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 studied due to its apparent environment, using a hard contact process: the wafer-scale fabrication and mechanical bonding. Silicon parts and substrates have nanoscale hydrophobic binding sites, which will be optimized by surface energy minimization. Force balance analysis of the assembled part leads to a model describing the dependence of the tilt angle on assembly parameters such as adhesive volume and interfacial interfacial tension. The effect of adhesive volume and interfacial tension is investigated experimentally. The assembly process is achieved by providing external energy to the system via vertical vibration.

Self-Assembly Process

- The assembly process is hydrophobic and heat curable, and is composed of 97 wt.%, triethylene glycol 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 hydrophilicity of the 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 wafer to 70°C for 3 hours, and mechanical bonding is achieved.

Correlation Methods

- Random direction of part approach during assembly causes vertical tilt.
- Surface roughness simulations show that the energy minimum of the system is lower near vertical tilt.
- Tilt correction can be achieved by external agitation which provides angular energy to the system to transfer to the global energy minimum.
- Vertical vibration is used as external agitation by positioning the assembly template on the stage of a sample, connected to a signal generator with a low-harmonic wave for 5 minutes.

Modeling and Experiments

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

  \[ V_t = W L (\sin(\alpha/2) \cos(\alpha/2) + W (R_1 + \beta - L \sin(\alpha/2) \cos(\beta))) \]

  \[ F_r = APA = \gamma A R (\sin(\alpha/2) \cos(\alpha/2)) \]

  \[ F_{r1} = \gamma A R \left(\sin(\alpha/2) \cos(\alpha/2)\right) \]

- 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 optimization needs very good control on dip-coating parameters.
- Model and experimental results comparison shows fine compatibility.

Conclusion

- A model of tilt angle as a function of assembly parameters is proposed.
- The system and optimization of part tilt in capillary-based self-assembly is demonstrated.
- A tilt correction method is demonstrated using external agitation.

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