PART TILTING IN CAPILLARY-BASED SELF-ASSEMBLY: MODELING AND CORRECTION METHODS

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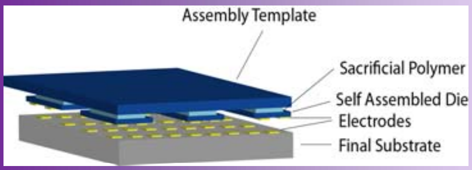
Abstract

We present a model and experimental results on tilt angle of microparts in capillary-driven self-assembly. The assembly is carried out in an aqueous environment, using a heat curable adhesive for part-substrate lubrication and mechanical bonding. Silicon parts and substrate have matching hydrophobic binding sites, which drive the assembly by surface energy minimization. Force balance analysis of an assembled part leads to a model describing the dependence of tilt angle on assembly parameters such as adhesive volume and water-adhesive interfacial tension. The effect of adhesive volume on tilt angle is investigated experimentally. Tilt correction of the assembled parts is achieved by providing external energy to the system via vertical vibration.

Design

- **Wafer-scale 3-dimensional microelectronics with high interconnect density needs high part lateral size to thickness ratio: $5\times5\times0.1mm^3$ silicon parts**
- **Rectangular binding site allows for asymmetry and thus more flexibility in the circuitry design**
- **The length to width ratio of rectangular binding sites needs to be more than 1.3:1 to get correct assembly orientations: $3.65\times4.9mm^2$ binding site**



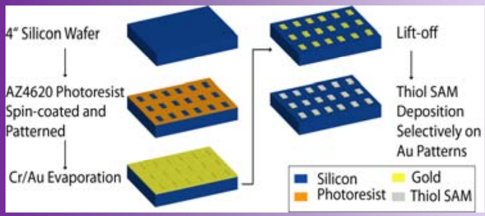
Fabrication

Substrate

- **Binding sites are patterned using Cr/Au evaporation and lift-off on silicon substrate**
- **A self-assembled monolayer (SAM) of thiol molecules which selectively attaches to the gold is used to make binding sites hydrophobic (water contact angle: 110º) by soaking the patterned substrate in 1 mM dodecanethiol in ethanol overnight**

Part

- **Binding sites are patterned using Cr/Au evaporation and lift-off on silicon wafer: lab atmosphere exposed gold has water contact angle of 70º which is hydrophobic enough for our purpose**
- **A grinding process from the back side of the wafer thins the silicon wafer to 100µm, and then the wafer is diced into individual parts**



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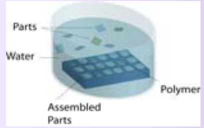
Self-Assembly Process

- **The adhesive used for assembly is hydrophobic and heat curable, and is composed of 97 wt.% triethyleneglycol dimethacrylate as a monomer, and 3 wt.% benzoyl peroxide as the thermal initiator**
- **The assembly template is immersed in a hydrophobic adhesive and pulled out into the water, because of surface energy minimization and hydrophobicity of adhesive and substrate binding sites, the adhesive selectively covers the hydrophobic binding sites**
- **Parts are introduced to the template, and due to surface energy minimization, they attach to the adhesive-coated binding sites**
- **After assembly completion, the adhesive is cured by heating the water to 70ºC for 2 hours, and mechanical bonding is achieved**



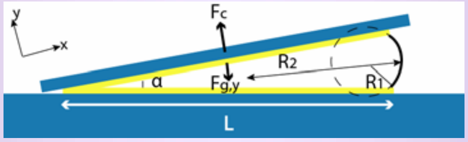
Modeling and Experiments

- **Force balance analysis is used to model part tilt angle as a function of assembly parameters**

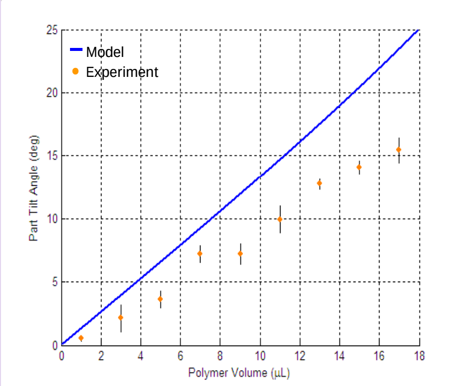
$$V_\alpha = WL^2\sin(\alpha/2)\cos(\alpha/2) + W(R_1{}^2\beta - L\sin(\alpha/2)R_1\cos(\beta))$$

$$F_c = \Delta PA = \gamma_{AW}\left(\frac{1}{R_1}+\frac{1}{R_2}\right)A \qquad R_1 = \left(\frac{t\rho g\cos(\alpha)}{\gamma_{AW}} - \frac{1}{R_2}\right)^{-1}$$

$$F_{g,y} = mg\cos(\alpha) \qquad \beta = \sin^{-1}(L\sin(\alpha/2)/R_1)$$

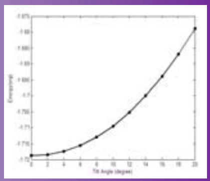


- **Tilt angle is measured as a function of adhesive volume. The tilt angle increases by adhesive volume increment, hence tilt can be minimized by volume minimization**
- **Volume minimization needs very good control on dip-coating parameters**
- **Model and experimental results comparison shows fine compatibility**

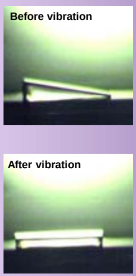


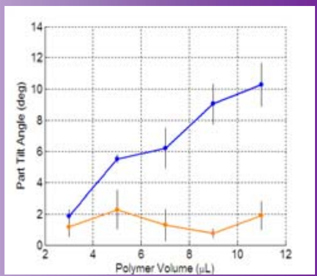
Correction Methods

- **Random direction of part approach during assembly causes vertical tilt**
- **Surface Evolver simulations show that the energy minimum of the system is in flat state**



- **Tilt correction can be achieved by external agitation which provides enough energy to the system to transfer to the global energy minimum (flat state)**
- **Vertical vibration is used as external agitation by positioning the assembly container on the stage of a speaker, connected to a signal generator with a 15Hz, 9V sinusoidal wave for 2 minutes**





Conclusion

- **A model of tilt angle as a function of assembly parameters is proposed**
- **The control and minimization of part tilt in capillary-based self-assembly is investigated**
- **A tilt correction method is demonstrated using external agitation**

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