Micro Snap-Fits for Latching 3D MEMS Assemblies

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MICRO SNAP-FITS FOR LATCHING 3D MEMS ASSEMBLIES

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ABSTRACT

This paper reports the design, fabrication and demonstration of micro-scale mechanical latches (micro snap-fits) for assembling 3D micro-structures from 2D patterned precursors. The latches consist of pairs of pointy arrowhead-like features mounted on cantilevers, on one membrane, and corresponding slits in the mating membrane. As the membranes are pushed together, the cantilevers bend elastically and squeeze the arrowhead tips through the slits to latch onto the back side of the mating membrane. The latches are reversible, enabling reconfigurable assembly. They are also designed to have no backlash, enabling precise positioning of the assembled structures. An analytical model of the latches was used to design the profile of the arrowheads subject to the geometrical constraints imposed by the alignment system. The micro snap-fits were demonstrated by assembling a corner-cube from two folded flat panels with the substrate serving as the third side.

INTRODUCTION

The need for 3D microfabrication is increasing, but its implementation remains challenging. In integrated circuits, 3D architectures promise to reduce interconnect power consumption and enhance connectivity. 3D microfabrication is also key in creating advanced optical devices and multi-functional hybrid microsystems. State of the art fabrication techniques allow the controlled fabrication of films of thicknesses on the order of nanometers with atomically smooth surfaces. However, they are tailored to patterning two-dimensional thin films and fall short of producing high quality 3D structures. For instance, patterning a thin tall vertical mirror is practically impossible with conventional techniques. The thickness of the structure is limited by the vertical dimension and the achievable aspect ratio, and the roughness and slants of the side walls are dictated by the etching process. The slants are usually hard to control and the surface roughness is often far from optically-smooth [1].

One way of creating 3D MEMS that utilize the advanced capabilities of 2D fabrication is to pattern thin films flat on a substrate, fold the patterned film structures, and assemble them into a prescribed 3D configuration [2-4].

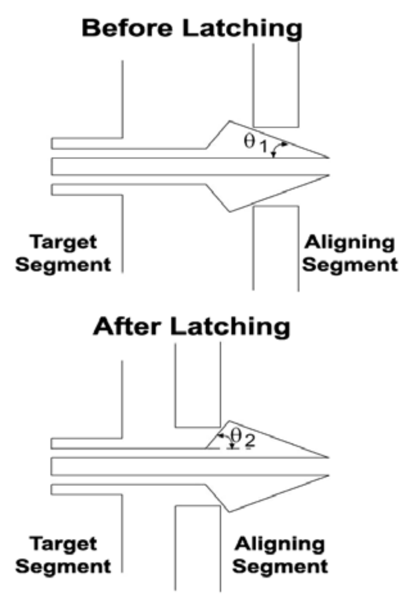

Figure 1: Schematic demonstrating the principle of operation of the micro snap-fits with snapshots before and after latching

CONCEPT

Assembling 2D films into 3D structures requires three steps: actuation of the 2D precursors, accurate alignment of the segments, and latching them in their final positions. Actuation methods for assembly are relatively well-developed, including actuation driven by bending moments from stress gradients [2], internal forces such as surface tension [3,4], and external magnetic or electromagnetic forces [5,6]. We have also developed a cascaded alignment system for accurately positioning 2D patterned segments at arbitrary angles in space [7]. The latching method presented here works in conjunction with the alignment system to hold the assembled structures in their final positions. The latches are arrowhead-like micro snap-fits that are patterned on the edges of one of the mating segments. Corresponding slits are patterned in the face of the second segment. The two segments latch together when the arrowheads squeeze through their corresponding slit and pop through to the back side of the membrane (Figure 1).

DESIGN AND MODELING

The latching-unlatching performance of the system was predicted from quantitative, analytically-based models and used to design the shape of the arrowhead latches.

The choice of cantilevers with arrowhead tips allowed for a decoupled design that achieved several functional requirements of the latching system. The ratio of insertion force to extraction force was set by choosing the profile of the arrowhead slants on the tip side and the cantilever side. The final minimum-energy state of the latches was chosen such that the cantilevers are not in their fully-relaxed state, to eliminate backlash. The overall strength of the latch was controlled, independently, by the cantilever design.

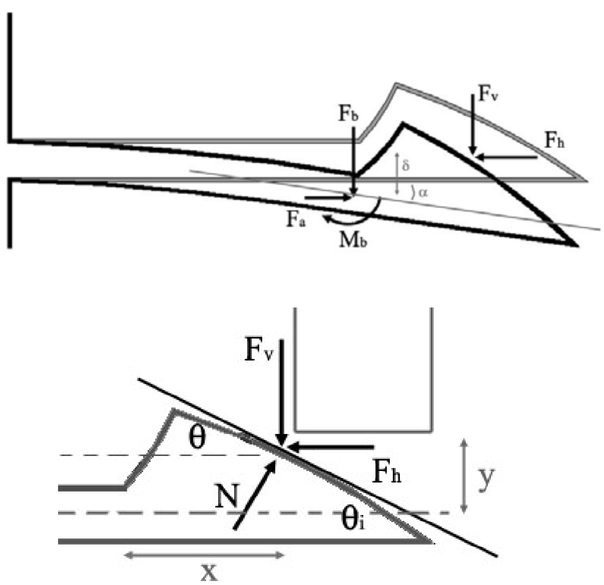

Figure 2: Free body diagram of the arrowhead latch showing the cantilever beam bending due to the applied latching force

For small elastic deflections of the cantilevers, the lateral and angular deflections of the beam's tip, at the base of the arrow head, are given by

$$\delta = \frac{F_b L^3}{3EI} + \frac{M_b L^2}{2EI}$$

$$\alpha = \frac{F_b L^2}{2EI} + \frac{M_b L}{EI}$$

where E is the Young's modulus of the material, I is the moment of inertia, L is the length of the cantilever (Figure 2).

When a snap-fit latch is subject to a contact force, F, at a position (x,y) relative to the tip of the cantilever, the beam is subject to a tip force and bending moment given by

$$F_b = F_v$$

$$M_b = F_v x - F_h y$$

where the subscripts v and h indicate the vertical and horizontal components of the contact force. The deflection of the contact point is

$$d = \delta + x \tan \alpha$$

The deflection of the latch is assumed to happen in a quasi equilibrium manner, since the response of the cantilever bending is much faster than the latching/unlatching speeds. A force balance at the contact point, between the arrowhead and

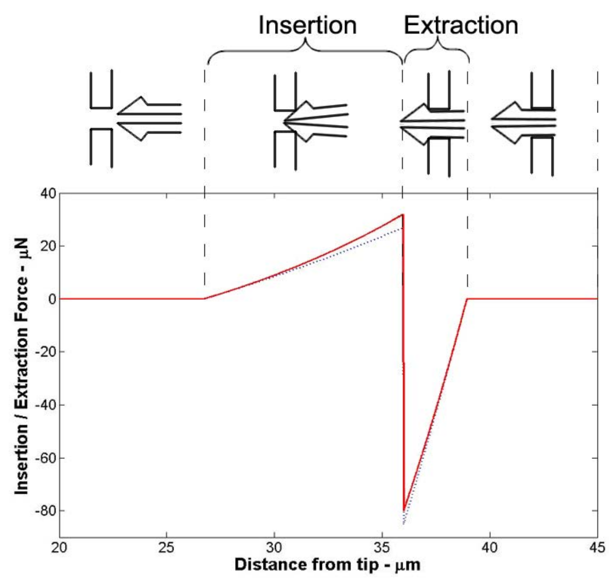

Figure 3: Insertion/Extraction force for an arrowhead latch showing the values of the insertion force (positive values), peaking at 32μN, and extraction force (negative values), peaking at 83μN.

the slit edge, correlates the horizontal insertion/extraction force to the vertical bending force as

$$\frac{F_a}{F_b} = \frac{\sin(\theta) + \mu\cos(\theta)}{\cos(\theta) - \mu\sin(\theta)}$$

where tan(θ) is the slope of the arrowhead profile at the contact point and μ is the coefficient of friction between the two surfaces.

Simulating the latching process requires solving the inverse problem of predicting what insertion force is required to deflect the cantilever such that the contact point on the arrowhead face coincides with the edge of the corresponding slit in the mating membrane. Figure 3 shows a plot of the insertion and extraction forces for a micro snap-fit latch simulated in MATLAB. The plot shows a peak insertion force of 32μN and a peak extraction force of 83μN.

FABRICATION PROCESS

The fabricated devices consisted of two layers, patterned on 6-inch Silicon wafers. Figure 4 shows the steps of the fabrication process: First, a 600nm layer of gold was evaporated on the wafer and patterned using a liftoff process. A 2um-thick image-reversal photoresist was used as the sacrificial layer. A 15um thick layer of SU-8 was then spun on top of the gold-coated wafers and patterned using photo-lithography. The devices were finally released by an isotropic gaseous etch of the silicon in a XeF_2 plasma with the patterned SU-8 structures serving as the etch mask.

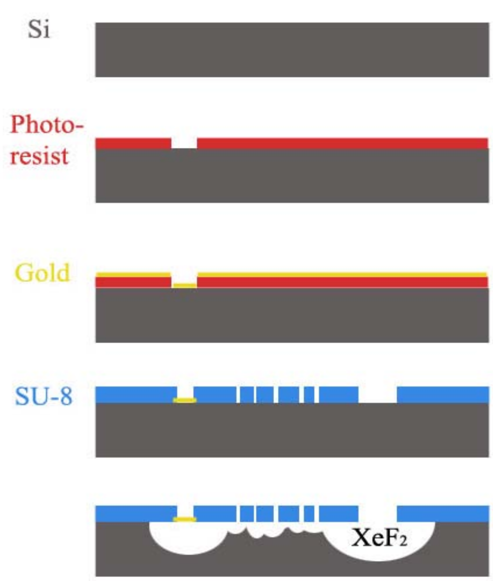

Figure 4: Fabrication process consisting of three main steps Gold liftoff, SU-8 photolithography and XeF2 isotropic etch

EXPERIMENTAL RESULTS

Precursors for a corner cube structure were fabricated in SU-8 with gold bending hinges, on a silicon substrate. The patterned segments were then released in a XeF2 isotropic etch and assembled using a probe station.

The segment of the corner cube that has the triangular-protrusions and the micro snap-fits (target segment) was folded first and allowed to spring back to an angle close to 90 degrees. The aligning segment, which has the rhombic holes and latching slits, was then folded into a vertical position. As the alignment features engaged, the target segment was brought into the targeted 90-degree alignment. At the same time, the micro snap-fits penetrated the rectangular slits and popped out on the back side of the aligning segment. Figure 5 shows an SEM image of the corner cube right before the alignment and latching features engage. Figure 6 is a top view of a successfully assembled corner cube with a magnified cropped portion showing an alignment feature pair and a latched micro snap-fit.

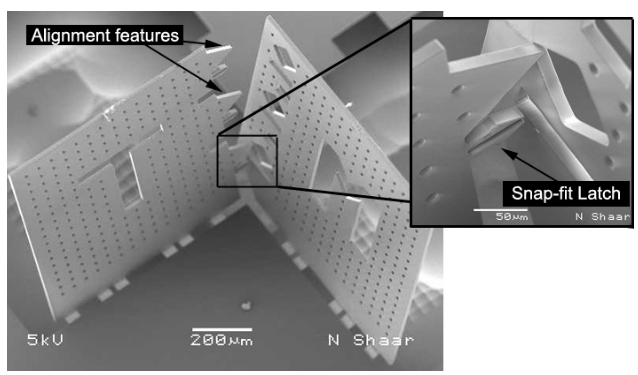

Figure 5: SEM micrograph of a corner cube just as the alignment and latching features start to engage

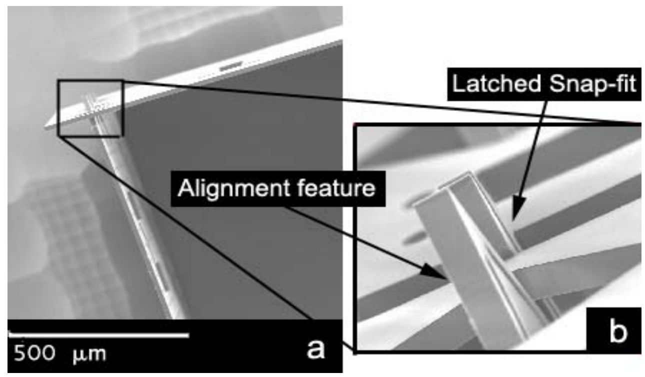

Figure 6: (a) Top view of an assembled corner cube. (b) Close up view of the mated alignment and latching features

ACKNOWLEDGMENTS

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