

# MULTI-BATCH SELF-ASSEMBLY FOR MICROSYSTEM INTEGRATION

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## Abstract

*In this paper, we describe a parts-to-substrate self-assembly approach driven by surface tension. To perform assembly, the substrates are prepared with hydrophobic gold patterns as binding sites. The binding sites are activated by adsorption of an alkanethiolate self-assembled monolayer (SAM), while they can be de-activated by electrochemical reductive desorption of the monolayer. Therefore, assembly can be controlled to take place exclusively at desired activated sites. This assembly process can be repeated to organize different micro parts into a system. We develop and demonstrate a self-assembly protocol, including micro fabrication process, surface modification techniques, and electroplating as a post-assembly process, for the purpose of full system integration and packaging.*

*Keywords: Self-assembly, SAM, surface tension, capillary force, reductive desorption, electroplating, microsystem integration*

## Introduction

Recent developments in the area of microfabrication offer the opportunity to create a large variety of functional micro devices (*e.g.*, chemical, electrical, mechanical, and optical). Promising applications, *e.g.*, in telecommunications, chemical analysis and biomedical instrumentation require integration of such devices into compact and robust microsystems. Monolithic integration of different functionalities often faces problems of material and process incompatibilities. Ideally, one would build each functional subsystem with optimized materials and processes, and then assemble the microsystem. Researchers have been investigating the adoption of macro scale “pick and place” methods to assemble micro or even nano scale components [1-3]. One major concern in these approaches is the “sticking effect” between assembly manipulators and components, due to electrostatic, van der Waals or surface tension forces [4]. On the other hand, new assembly approaches have emerged by taking advantage of the “sticking effect”: Whitesides and coworkers first demonstrated capillary-force-driven assembly of a simple circuit [5]; Srinivasan *et al.* extended the strategy to assemble identical microscopic parts onto a single substrate [6]. In this paper, we describe an approach to achieve multiple batch assembly and bonding of micro components onto a substrate. In addition, electroplating as a post assembly process is used to establish electrical connections for assembled components in a parallel manner.

## Principle

In our assembly method, capillary force is exploited to drive the assembly, and the force is created by hydrocarbon-based lubricant between hydrophobic surfaces as in [5, 6]. A schematic illustration of our assembly process is shown in Figure 1. We fabricate a

silicon substrate with gold patterns as destined binding sites for assembly of parts (Figure 1a). To activate the binding sites on the substrate, hydrophobic alkanethiol ( $\text{CH}_3(\text{CH}_2)_n\text{SH}$ ) SAM is adsorbed on the hydrophilic gold patterns. For each batch of micro parts, only desired binding sites on the substrate are activated by selectively deactivating other binding sites. In the de-activation process, electrochemical reductive desorption of the SAM, i.e.,  $\text{CH}_3(\text{CH}_2)_n\text{SAu} + e^- \rightarrow \text{Au} + \text{CH}_3(\text{CH}_2)_n\text{S}^-$  [7, 8] is performed. Thus we can control the assembly not to occur in the gold regions where the SAM desorption has taken place. To create the driving force, we apply the lubricant to the substrate prior to assembly. Next, the substrate is immersed in water and the lubricant forms droplets exclusively on the activated binding sites (Figure 1b). After the parts are transferred into water, the parts with a hydrophobic side are attracted and aligned to the binding sites on the substrate. The lubricant can be cured by heat and bonds the part to the substrate permanently (Figure 1c). The SAM adsorption, desorption and assembly steps can be repeated for multiple batches of parts assembly. Finally, electrical connections can be established between the assembled parts and the substrate by electroplating (Figure 1d).

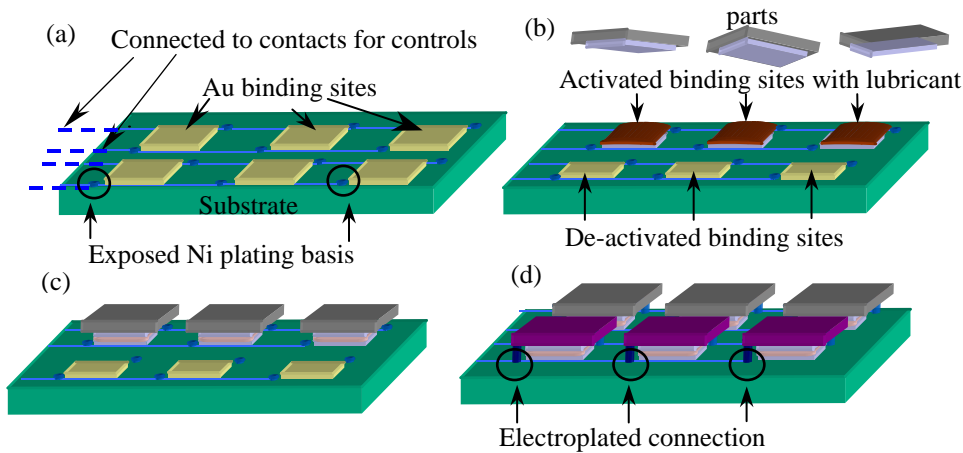


Figure 1. Multiple batch assembly schematic flow. (a) A fabricated substrate for assembly with Au binding sites and Ni plating basis. (b) A substrate prepared for first batch assembly. The substrate is immersed in water with lubricant wetting exclusively the activated binding sites. (c) First batch assembly. (d) By repeating the assembly process, the second batch of components is assembled. Electroplating is performed afterwards to establish electrical connections.

### Experimental

To demonstrate the assembly, we use two different kinds of components: silicon diced chips ( $1\text{mm} \times 1\text{mm}$ ) with one gold-coated side and commercial light emitting diodes (LEDs). Destined substrates for assembly are specifically designed for different kinds of components. For square silicon chips, electrically isolated gold stripes are patterned in a lift-off process on a silicon substrate with thermal oxide layer of approximately  $4000\text{\AA}$ . A passivation layer of silicon nitride is patterned by photolithography and reactive ion etching (RIE) until gold squares ( $1\text{mm} \times 1\text{mm}$ ) as the binding sites are exposed. The

substrate for LED assembly has an additional metallization layer of 350Å Cr/Ni, prior to the Cr/Au layer deposition, which is patterned as the basis for electroplating. To activate the binding sites for assembly, a SAM is adsorbed on all the gold binding sites after immersion in ethanolic dodecanethiol solution for two to twenty-four hours. For multi-batch assembly, desired binding sites for the first batch assembly remain hydrophobic, while other binding sites are de-activated and transformed to hydrophilic via an electrochemical SAM desorption process [9].

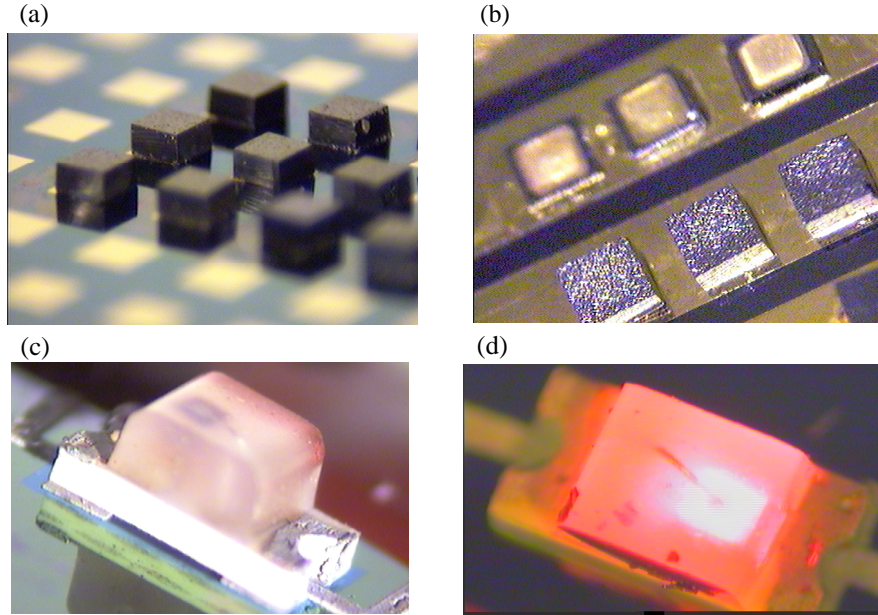


Figure 2. Assembly results. (a) An assembly result of one batch of diced silicon chips (b) A two-batch assembly result. (c) An assembled LED. (d) An assembled LED with electrical connections to the substrate. The LED is activated by applying potential bias

To prepare for the assembly, a hydrocarbon lubricant composed of 97wt.% triethyleneglycol dimethacrylate (Sigma) as crosslinker, and 3wt.% benzoyl peroxide (Sigma) as thermal initiator is spread on the whole substrate. The substrate is then immersed in water. The lubricant wets only the activated binding sites in water. When being added in water, the parts are attracted, and self-aligned to the binding sites on the substrate simultaneously. The lubricant is then polymerized by heat at 80°C for thirty minutes to permanently bond the parts to the substrate. Figure 2a shows the assembly result from one batch of silicon test chips. A second assembly is performed by repeating SAM formation and the assembly steps. A two-batch assembly is demonstrated in Figure 2b. After the assembly, electrical connections between the parts and the substrate are established by electroplating. We use LEDs to demonstrate both assembly and electroplating methods. Figure 2c is an example of an assembled LED. Figure 2d is an assembled LED with electrical connections to the substrate, and the LED is activated by potential bias applied on the contacts on the substrate.

## Conclusions and discussions

Previously, we have presented a self-assembly protocol. As an enabling technology, this technique offers the prospect of efficient integration of complex microsystems from a wide range of different micro components. Currently, we have been investigating in applying this approach to construct hybrid complex systems such as micro fluidic systems. By expanding and modifying the current assembly processes, we are able to assemble piezoelectric actuating elements with precise alignment and establish electrical connections through post-bonding electroplating in order to construct hybrid piezoelectric micro-pumps. We believe micro assembly becomes increasingly important for system integration with the emergence of innovative techniques, materials and devices for microsystems. Our self-assembly protocol demonstrated in this paper provides a feasible solution to overcome the incompatibility between system components and helps to achieve optimal materials and designs for individual components. It is anticipated that this technique can be applied to a wide range of components for the integration and packaging of complex systems.

## Acknowledgements

We would like to thank R. T. Howe and U. Srinivasan for discussions and M. B. Cohn for some micro parts. We thank the members of the Washington Technology Center Microfabrication laboratory. This research is supported in part by NSF Career Award ECS9875367 to K. Böhringer and by donations from industrial affiliates. D. Schwartz acknowledges partial support by an NSF Young Investigator Award CTS-9457097. Y. Hanein acknowledges partial support by an NSF CISE Postdoctoral Research Associateship EIA0072744. X. Xiong acknowledges support from a Ford Fellowship.

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