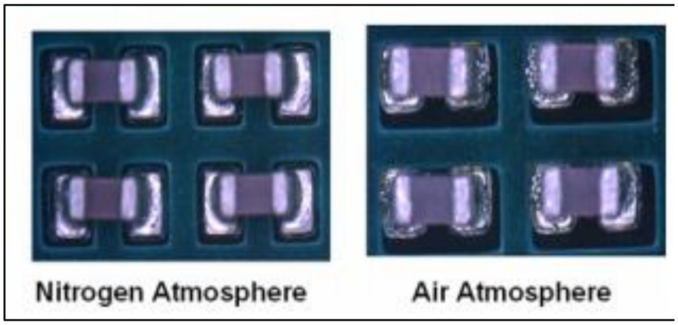

Figure 8b. Non-reflowed solder balls in nitrogen atmosphere vs. air [4]

Vacuum Sensing

Another tooling/machine consideration is vacuum design and sensing. This is especially critical when using more automated machines. Reworking these tiny devices requires high resolution vacuum sensing to allow the tooling to verify when a component is being held for placement or removal. Without this vacuum control, the system could fail in placing/removing the component, which will cause unnecessary thermal cycles. Removing the operator and allowing the equipment to perform the process is the most desirable approach. Sensitive tooling removes one more variable from the process. With extremely small devices, vacuum sensing is essential to achieving high yield rework. See the example in Figure 9.

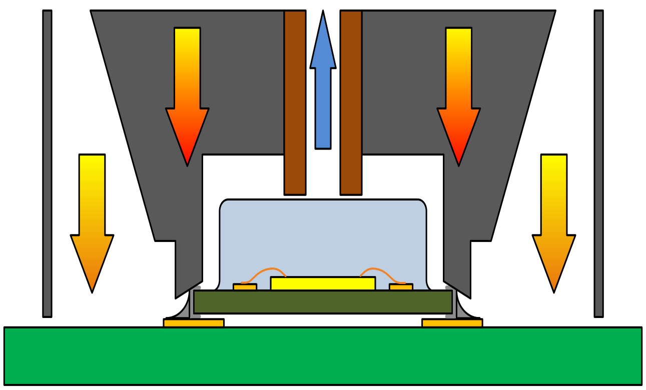

Figure 9. LED nozzle w/ controlled vacuum (blue arrow - vacuum channel)

REWORK PROCESS STEPS

Clamping of the board

Depending on the size and shape of the boards, sometimes special adaptors for small boards, flexible holders or custom-specific solutions are necessary. Figure 10 shows spring loaded clamping for bottom convection pre-heating, along with cables from attached thermocouples used for profile development.

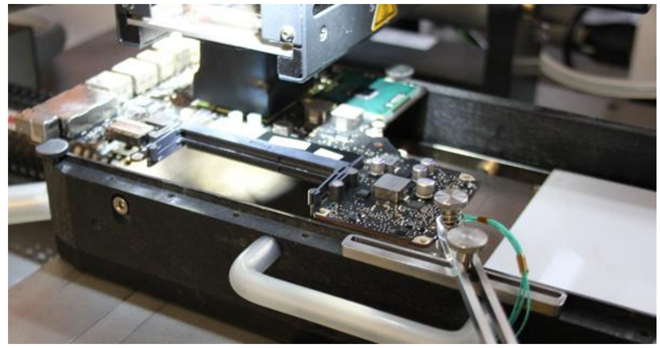

Figure 10. Board in spring loaded clamp

Preparation with thermocouples

Ideally, a sample board with thermocouples is prepared to measure key temperatures in developing a repeatable repair process. For very small LEDs, however, preparation of the solder joints is hardly possible due to the small size. Since the thermal mass is negligibly small however, the soldering head can be placed directly on a thermocouple. Ideally, the ball at the tip of the thermocouple is pressed into a coin to ensure better heat connection.

- » Test series provide information on quality and reproducibility. The preparation can be non-destructive or destructive. Each has advantages and disadvantages, which are case specific.
- » In the non-destructive method, the thermocouples are fixed with Kapton tape at the soldering point.
- » In the destructive method, the board or component is drilled, and the thermocouples are fixed with SMD adhesive.

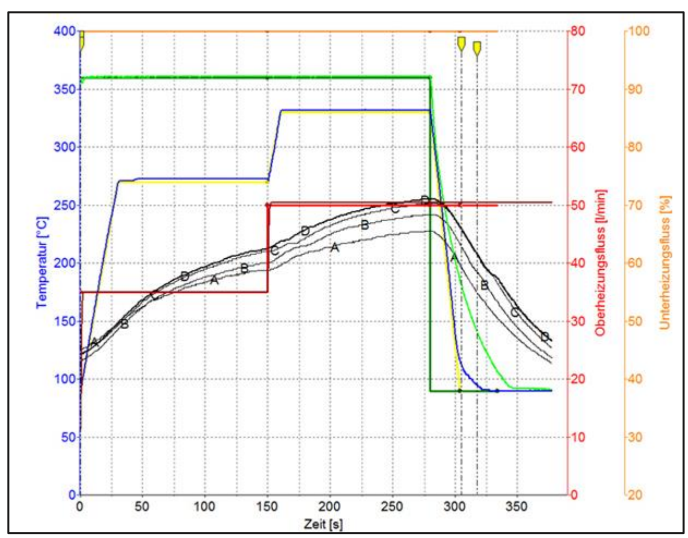

Figure 11: Soldering profile with attached thermocouples A, B, C, and D

Figure 11 shows an example of integrated temperature readouts vs. time (seconds), for the attached thermocouples A, B, C, and D.

Advantages and disadvantages of each:

- » **Non-destructive method**
  Advantages: time-saving, board reusable
  Disadvantage: Inaccurate (contact can be lost), not always reproducible.
- » **Destructive Method**
  Advantage: reproducible, good thermal connection of the thermocouple
  Disadvantage: Destruction of the module, more time-consuming

Nevertheless, the contact between the thermocouple and the solder joint should be checked.

Process Observation
The measured temperatures should be confirmed visually via a process camera to coincide with a change in the state of the solder. Based on the measurements, a suitable profile can then be created according to IPC/JEDEC J-STD-020D.1 or customized if another standard is required.

Desoldering and removal of residual solder
In the case of very small LEDs, the desoldering and residual solder extraction is often carried out together in a single process step. A suction head is used, which detects all three LEDs of an RGB pixel. The solder is melted with heat from below and above and the components are vacuumed with the solder. This can only be done if the components are not intended for re-use. See Figure 12.

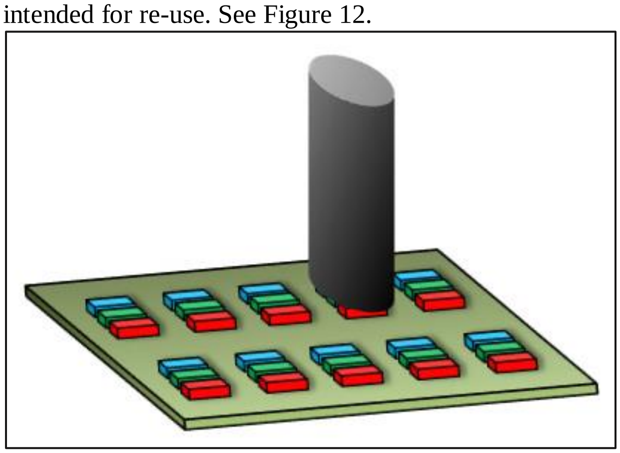

Figure 12: Soldering and extraction in one step

MicroLED rework experience has shown that with a precisely controlled thermal profile, and repeatable machine mechanics, the residual solder volumes can be very consistent. [5] In some cases, this can eliminate the need for site dressing/residual solder removal. Saving this process step can be very advantageous for the mass production LED market, where cycle time for repairs is a critical factor.

Dispensing
Once the known defective component has been desoldered, the next step is to either re-use or remove the residual solder from the pads. As previously mentioned, having N^2 present during this desoldering stage is helpful, but not always possible, or a requirement. Nitrogen can leave a better residual surface to reuse and is more common in very small passive rework. But in most cases, new paste needs to be applied. One dispense challenge is to achieve consistent dots of solder in a repeatable manner. Stencil printing is industry standard for PCB production, but during the rework process, it is not possible at this scale.

Integrating a dispensing process is easiest utilizing type 6 or 7 solder paste for extremely small microLED's or 01005 passives. Type 6 and 7 are manufactured with <25µm particle sizes and flux content to allow the use of very small diameter dispense needles. Larger particle sizes will tend to clog the needle and will result in an unreliable process. Because of the range of miniature components covered in this paper, a specific rule for paste and needles cannot be defined.

Accuracy of the dispense process is almost as important as placing the new component. In other words, if the solder paste does not hit the pad, more rework is being created. These tiny LED's are very similar to small passives in reflow – tombstoning, bookending, etc. is a common method of failure. Without proper accuracy during the dispensing process, the chances of a successful rework cycle are reduced.

- » Dispensing traits:
  Advantage: fast, reproducible, flexible
  Disadvantage: Dot diameter only down to approximately 200 µm is typical.

Needle Transfer
In the case of extremely small volumes, the transfer method (see Figures 13 and 14) has proven to be particularly effective to apply very small quantities of solder with pad to pad consistency and site to site repeatability. Solder paste manufacturers have developed specific solder formulations for dip and transfer applications. Package on package (PoP) rework uses this technology. [6]

- » **Needle transfer traits:**
  Advantage: reproducible, flexible, dot diameter down to 50 µm possible
  Disadvantage: time-consuming, and more tooling intensive.

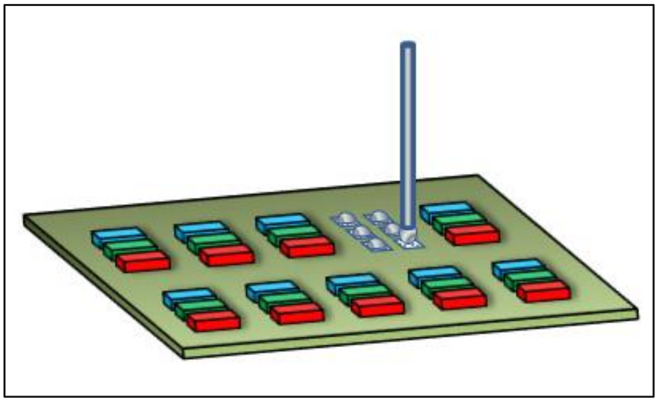

Figure 13: Solder application with needle transfer tool

Needle transfer is simply another method of applying solder paste to the site for repair, using a tool that has two micro sized needles, evenly spaced apart that matches the pitch of the pads on the circuit board. This method of applying solder paste is also referred to sometimes as “dip and dab”. It is not uncommon to have a flux dip station configured on a rework machine, this is a typical process when reworking BGA, QFP and other mainstream SMT devices. Instead of filling the flux station with that medium, solder paste is used in its place. Keeping the flux fixture with a minimal depth (0.1mm as an example) will help prevent the needles from “grabbing” too much solder paste. Subsequent steps are quite easy – once the solder is on the pins, simply align to the pad and bring the needles down until contact is made. The solder is transferred, the site is ready for a new component.

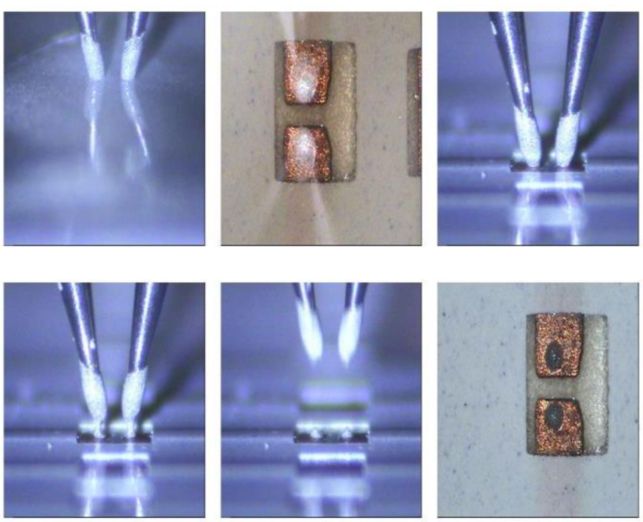

Figure 14: Needle transfer examples.

Soldering
After the successful solder paste application, the new microLED or passive can be soldered in. The individual components are aligned to the pads one after the other and placed in the solder paste. The alignment is typically achieved by using an overlay image of a capable rework system.

In the case of microLED technology, the so-called triplets can be reflowed at once. A two-step process of first placing the LEDs individually (see Figure 15), and then reflowing all three LEDs together with a special hot gas soldering head (see Figure 16). This approach will save precious cycle time and reduce the total heat cycles on the substrate.

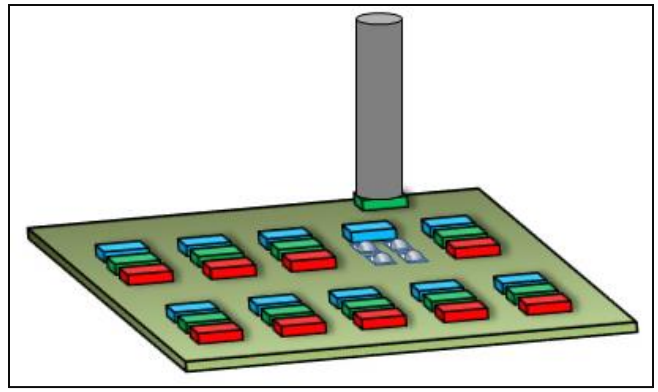

Figure 15: Placing the components

When soldering the LEDs, the underheating only preheats the entire module to such an extent that melting of the solder joints is impossible. For local melting of the solder, the required energy impulse is introduced by the hot gas top heating and controlled through nozzle design and flow control of the rework system (not disturbing neighboring sites).

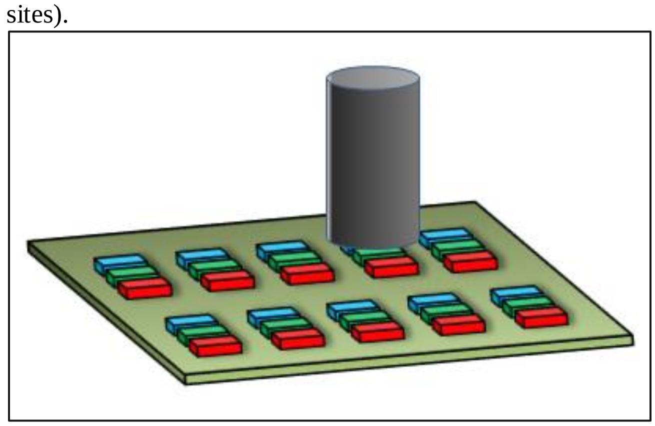

Figure 16: Soldering of the 3 LEDs at the same time

CONCLUSION
Miniaturization of electronics is a strong driving force in the design and manufacturing of many of today’s products. The advent of microLED technology is a recent example of how fast the market needs can change. Equipment manufacturers must try to adapt and those who can provide the application knowledge and innovative tooling solutions will lead the way. Miniaturization of electronics will continue in all aspects of our lives, from home and business devices to large panel displays that end up in Times Square, New York. Here large LED panels light up the city using millions and millions of pixels.

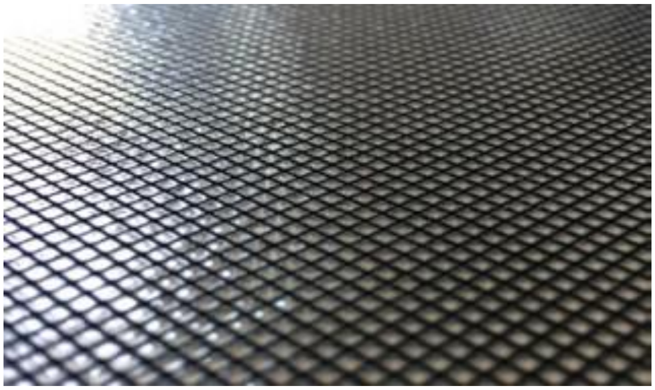

Figure 17. Large panel LED array

As shown in Figure 17, one square meter of such a display can contain well over 3 million LEDs.

Just below these billboards are passing cars already equipped with miniaturized control modules, as well as the latest LED technology. The microLED advances are likely to be seen first in the display areas of vehicle data. LED technology is here to stay and will continue to grow with stealth companies emerging from Silicon Valley and elsewhere. With the likelihood of exponential volume growth, it's no surprise the state of microLED manufacturing will need to evolve at a rapid pace. Rework is a necessary task in such a process. Efficient, repeatable, and high yield solutions are in demand.

Testing and research by rework system manufacturers has resulted in proven rework processes for continually shrinking SMD components. The extreme reduction in size of resistors and capacitors is one of the more significant areas of research during this time. This evolving knowledge and experience has led to volume rework solutions for OEM's and contract manufacturers worldwide. As shown in this paper, much of what has been learned can now be applied in new ways to support the microLED marketplace.

REFERENCES

[1] S.K. Moore, IEEE Spectrum "Coming Soon to a Wrist Near You: MicroLED Displays", March 19, 2018.

[2] Plessey Semiconductors, "The Future of MicroLED Displays Using Next-Generation Technologies", February 2018.

[3] Finetech GmbH, Core+ and Pico RS model specifications. www.finetechusa.com

[4] Process Development for 01005 Lead-Free Passive Assembly. IPC. PN S28-01.

[5] N. OBrien, "QFN Lead Free Rework", IPC Midwest, September 2007.

[6] Dr. Ning-Cheng Lee, "Selection of Dip Transfer Fluxes and Solder Pastes for PoP Assembly". Indium Corporation.