Parallel Assembly of 01005 Surface Mount Technology Components with 100% Yield

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ABSTRACT

This paper demonstrates a novel method to perform the delivery and assembly of standard 01005 format (0.016”×0.008”, 0.4mm×0.2mm) thin-film resistors and monolithic ceramic capacitors with a programmable batch assembly process that leads to 100% yield within tens of seconds, that is high volume manufacturing compatible. By characterizing the electrical performance of functional industrial-grade components assembled onto test substrates, we extend previous stochastic assembly work performed with dummy parts, validating our assembly methodology.

INTRODUCTION

Driven by the demand for product miniaturization, the electronics industry has continuously shrunk passive components, alongside electronic packages, for assembly onto printed circuit-boards (PCBs) using surface-mount technology (SMT). For their size, 01005 format components are beginning to be adopted by the industry [1]. However, also due to their sizes (thin-film resistors and monolithic capacitors have different thicknesses), 01005 devices (currently the smallest in the SMT selection) pose a significant bottleneck for design, assembly process and thus, the throughput of products [2].

In Transducers 2009, we introduced a methodology that enables parallel micropart assembly with 100% yield through the precise delivery of microparts across an assembly area, enabled by real-time automated feedback [3]. We extend this technology to the delivery and assembly of 01005 components as a cost effective and efficient alternative to pick-and-place robotics. The key differences between this and our previous work are: we are now using functional parts instead of dummy silicon chips, we employ a novel two-template method to achieve orientation control instead of using water vapor or invoking surface chemistry on the components to be assembled, and we can orient the components in any arbitrary angle in the plane of the target substrate, which is a bottleneck for pick and place robotics.

ASSEMBLY PROCESS FLOW

Our assembly process flow is shown in Figure 1. It is a modification of a similar process developed for the delivery and assembly of test parts [3]. Besides the fact that we are now assembling SMT resistors and capacitors instead of silicon parts, our current process uses two alignment templates on top of our target substrate, and we now include the solder reflow step to establish electrical and mechanical bonding to the target substrate.

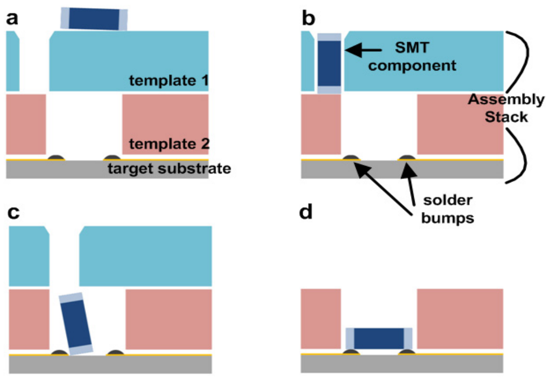

Figure 1. Assembly process: **a**. walking mode [3] component delivery performed on assembly stack in Configuration 1; **b**. a single component is captured by template 1 near the binding location; **c**. Configuration 2 – component is allowed to drop into template 2; **d**. slightly agitating the system aligns the component to the orientation of the aperture on top of the binding location on the target substrate. After step **d**, solder reflow is performed to bond the component to the target substrate mechanically and electrically.

The assembly stack, a sandwich of template 1, template 2, and the target substrate (Figure 1b), is first aligned at Configuration 1 (Figure 1a). Configuration 1 allows components to assemble into template 1, but prevents the parts from falling through into template 2. The assembly stack is then placed on a custom aluminum weight-biased disk-platform that is driven by a vertical actuator (Figure 5b). Using our feedback enhanced walking mode [3], we fill all apertures on template 1 with a component each (Figure 1b). We then shift the assembly stack to Configuration 2. In Configuration 2, each aperture in template 1 is aligned with its designated aperture pair in template 2, such that the components fall onto the target substrate, within the confines of the apertures in template 2 (Figure 1c). Template 1 captures the passive components at designated locations above the target substrate, allowing only a single component into corresponding apertures in template 2, while template 2 controls the orientation of the components as they fall onto their sides. An example of a 100 component test circuit with its associated template 1 and template 2 is shown in Figure 2.

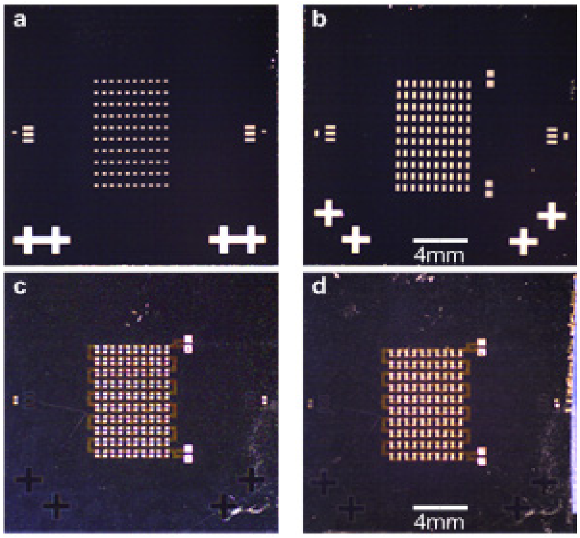

Figure 2. **a**, **b** and **c** are the template 1, template 2 and target substrate of a 100 component series-connection test circuit, respectively; **d**. a completed assembly of a 100 component series-connection test device target substrate.

Figure 2d shows completed assembly. Each test circuit is designed as a circuit, including contact pads, to permit electrical analysis. Close-up views of empty and bonded binding sites are shown in Figure 3.

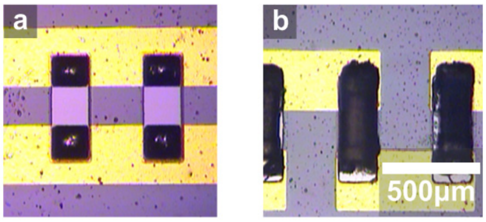

Figure 3. **a**. empty binding sites between two parallel gold lines; **b**. SMT components bonded to solder bumps connect segments of gold lines in series.

Similar to our work with silicon test parts, we have to first establish the various movement modes for our 01005 capacitors and resistors. With total control over the movement modes of our components, we can use both the feedback and non-feedback driven methods to move our components in the delivery step as shown in Figure 1a. To guarantee 100% assembly, we employ the feedback driven method [3] as shown in Figure 4. After step d in Figure 1, template 2 is removed, and our passive components will be electrically and mechanically bonded, by solder reflow, to the target substrate as shown in Figure 3b.

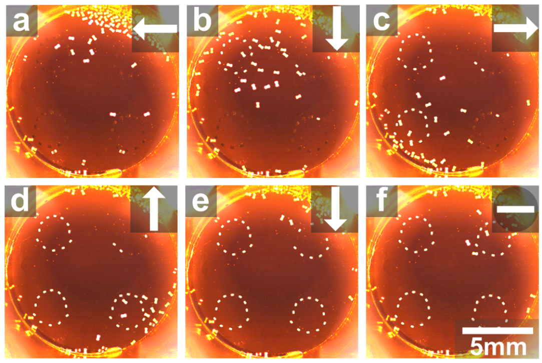

Figure 4. Delivery of SMT components into the template 1 apertures of circular test circuits with 48 components using feedback driven assembly [3]; arrows in each frame indicate the direction in which the SMT components are driven: **a**. assembly begins with parts being driven to the left from the top right corner; **b**. after the components for the top left ring have been delivered, the parts are driven downwards to the bottom left; **c**. rightwards; **d**. upwards; **e**. now that most of the excess parts are located above the top right ring, we drive the parts downwards, as some sites in the top right ring remained vacant after step **d**; **f**. delivery completed. 100% excess parts has been used in this assembly (96 components used); this design demonstrates our ability to place components at arbitrary in-plane orientations, and is not a demonstration of packing density.

FABRICATION AND EXPERIMENTAL SETUP

Our assembly templates are fabricated from silicon wafers using standard microfabrication techniques. To fabricate the test substrates, we first pattern gold lines on silicon wafers. We then use SU8 to define openings on the gold lines on which solder will wet during dip-coating. Dip-coating is performed on a custom dip-coating tool, with an Indium-Tin-Bismuth solder alloy with composition tuned to melt/reflow at 60˚C.

Aligning the assembly stack and changing it between Configuration 1 and Configuration 2 are performed using a precision linear-positioning stage shown in Figure 5a. Assembly stacks are held in place (at the two configurations) using adhesive tape.

The linear-positioning stage is also used to remove template 1 from the assembly stack before the step shown in Figure 1d, as well as removing template 2 at the end of the reflow step. Figure 5b shows the assembly stack set in the middle of the weight-biased platform on an electromagnetic vertical actuator. The assembly stack needs to be placed at a distance from the electromagnetic actuator as shown in Figure 5b. This is because the SMT components are paramagnetic, and will likely stand on their ends when being in close proximity to the magnetic components within the actuator.

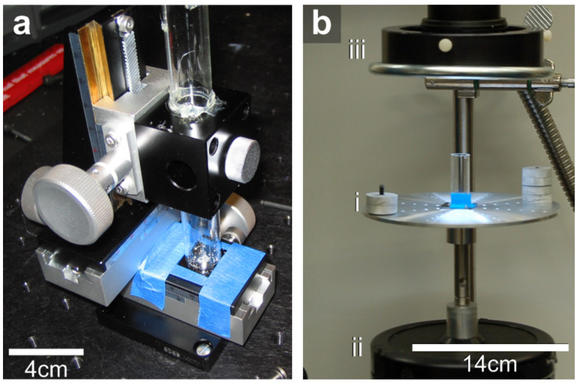

Figure 5. **a.** Three-axis precision stage to perform the assembly, alignment, shifting (between Configuration 1 and Configuration 2) and disassembly of assembly stacks. Assembly stacks are temporarily secured with tape between stages of the assembly process. Glass tubes are used to confine the 01005 components; **b.** weight-biased platform – vertical actuator setup [3]: **i.** an assembly stack is set in the middle of a weight-biased disk-platform to perform walking mode delivery; **ii**. electromagnetic vertical actuator; **iii**. optical and lighting equipment for real-time feedback and post-experiment analysis.

At step d in Figure 1, solder reflow is performed in a laboratory oven.

RESULTS

Part Delivery

The performance of our non-feedback driven assembly of SMT components is analogous to that of square silicon parts [3]. Figure 6 shows image analysis results from videos of our assembly process on a 100 component test device (Figure 2).

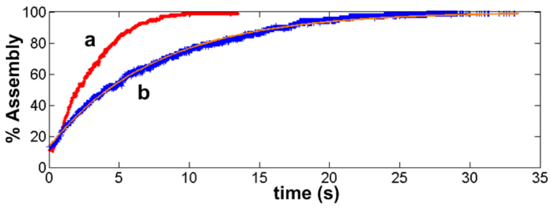

Figure 6. Video analysis results from two runs of the 100 component test device shown in Figure 2, driven by **a**. 300 Hz and **b**. 330 Hz, actuator calibrated to output 4.00 g at 100 Hz, with 50% part redundancy. Experimentally extracted first order rate constants for curves **a** and **b** are $0.35s^{-1}$ and $0.18s^{-1}$ respectively. Refer to our previous work [3] for an in-depth discussion of a model we have developed for the process.

Arbitrary Orientation of Parts

In Figure 7, we demonstrate the ability to assemble the SMT components in arbitrary orientations, allowing greater design freedom in PCB layouts, potentially permitting greater packing density of components, and/or the reduction of device size.

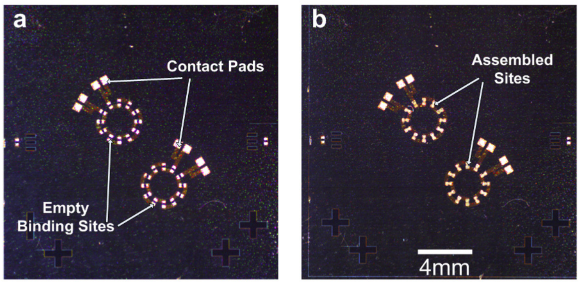

Figure 7. **a**. target substrate of a circular test device; **b**. a completed assembly of a circular test device target substrate.

Electrical Connectivity

Figure 8 shows a test circuit we used to verify electrical connectivity.

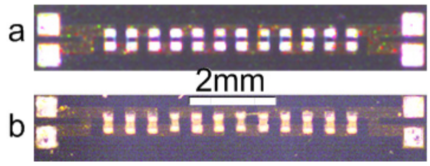

Figure 8. A 10-component series test circuit before (**a**) and after (**b**) the assembly of 01005 100 kΩ resistors.

In Figure 8b, we have a chain of 10 100 kΩ resistors in series. The average effective resistance across these 10 resistors is found to be 1.05MΩ over five individual test circuits. To verify that the electrical path runs through the 10 resistors, we pry off resistors from the circuits, and consistently obtain an open-circuit reading for effective resistance.

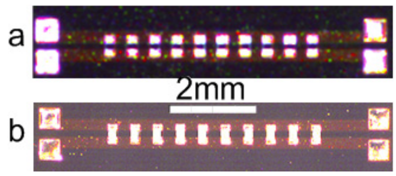

Figure 9. A 10-component parallel test circuit before (**a**) and after (**b**) the assembly of 01005 100 kΩ resistors.

In Figure 9b, we probe the effective resistance across 10 100 kΩ resistors assembled in parallel. Figure 10 shows the effective resistance of the test circuit with the indicated number of resistors left intact (not pried off). The results in Figure 10 verify that electrical connection is established with our assembly process.

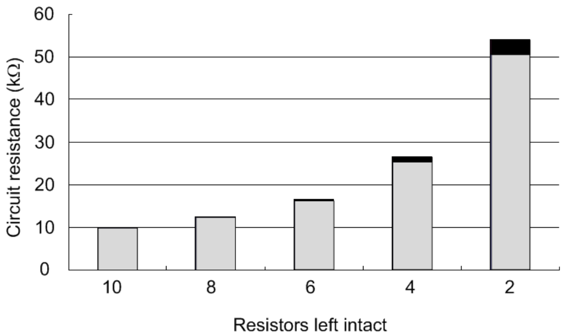

Figure 10. Average effective resistance of 10 100 kΩ resistors on 5 parallel-connect test circuits (Figure 10b). Variances are indicated with the black segments on top of each bar.

DISCUSSION

The choice of a tertiary, low melting temperature solder (60˚C, In-Bi-Sn) is made for the flexibility it accords with the ability to place solder bumps on our test devices with conventional laboratory equipment, and thus reducing prototyping turnaround time. The mechanical strength of our reflowed bonds is significantly weaker (and more inconsistent) than those found on surface mounted devices on the PCBs of commercial electronics, likely due to the presence of the many intermetallics and oxides associated with our solder.

We are currently working on the application of binary or pure-metal solders to improve the mechanical performance of our connections. Our process is compatible with industrially used solders and reflow techniques.

In this paper, we have demonstrated assembly of an industry standard SMT component (smallest size) onto electrical test structures fabricated in silicon substrates. However, the process is fully compatible with assembly on IC package organic substrates or advanced small form factor PCB substrates. Templates 1 and 2 are fabricated in silicon but could also be implemented in metal or other material systems in high volume manufacturing. In this paper, we did not pursue aggressive packing of SMT components since the design was optimized for electrical data collection. In our previous works [3], we have shown that this method of assembly achieves very high packing density *i*.e. tight pitch of assembly. Also, we have demonstrated various in-plane angular assembly and electrical connection of the parts – which is a challenge to achieve in pick-and-place robotics.

This assembly process can be designed to be done in an extremely parallel fashion, for instance, in panel level for IC package substrate passives attach. The key limitation to the extent of parallelism is the co-planarity of the substrate. Note also that in our assembly process, the 01005 parts are delivered in "bulk" for assembly in contrast to pick-and-place robotics where they need to be in tape and reel or other pre-oriented/specific placement for the robot arm to locate and pick up. This translates to not only throughput time enhancement but also to potential cost savings. The three-axis precision stage used in our experiments for template alignment and shifting also needs to be translated to a larger tool in high volume manufacturing. In order to simplify the requirements of this stage, we are currently working on a variation of the current process flow that has only one template instead of two.

CONCLUSION

In summary, we present results of programmable batch assembly of 01005 SMT components leading up to 100% yield. We developed a process flow for delivering, aligning, and bonding said components based on a complete set of experimental and analysis capabilities previous developed for stochastic microchip assembly, and verified the electrical viability of our process. These advancements in the field of surface mounting will greatly improve the throughput and packing densities of electronic devices.

ACKNOWLEDGEMENTS

This work was funded by the Center on Interfacial Engineering for Microelectromechanical Systems (CIEMS) under DARPA grant HR0011-06-0049 (Dr. D. L. Polla, Program Manager) and by Intel Corporation.

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