Proceedings of IMECE04
2004 ASME International Mechanical Engineering Congress and Exposition
November 13-20, 2004, Anaheim, California USA

IMECE2004-61992

SINGLE HIGH ASPECT RATIO PILLAR SUPPORT STRUCTURES:
Multi-scale Chip Integrated Conformal Structures

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ABSTRACT

This paper describes the realization of the integration of micro and nanoscale conformal structures. A new dry processing technique is used to create structures supported by a *s*ingle *h*igh *a*spect *r*atio *p*illar *s*upport (SHARPS), creating submicron single crystal silicon features, with tight geometric control, attached to much larger (10-200μm) silicon dioxide platforms. The platforms have lithographically defined two dimensional shapes. The curvature of the platforms is adjusted through metal deposition and subsequent processing. The flexibility of the structures allows them to conform to meso and microscale roughness. To account for nanoscale conformance stochastic arrays of vertically aligned titania nanofibers are created on the platform surface. The application of the system as a passive microadhesive is investigated using a nanoindenter. Results show that the titania nanofiber surface offers significant increase in adhesion over smooth silicon dioxide or titanium surfaces. However when used in conjunction with the SHARPS structures the fibers are too stiff to allow for conformance to the surface prior to larger scale conformation, thus the combination does not increase the overall adhesion.

Keywords: microadhesive, 3-d processing, micromasking, micropillar, nanoindenter, nanofiber

INTRODUCTION

By extending IC fabrication techniques into the rapidly growing field of micro electro mechanical systems (MEMS) researchers have been able to carve microdevices out of bulk materials, or build them up layer by layer[1]. These fabrication techniques have led to the creation of new device architectures with many applications. The emergence of microsensors has come about due to increased microfabrication abilities and gain in understanding of microscale mechanics. Sensors for location determination, chemical sensors, mass sensors, pressure sensors, inertial sensors, are among the most common thus far[2-14]. Significant developments in microscale sensors have enjoyed interest because they possess important properties, including high sensitivity and the ability to be fabricated in large arrays of thousands to millions. However, there still exists a question in the deployment of these arrays. Adhesion of sensor arrays is one area necessary for many applications that require the deployment of microdevices. In addition chip-scale recognition and adhesion systems will be of great interest for use in fabrication, self-assembling microdevices and immerging miniature aerospace applications. The idea of micromechanical Velcro was laid out over a decade ago by Han et al.[15]. In the work the idea of recognition and mechanical interlocking on two separate chips was introduced.

A common adhesive system found in nature is the fine hair adhesive motif. This adhesive system can be found in beetles, flys, spiders and geckos[16, 17]. The adhesive uses Van der Waals forces and relies on a large amount of surface contact between protruding nanofibrils and the adhesion surface [17-19]. To accomplish inelastic adhesion the nanofibers easily conform to the small scale roughness of the surface. Conforming to the larger scale roughness are the microscale stalks to which nano-scale fibers are attached. Ultimately the roughness becomes so large that the insect itself conforms to the roughness or in the case of the gecko its toe. Thus the adhesive system requires not only nanoconformation abilities but micro and meso scale as well. Here initial efforts to produce a multi-scale microchip compatible adhesive are discussed.

EXPERIMENTAL

FABRICATION

A number of different single high aspect ratio pillar support (SHARPS) structures have been produced [20], Figure 1. Fabrication begins by growing 2 μm of oxide on a 4 inch silicon wafer in the (100) orientation. The top SHARPS platform is then defined in the photoresist using an I-Line stepper. This pattern is then transferred into the oxide through ICP reactive ion etching using CHF_3 chemistry. The remaining photoresist is stripped from the wafer and the oxide is then used as a mask in etching the silicon below. This is accomplished by placing the wafer in a PlasmaTherm ICP etcher and performing a modified Bosch etch process, in which the plasma gas is cycled between a reactive etching chemistry, SF_6, and a polymer producing species, C_4F_8, producing high aspect vertical trenches. The duration of each etch or passivation step can be modified to control the vertical profile of each trench, the extreme of this being a sustained SF_6 where the silicon is nearly isotropically etched. By controlling these parameters it is possible to create silicon dioxide platforms supported in a single point by a silicon pillar, Figure 1.

Additional processing was performed by sputtering different thicknesses of titanium on the surface of the SHARPS platforms, Figure 1. The addition of titanium introduces a significant amount of tensile stress which causes the platforms to curl upwards. Further processing using a reactive ion etch with chlorine chemistry yielded titania nanofibers on the surface of the SHARPS, Figure 2.

EQUIPMENT

Single crystal silicon wafers 100 mm in diameter in the (100) orientation were used for all processing. Silicon dioxide was grown to a thickness of 2 μm using the wet oxidation process at 1050 C in a Tystar Tytan Furnace (Tystar Corporation, Torrance, California). Standard stepper lithography was carried out using a GCA Mann 5x I-line stepper (Hampton, New Hampshire). The photoresist pattern was transferred into the oxide using a Panasonic E640-ICP dry etching system using CHF_3 chemistry (Panasonic Factory Solutions, Osaka, Japan). The deep etching and release was carried out using a modified Bosch Process in a PlasmaTherm 770 ICP reactive ion etcher (Plasmatherm, North St. Petersburg, Florida). In the case where titanium was deposited, DC reactive sputtering was used using an Endeavor 3000 cluster sputter tool (Sputter Films, Santa Barbara, CA). Titanium was transformed into titania through ICP etching of the samples in Cl_2/Ar.

Scanning electron micrographs were taken in a S2400 Hitachi scanning electron microscope (Hitachi Instruments Inc., San Jose, California) or on a FEI XL40 Serion FEG Digital Scanning Microscope (FEI, Hillsboro, Oregon). Surface profilometry was performed with Wyko NT100 Optical Profiler (Veeco, Woodbury, New York). Nanoindentation and adhesion experiments were performed in a Hysitron Triboindenter (Hysitron Inc., Minneapolis, Minnesota).

RESULTS AND DISCUSSION

A variety of different SHARPS structures have been fabricated, Figure 1 and reference [20], having top platforms varying in size from 10 to 200 μm and pillar diameters from 0.5-10 μm, and heights from 5 to 40 μm. The various geometries of the top platform outline and curvature are varied, Figure 1, as well as the pillar geometries (radially and longitudinally) [20].

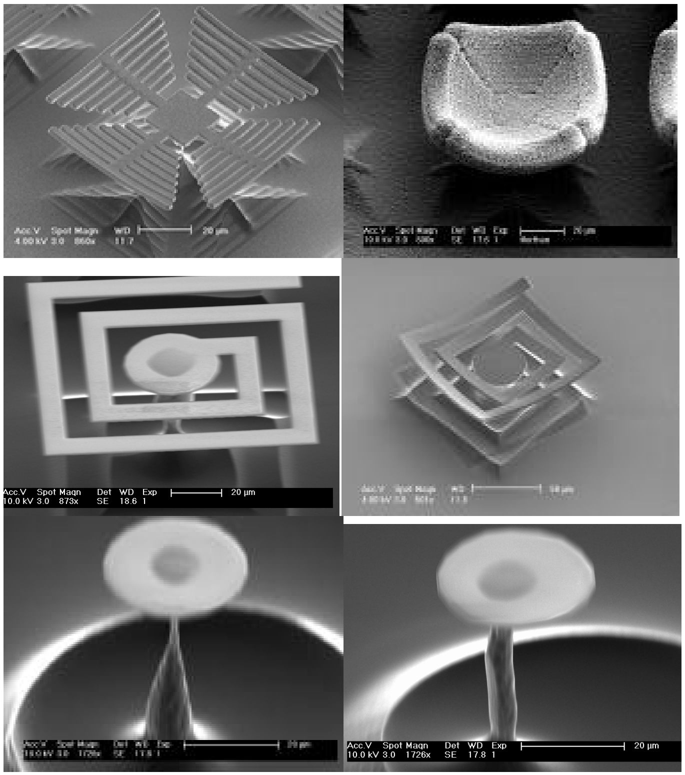

Figure 1. Electron Micrographs showing variable structure of the SHARPS. (from left to right, top to bottom) branched fingered, branched fingered with ~5 μm sputtered titanium deposited on the surface, serpentine, serpentine with ~0.5 μm titanium, circular platform with straight pillar, circular platform with angled pillar.

The planar shape of the top platform is easily controlled by photolithography. A variety of different shapes including platforms, slotted platforms, serpentines of different varieties, branched fingers and radial meanders have been produced, Figure 1. The thermally grown silicon dioxide platforms stay remarkably planar over large distances, ~50 nm height change over 40 μm. The planarity of the platform was disrupted by DC reactive ion sputtering of titanium on the top surface. This served to curl the platform upwards due to a stress gradient. With increased thickness of titanium there was an increase in the radius of curvature of the platforms, Figure 1 and 3. The surface of the platforms was further modified by etching the titanium. Dense arrays of titania nanofibers were created, extending vertically from the surface, through micromasking, Figure 2.

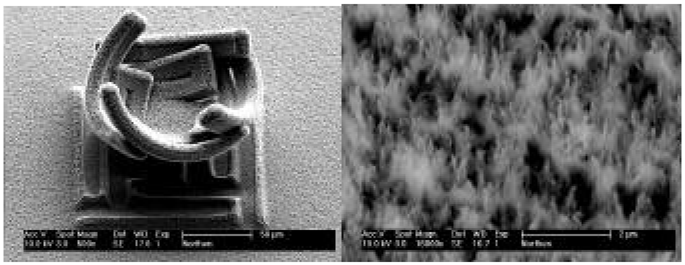

Figure 2. Electron micrographs of a radial meander SHARPS coated with titania nanofibers.

CHARACTERIZATION

Characterization of the structures created has primarily been carried out using scanning electron microscopy. The electron micrographs give us detailed information on the structures created, including shape and dimensions. More quantitative characterization of the surface topology of the supported platforms was carried out using a Wyko Profiler. Using the light interferometer system quantitative surface plots of the silicon dioxide platforms with and without titanium sputtered on the surface were obtained, Figure 3. The addition of 0.5 micrometers of titanium causes the flat silicon dioxide structures to bend 7 μm over 40 μm. With the addition of approximately 5 μm the edges rise up 23.5 μm, with the distortion ultimately limited by steric constraints against another portion of the deflecting structure. By altering the geometry it is possible to increase the deflection.

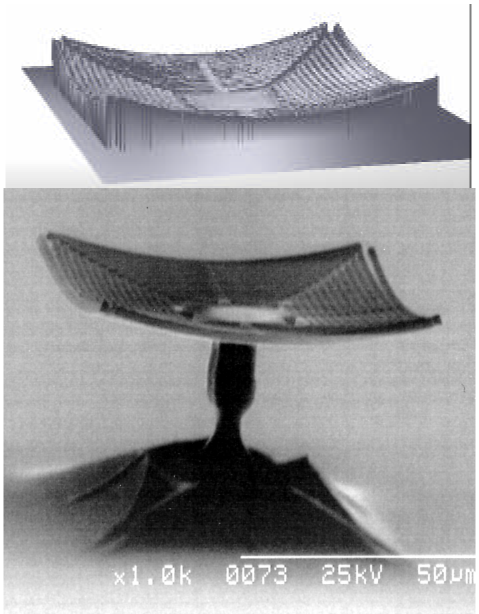

Figure 3. Comparison of light interferometer plot (top) and electron micrograph (bottom) of sputtered titanium curvature induced platforms.

Modified nanoindentation equipment was used to measure the adhesion between test surfaces and a 1.5 mm diameter polyamide sphere. A polyamide sphere was glued to the tip of a nanoindenter probe and pressed against various surfaces. The nanoindenter was operated in displacement control and recorded the load versus displacement. Initially a plot would show a no load versus displacement until the sphere came into contact with the surface. There would then be a positive increase in the load with further displacement. Upon retraction the load curve would fall below zero to a critical point when it would then return to the origin. The minimum load value is taken to be the maximum adhesive force. The maximum adhesion was found to be highly dependent upon the maximum positive load value, Figure 4.

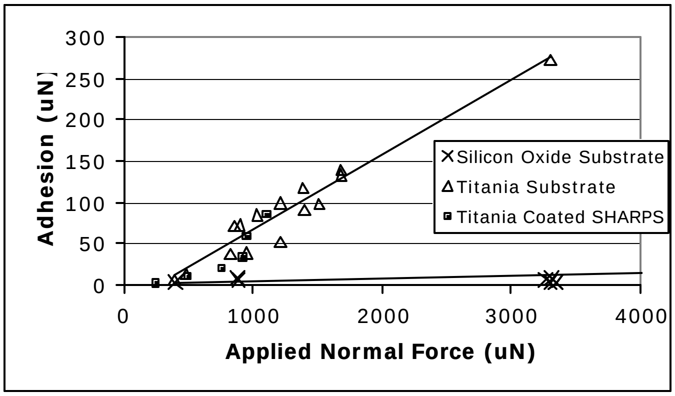

Figure 4. Adhesion comparison SHARPS structure and a solid substrate obtained using modified nanoindentation equipment.

Testing was performed on titania nanofibers approximately one micrometer in length and 20-100 nm in diameter, Figure 2. When the nanofibers were tested on a solid substrate they showed a considerable increase of adhesion over silicon dioxide, Figure 4. However when the fibers were created on the SHARPS structures there was no noticeable increase in adhesion over the titania fibers on the solid substrate. Two explanations of this behavior are that either the structures are not deforming and acting as a solid substrate, or that the nanofibers are not conforming to the surface. Previous testing, [20], has shown that the structures are highly compliant and do not behave at all like a solid substrate. While calculations show that if more than 20 titania fibers are in contact with the indenting sphere then the structure will deform before the fibers conform to the surface. This means that the number of fibers that come into contact with the sphere is dependent on the stiffness ratio of the fibers and the structure. To increase overall conformation the structures need to be compliant, making it necessary for the terminal fibers to be highly compliant.

FUTURE WORK

Future work on this project will entail continued development of novel processing to fabricate new SHARPS structures. In particular work to increase the compliance of the nanofibers in relation to the structures will be pursued. Helping guide the development of new structures will be new and refined characterization techniques. Initial work in adhesion testing has been discussed. Further development of these techniques to make robust test methodologies is needed. These techniques may include continued development of nanoindentation test techniques and integrated manipulation and SEM systems. With improved fabrication and testing techniques, the integration of the SHARPS structures into a working device will be explored. Of particular interest is the use of the SHARPS structure as a chip-scale microadhesive. To this end, investigations of integration and reliability will be explored.

CONCLUSIONS

SHARPS structures consisting of a silicon dioxide platform supported by a single support have been fabricated. The three dimensional structures were created through a unique process requiring only a single lithographic step. Platform geometry can be designed to control the geometry of the support pillar about the radial and long axis, [20]. Sputtered titanium was used to alter the curvature of the platform. Titania nanofibers were fabricated atop the platforms through micromasking during etching and transformation of the titanium through oxidation. The adhesive properties were measured using a modified nanoindentation set-up. It was shown that the titania nanofibers offer increased adhesion over a smooth surface, and the titania nanofibers atop the SHARPS structures offer no apparent increase in adhesion. Future work will primarily focus on using other materials to reduce the stiffness of the nanofibers .

ACKNOWLEDGMENTS

The authors would like to thank Marco Aimi and Masa Rao for all of their processing insight. Funding for this work was provided by the University of California, Santa Barbara.

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