

# FULLY DRY 2D AND 3D SELF-ASSEMBLY WITH INTERLOCKING PIN FASTENERS

Sangjun Park and Karl F. Böhringer

Department of Electrical Engineering, University of Washington, Seattle, USA  
(Tel : +1-206-221-5177; E-mail: karl@ee.washington.edu)

**Abstract:** This paper presents a novel method for fully dry, 2D and 3D self-assembly of silicon parts by implementing interlocking structures. The assembly parts have interlocking pins similar to a nail, whereas the corresponding substrate has binding sites with interlock holes that guide the interlocking pins to the fastened positions. These interlocking features are fabricated by a series of silicon deep RIE, sidewall passivation film coating and isotropic silicon RIE. Test results show 100% assembly on the substrate with 18% packing density, and 81% on the substrate with 40% packing density. These assembly rates are achieved with much less use of excessive parts compared to fluid-based self-assembly processes.

**Keywords:** dry self-assembly, 2D self-assembly, 3D self-assembly, interlocking structure

## 1. INTRODUCTION

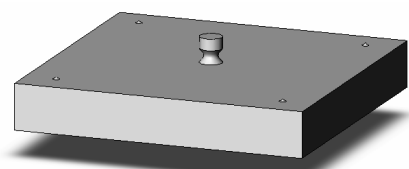
Self-assembly processes at the micro-scale are gaining increased attention as the size of the micro-components is shrinking further beyond the reach of pick-and-place robots. The established methods for self-assembly, such as fluidic shape-driven self-assembly [1, 2, 3] and capillary-driven self-assembly [4, 5], have achieved successful integration of small components like RFIDs, LEDs, circuit elements and PZT micro-pumps. However, these methods involve wet processing, which makes the assembly of water-sensitive devices very difficult. Use of liquid flow requires large amount of excessive parts (typically 6-7 times number of binding sites [1]) to achieve high yield. This would make “recycling” of unused parts necessary and entail more complex equipment. These methods are also limited mostly to two-dimensional assembly.

This paper presents a novel method for fully dry, three-dimensional self-assembly by deploying interlocking features on silicon dies. These interlocking pin fasteners are designed such that during a stochastic self-assembly process, parts are guided towards correct assembly while accidental disassembly is minimized.

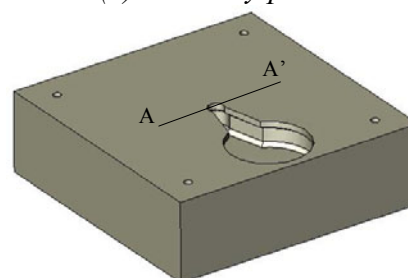
## 2. DESIGN OF THE ASSEMBLY ELEMENTS

Figure 1 shows the schematic view of the assembly system. The assembly part has an

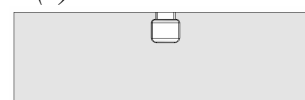
interlock pin similar to a nail as shown in Fig. 1(a). The corresponding carrier substrate has a binding site consisting of a large circular hole, a small interlock hole, and a pathway between them. When vibration is applied to the carrier substrate with the assembly parts on it, the interlock pin will fall in the large circular area initially, and then move to the small interlock hole. When the “nailhead” part moves into the small pocket of the interlock hole, it is designed to be difficult to get out.



(a) assembly part



(b) carrier substrate



(c) cross section of AA' in (b)

Fig. 1. Schematic view of the assembly system.

### 3. FABRICATION

The fabrication process is shown in Fig. 2. It is identical in both the fabrication of the assembly part and carrier substrate, with a slight change in the etching depths. The process starts with deposition and patterning of an etch mask (PECVD oxide) on the silicon substrate. Then the silicon is etched by the Bosch process (Fig. 2(b)). A passivation film is deposited over the surfaces as shown in Fig. 2(c). In this paper, PECVD oxide was used for the passivation. The passivation film is etched anisotropically by RIE, thus exposing bare silicon at the bottom as shown in Fig. 2(d). The silicon is etched again by deep RIE, and an SF<sub>6</sub>-based isotropic RIE etches the unprotected area exposed by the second deep RIE (Fig. 2(e)~(f)). This isotropic etch makes the shank of the pin and the pocket in the binding site. Finally, all etch masks and passivation films are removed in hydrofluoric acid (HF). This process could be duplicated on the back side of the wafer such that the assembly parts can be mated on either side.

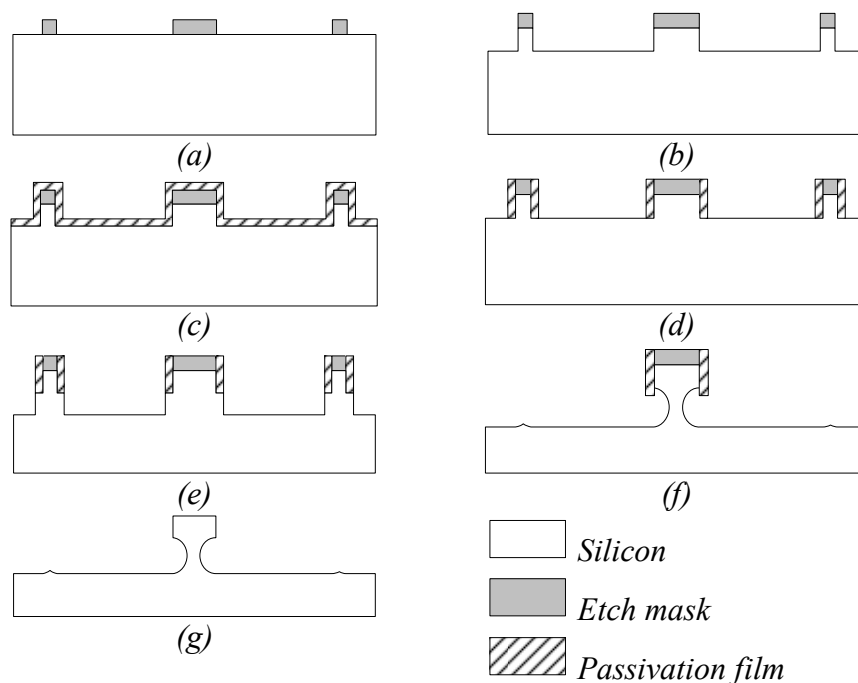
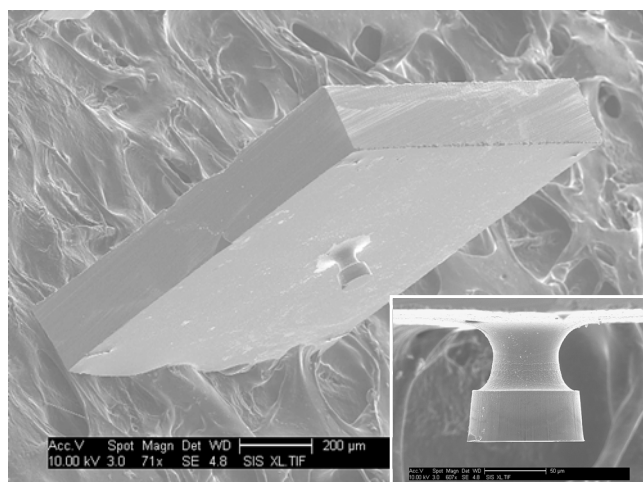


Fig. 2. Fabrication process flow; (a) patterning etch mask, (b) 1<sup>st</sup> deep RIE, (c) sidewall passivation film deposition, (d) passivation film etching, (e) 2<sup>nd</sup> deep RIE, (f) isotropic RIE, and (g) removal of etch mask.

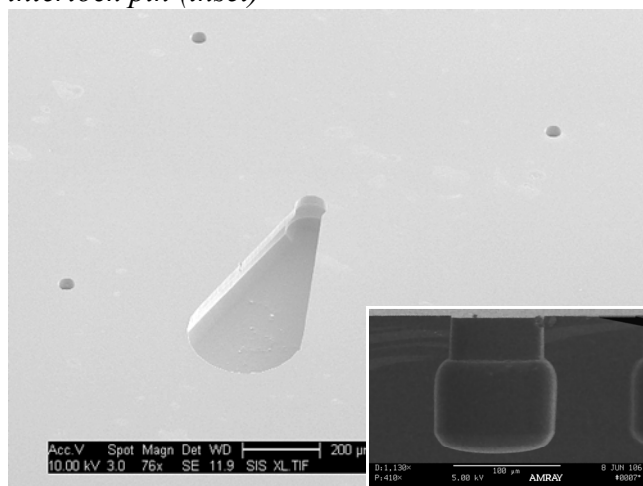
The SEM pictures of the fabricated system are shown in Fig. 3. The assembly part has 1.27mm width and 200 $\mu$ m thickness. The circular pin is 100 $\mu$ m in diameter and the undercut beneath the head is about 20 $\mu$ m. The assembly parts are made double sided such that either side of the parts could be used for the assembly. The carrier substrate has 21 (for 18% fill factor) or 52 (for 40% fill factor) binding sites in 314mm<sup>2</sup> area. The fill factors are simply calculated by  $a^2 / (a+d)^2$ , where  $a$  is the width of a part and  $d$  is the distance between neighboring parts. On the carrier substrate, the larger hole is 400 $\mu$ m in diameter. The interlock hole has 80 $\mu$ m diameter at the neck and 120 $\mu$ m at the pocket.

### 4. EXPERIMENTAL RESULTS

Figure 4 shows the experimental setup for the assembly system. The carrier substrate is mounted on a loudspeaker, and a glass tube is placed on top of the substrate to prevent the assembly parts from being scattered away. The loudspeaker is vibrated by an amplifier connected



(a) assembly part, and close-up view of the interlock pin (inset)



(b) carrier substrate, and cross section of the interlock hole (inset)

Fig. 3. SEM pictures of the fabricated assembly system.

to a function generator. The experimental video data are recorded by the high speed camera. Figure 5 shows the assembly result with 5 minutes of excitation with 230Hz sinusoidal wave. For Fig. 5(a), 42 assembly parts are used in this experiment (100% redundancy), and all of the 21 binding sites are occupied with the assembly parts. For Fig. 5(b), 78 parts are used (50% redundancy), and 42 of 52 sites (81%) are assembled. The difference in the yield is considered to be due to the different redundancy and fill factor. Note that the amount of parts used is significantly less than

in a typical fluidic self-assembly process, although an acceptable assembly yield is achieved.

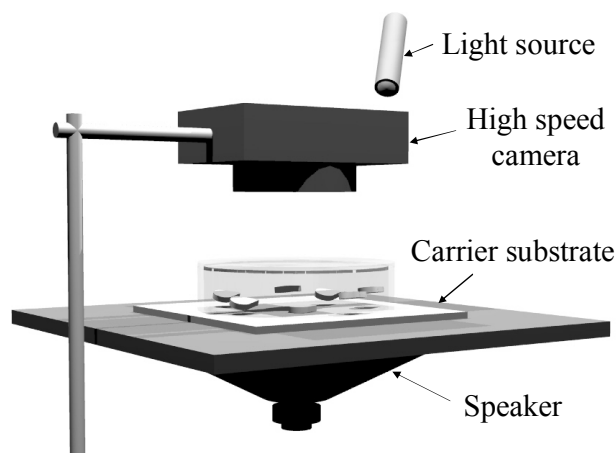


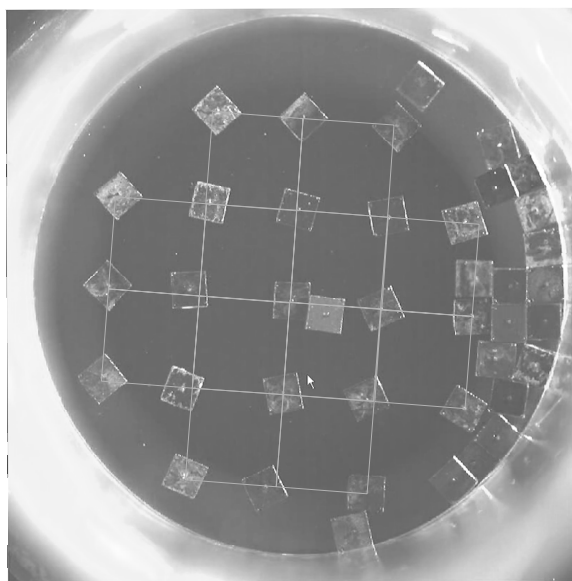
Fig. 4. Schematic of experimental setup.

## 5. CONCLUSION AND DISCUSSIONS

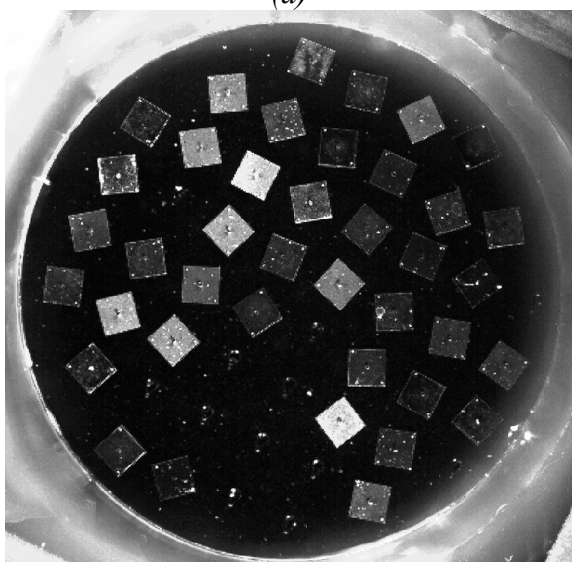
In this paper, we developed a novel method for fully dry, 2D and 3D self-assembly. In addition to the capability of handling water-sensitive devices, the developed method requires much less amount of excessive parts than the fluid-based self-assembly.

The effect of fill factor and redundancy to the assembly yield should be investigated by further experiments. The current assembly design with a single centered pin only positions parts but does not orient them. Experiments are underway to achieve precise orientation with additional smaller pins in the part corners, or asymmetric pins.

It is possible to stack the parts with interlock holes on the bound parts since they are double-sided. Work is undergoing to realize this 3D self-assembly.



(a)



(b)

*Fig. 5. Assembly result after 5 minutes of shaking. (a) on 18% fill factor stage. All 21 binding sites on the rectangular grid are occupied with assembled parts. (b) on 40% fill factor stage. 42 out of 52 sites are occupied. The excessive parts for (b) have been removed after the assembly, by flipping the substrate over.*

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