TEMPLATE BASED HIGH PACKING DENSITY ASSEMBLY FOR MICROCHIP SOLID STATE COOLING APPLICATION

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Abstract. 100% dry assembly using shape matching and van der Waals attraction for parts transfer has been performed to achieve high density parts packing (up to 92%) of thermoelectric cooling components. The feasibility of this approach has been examined for component sizes across a range of 130-800μm.

1. Introduction

In a microprocessor package design, two thermal power metrics are significant - the total thermal design power and the cooling of 'hot spots' or high heat flux regions of the 'core' [1]. Many active cooling solutions have been proposed including microchannel liquid cooling [2] and solid state refrigeration [3]. In the case of thermoelectric cooling (TEC) shown in Figure 1, simulations using methods in [4] show that the hot spot temperature reduction is enhanced by up to 3 times when TEC element density is changed from 25% to 90% at use conditions. To this end, in this paper we present a massively parallel assembly method that has been examined for part sizes across a range of 130-800μm. We obtain successful self-assembly of densely packed arrays of parts from 400-800μm size.

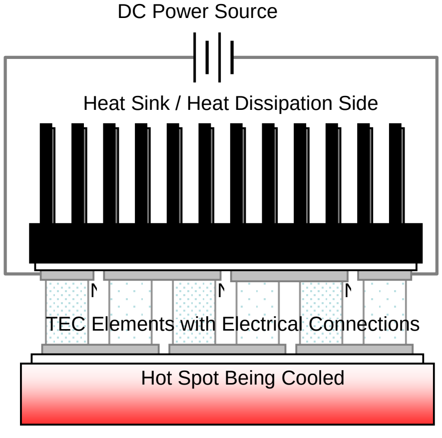

Fig. 1. Thermoelectric cooling using Peltier effect absorbs heat from the substrate at one junction and transfers it to the heat sink at the other junction. The cooling performance is governed by the total electric current (which is constrained by the contact area) so the space efficiency of the TEC packaging density is critical.

2. Working Principle of Fully Dry Self-Assembly

Self-assembly is the spontaneous organization of components into ordered structures, driven by energy minimization [5-8]; it is employed here to arrange the two types of TEC cooling elements into regular arrays without the use of robotic pick-and-place. The approach taken here is distinct from prior work by the combination of (a) 100% dry assembly using coil motor assisted agitation and shape matching, (b) parts transfer using van der Waals attraction, (c) dynamic annealing for parts settling and alignment, (d) high density parts packing up to 92%, (e) the possible simultaneous self-assembly of two types of components into closely packed arrays.

Figure 2 shows a schematic and photo of the experimental setup for parts assembly. We have developed a three-step process (Figure 3) for achieving high density of parts. First, using the competition among template trapping potential energy, part kinetic energy (applied to the parts by mechanical agitation at controlled amplitudes and frequencies) and surface energy between solid-solid interfaces, we trap the parts in shape matched recessed templates. The parts are then transferred to a carrier surface with modified PDMS (Reprorubber© on smooth silicon wafer) using the higher van der Waals attraction for increased co-planarity and semi-permanent lock-in of assembly. A solder (eutectic AuSn or SnAg) patterned substrate is then flip chip bonded at 310°C / 230°C to the assembled parts to obtain permanent mechanical, electrical and thermal interconnect formation. In the proposed application, the TEC components consist of two types with different dimensions for optimal performance. Using this process, we can also develop multi-batch assembly of different types of components.

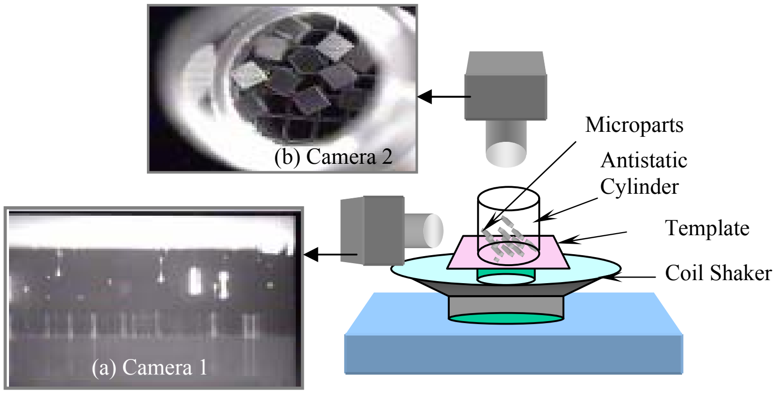

Fig. 2. Experimental set-up for parts assembly: The recessed template is attached to a coil shaker whose vibration is controlled by a function generator and optional power amplifier. The vibration amplitude is monitored by imaging the side of the template die with Camera 1 (inset **a** shows an image). The parts are confined to a volume above the template using an antistatic open cylinder and Camera 2 captures the assembly process (inset **b** shows an image).

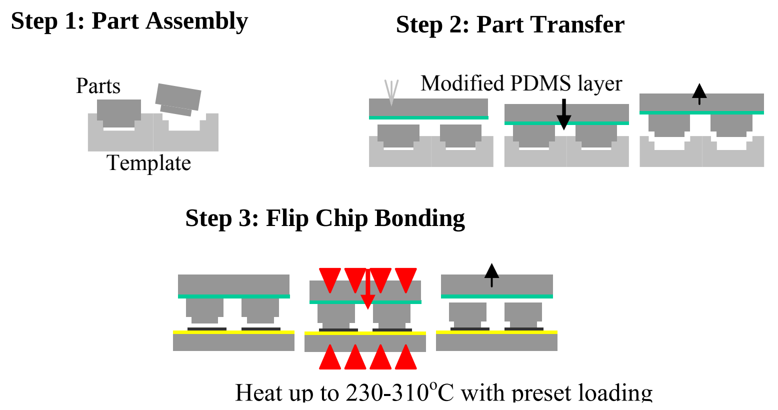

Fig. 3. Process flow schematic: (Step 1) The parts are first assembled using a coil shaker. (Step 2) They are then transferred to a rubber surface with high van der Waals forces for increased co-planarity and ease of handling. (Step 3) The parts are then transferred to the final destination substrate (silicon die with patterned solder) by flip chip bonding.

3. Testing Procedure and Results

We define three states of the parts on the surface of the template: Initially, the parts are static and the vibration of the coil is initiated. At a certain input power, named *Migration Voltage*, the parts start moving along the surface. As the voltage is increased, the parts start flipping over, called *Jumping Voltage.* Subsequently, if the voltage is decreased slowly, the parts settle on the surface and this voltage is called *Settling Voltage* (Figure 4). When the part kinetic energy is less than the sum of solid/solid interfacial energy and template trapping potential energy, the parts will assemble to the templates. The control voltage is maintained above the Settling Voltage for parts delivery but below the Migration Voltage to confine the part kinetic energy within good trapping conditions. Preliminary experiments using various part size/trap configurations have shown the feasibility of using this method to successfully assemble square parts (thickness: 120μm) in the 400-800μm range. However, for the small parts (width: 130 and 200μm, thickness: 120μm), the combination of low aspect ratio (width:thickness) and inertial/surface force ratio caused the disappearance of the Migration Voltage, which caused the parts to either jump around the traps without assembly or to not move at all. On the other hand, assembled parts (width: 400-800μm) were successfully picked up using the modified PDMS layer (Figure 5 a-c). We have also transferred parts from the PDMS layer to solder defined substrate sites using thermo-compression flip chip bonding (Figure 5d).

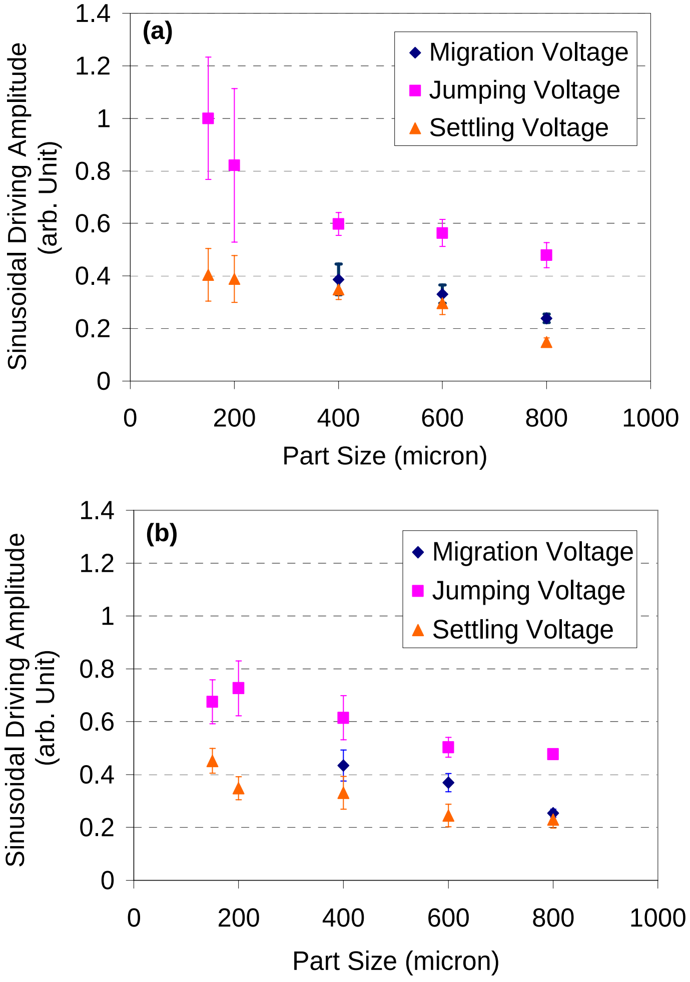

Fig. 4. Migration Voltage, Jumping Voltage and Settling Voltage for different part sizes from 150µm to 800µm scaled to the highest average value. Graph (a) is for double side polished parts on smooth surface and (b) double side polished parts on rough surface. All these parts are ~120µm thick and made from polished SOI wafers. The vertical bar shows the standard deviation measured from experimental results from 5 different measurements. For the small parts (130 and 200µm), it was difficult to distinguish between the migration and jumping voltage and hence only one state (jumping) is identified. Note that the jumping voltage is significantly higher than the settling voltage for all part sizes. This indicates that with good control of the input voltages, parts can be coerced to "settle" in the traps.

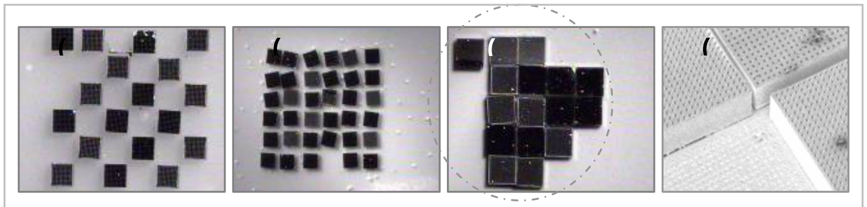

Fig. 5. Images of parts after assembly and transfer to Reprorubber substrate for various part sizes. The bar is 800μm in all the 3 images. (a) 600μm size parts assembled on traps made of an array of alternating 600μm and 580μm traps. (b) 400μm size parts assembled in alternating 600/580μm 6×6 traps (c) 780μm parts assembled in alternating 800/780μm traps (the partial array fill is due to use of a small antistatic confinement cylinder on top of the trap). The density of packing for this case is close to 90%. (d) 780μm parts also can be transferred from the PDMS layer to solder defined substrate sites using thermo-compression flip chip bonding. To continuously investigate the scaling boundary of this method, we are currently testing small parts with thickness 25μm and shallower traps (18μm) as well.

4. Conclusions

In conclusion, we have shown the feasibility of a novel dry assembly method for small parts (width: 400-800μm, thickness: 120μm) using a reusable template with intermediate PDMS pick-up step and subsequent flip-chip bonding. This method holds promise for applications in assembly and interconnects of solid state cooling elements for hot spot cooling of microprocessors.

References

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