Fluidic Self-Assembly of Micromirrors onto Surface Micromachined Actuators

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Abstract

We have developed a microassembly technique whereby single-crystal silicon micromirrors are fluidically self-assembled onto MEMS actuators with submicron precision. This technique decouples the mirror and actuator fabrication processes, thus giving optimal mirror quality.
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This paper describes the fluidic self-assembly of ultra-flat, single-crystal silicon micromirrors onto a surface micromachined actuator array. Sub-micron precision self-alignment of the mirrors onto the actuator platforms is achieved by patterning matching hydrophobic binding sites on the underside of the mirror and on the platform. An acrylate-based adhesive lubricates the binding sites during assembly and is later cured by heating to 80°C after completion of the assembly process [1,2]. By decoupling mirror fabrication from the actuator fabrication process, each can be optimized independently of the other and the requirement for extremely low stress and stress-gradient films is relaxed. Parallel or batch assembly processes will enable for low-cost, precision fabrication of microsystems that require a variety of materials and fabrication processes [3].

Evaporated films of gold/chrome were patterned on the surface micromachined actuators using the lift-off process to give binding sites for the micromirrors. An array of seven actuators is shown in Fig. 1a. The micromirrors were defined using deep reactive ion etching of a silicon-on-insulator wafer with silicon layer thickness of 15 µm. Photoresist lift-off was used to pattern evaporated films of gold/chrome into binding sites on each mirror. We used hexagonal mirrors and binding sites of diameters 400 and 200 µm, respectively, as shown in Fig. 1b.

Before the sacrificial layer etch to release the actuators, the chips are immersed in hydrogen peroxide to oxidize the polysilicon and nickel areas, and gently clean the gold regions. The chips are rinsed in ethanol and immersed in a 1 mM solution of octadecanethiol in ethanol for 1 hour. This results in the formation of a hydrophobic monolayer only on the gold regions, leaving the remaining surface area hydrophilic. The chips are rinsed in pure ethanol, dried, and then lowered through a film of acrylate-based adhesive on water (adhesive consists of dodecyl methacrylate, 1,6-hexanediol diacrylate and benzoyl peroxide). Due to interfacial free energy minimization, thin films of the adhesive selectively coat only the hydrophobic gold binding sites (Fig. 2a). Now, the single-crystal silicon mirrors (which have been released in hydrofluoric acid and the gold regions coated with the hydrophobic monolayer) are pipetted towards the actuator chips under water. Once the hydrophobic binding site on a mirror comes into contact with a lubricated binding site on an actuator, spontaneous self-alignment occurs due to the capillary forces of the adhesive. Fig. 2b shows an array of seven mirrors self-assembled onto unreleased actuators under water. Once the assembly is complete, the adhesive is hardened by heating in a water bath at 80°C with nitrogen bubbling. Finally, the actuators are released in hydrofluoric acid and dried with carbon dioxide critical point drying.

An SEM of a bonded mirror on a released actuator is given in Fig. 3. We measured a mirror tilt of 8 µm, or 1.1°, over this mirror. The tilt may be reduced by adding geometric features to the mirrors to define planarity. Interferometry was used to investigate the flatness of the assembled mirrors. Varying levels of adhesive-induced curvature have been observed depending on the adhesive formulation, the curing schedule, and the binding site area. The acrylate-based formulation gives a flatness within 50 nm, excluding tilt, over the 200 µm diameter hexagonal mirror binding site as shown in Fig. 4. The mesa profile outside the binding site is also present on unbonded mirrors while the reverse side of the mirror is measured as flat to within 60 nm. Therefore, this profile is probably due to an etching effect during the 1.5 h mirror release in HF. We believe that once this etching problem is cleared, a curvature of less than 60 nm, or λ/10 for red light, over the entire mirror is attainable.

The self-assembly technique used here has the potential to assemble large arrays with high yield. We believe this approach holds promise for the MOEMS community, at first to put mirrors onto actuators, and later to assemble various components—lenses, gratings, and beamsplitters, for example, onto a substrate of choice to give micro-optical benches.

References


Figure 1. a) Array of surface-micromachined actuators with hexagonal Au/Cr binding site for mirror attachment b) Array of Si (100) mirrors with Au/Cr binding sites, fabricated from SOI wafer with silicon thickness of 15 µm.

Figure 2. a) Actuator array with acrylate adhesive selectively coating the hydrophobic gold binding sites under water. b) Actuator array with self-assembled mirrors under water. The unbound, upside down mirror in lower right was later removed with flowing water.

Figure 3. SEM of released actuator with self-assembled and bonded single crystalline silicon mirror. Dark region at center of mirror may be due to an etch effect in the 1.5 h mirror release.

Figure 4. Interferometry shows that the adhesive-induced curvature excluding tilt on the mirror within the binding site is ~50 nm. The profile outside the binding site may be due to an etch effect since it is also present on unbound mirrors.

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