

THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF ENGINEERING SCIENCE AND MECHANICS

SELF-FOLDING PDMS POLYMER FILMS IN RESPONSE TO CAPILLARY
FORCES

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Spring 2010

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree
in Engineering Science
with honors in Engineering Science

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Abstract

Folding processes have proven to be highly beneficial in both nature and man-made devices for a variety of functions such as in protein folding, insect wing functionality, and spacecraft storage. On a micro-scale, folding can be a novel and effective method for fabrication of complex 3-D structures. At this scale, capillary and surface tension forces dominate over bulk body forces, which usually pose a serious threat to nano- and micro-structures due to the deformation of surface geometries. However, in a self-folding film application, these surface tension forces can be harnessed to drive fabrication of three-dimensional structures out of easily synthesized two-dimensional patterns. In this study, the effectiveness of this mode of fabrication is examined through the folding of a variety of three-dimensional polydimethylsiloxane (PDMS) shapes out of thin (25-30 μm) sheets. Furthermore, the capability to directionally fold is investigated through the deposition of a poly-p-xylylene (PPX) surface layer to induce anisotropy to the PDMS surface. Theoretically, this will allow for controllability of the direction of folds.

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Introduction

Polydimethylsiloxane (PDMS) polymer films have demonstrated usefulness in a variety of different applications due to their favorable properties and ease at which they can be tuned at a small scale. Increased interest has been placed on the usefulness of creating patterns or devices at the micro and nano-scale. Fabrication of a desired geometry at such a small scale can be difficult, thus self-driven folding is a promising method for creating unique 3-D shapes which may be valuable self-assembly on the micro-scale.

Folding using capillary forces and surface tension is a relatively new concept as more interest has been shifted toward assembling components on a small scale. Before this idea was executed, surface tension driven forces were almost exclusively seen as negative phenomena, as fine features of a nano-sized surface or a micro-sized surface can be damaged by capillary forces from humidity. On the other hand, these forces can be seen as advantageous driving mechanisms for different three-dimensional structures. The focus, then, is placed on creating an accurate two-dimensional projection of the desired 3-D shape.

Literature Review

Polydimethylsiloxane

PDMS is a commonly used silicone polymer with a variety of applications in everyday use and biomedical/microfluidics devices.^[1,2,3,4] In micro and nano-scale engineering, it is particularly useful for several advantageous properties including a lack of absorbance to visible light, which makes it ideal for biological microfluidics using fluorescence-based detection, and an ability to replicate feature sizes in the sub-micron range.^[2] Moreover, PDMS substrates have the ability for spontaneous adhesion to flat surfaces which allows for microfluidic chambers to be created by creating channels out of lithographic processes and connecting the resulting structure to a planar surface. Another reason for our examination of PDMS structures is its

known bio-compatibility. As one of the most widely used bio-compatible polymers, PDMS allows for a wide-range of bio-medical applications based on desired function. However, PDMS has the disadvantageous property of lacking adhesive properties for cell seeding. Normally, PDMS surfaces are not favored for cell-seeding applications such as in vascular prosthetics. Studies have been conducted to increase cell adhesion by roughening the PDMS substrate on the nano-scale, but these experiments have not replicated the success of other more advantageous polymer surfaces.^[5] In other attempts, PDMS surfaces were altered with extracellular matrix (ECM) proteins prior to cell seeding, and bonding mechanisms such as physisorption, chemisorptions, and covalent bonding were examined. Differences between surface bonding mechanisms were relatively inconclusive, and the cells did not exhibit the desired shift from synthetic to contractile states.^[6] Nevertheless, PDMS is a good model material for us to work with due to its ease of use and highly repeatable results.

Self-Assembly by Spontaneous Folding Processes

Self-assembly processes have gained widespread interest in micro- and nano-machining because of the accuracy and repeatability of these processes for making small-scale structures. Molecular self-assembly is already commonly used to create surface layers on substrates with a high coverage and nano-sized control and manufacture actual molecules or molecular compounds. On a higher order, self-assembly has become an interesting new area of research for the fabrication of parts on the micro-scale. This scale brings about a greater amount of flexibility in engineering designs because you are able to employ a wider variety of force interactions such as capillary, electrostatic, magnetic, optical, etc. Furthermore, manufacturing components on this level, thus far, is almost always limited to processes such as lithography, etching, and e-beam writing.^[7]

There are a couple different approaches for the development of self-assembly methods

such as electronic-based self-assembly (MEMS), self-folding, hierarchical self-assembly (building complex systems from hierarchical ordering of small components), template self-assembly (geometrical restriction of self-assembled systems), and changeable self-assembly systems (components that will alter based on environmental cues).^[7] The focus of this paper will be on self-folding.

In biological systems, folding is an important method for fabricating many different biological molecules and structures. When synthesized, proteins are folded based on their chemical and physical structure, alongside their desired function. Other molecules, such as DNA, RNA, and their derivatives are folded in a variety of ways which reflect the way they function within the biological system. On the macro level a good example is the folding of the bud of a flower.

In man-made folding pastimes such as Japanese origami and paper art, folding into precise 3-D shapes depends on a number of factors. Two-dimensional sheets will fold into three-dimensional structures as a function of the number and direction of folds.^[8] Thus, by tailoring the planar surface and geometry, a number of different three-dimensional structures can be created, as seen by works of Japanese art. This can also be illustrated by the works of Peter Callesen, an artist who folds 8.5"x11" sheets of paper to form intricately complex three-dimensional works of art. Inspiration from these types of works is the main drive for investigating self-folding techniques on a micro-scale.

Self-folding based manufacturing of micro-scale devices is a developing idea that has already been accomplished in a variety of ways by harnessing both magnetic, stress, and surface tension forces. In these types of studies, as discussed above, the planar surface is constructed based on the desire for a specific 3-D shape. In one particular study, the group constructed a planar projection of a globe which was subsequently patterned with magnetic dipoles. This two-dimensional surface could then be folded, under control of the patterned dipoles, into a

three-dimensional globe structure.^[9] This type of experiment exposes a variety of different challenges within the self-folding field such as creating stable and reproducible projects of the intended 3-D shape and accurately creating the mechanism for consistent folding. In this case, the true challenge is correctly positioning the magnetic dipoles for correct folding of the planar surface layer.

Hydrogel substrates have been used in folding applications in response to a variety of different environmental stimuli. Hydrogel materials are composed of a polymer network that has the ability to hold different amounts of fluid in response to different environmental factors. Two hydrogel layers could be placed on top of one another, each with a different swelling ratio when introduced to chemical triggers. The differential in swelling ratio will cause the hydrogel to bend.^[10] This type of bending is induced by the differences in surface layers and has similarly been produced by pre-straining a substrate causing different levels of stress in an object. By pre-straining a surface during fabrication, the release of this strain can cause the surface to wrinkle. Nano-pillars incorporated onto a PDMS surface in such a method has allowed for a promising tunable adhesive interface.^[11]

In other instances, and in the main focus of this paper, folding was achieved by harnessing the power of capillary forces through surface tension. Thin films, on the order of 40-80 μm have been folded in a variety of shapes using a drop of water as the driving force for folding.^[3,4,8,12] In these studies, PDMS was also used as a substrate, and a couple different designs were investigated. However, the foldable material used is not limited to PDMS as the same results have been attained through Silicon thin films.^[12] Silicon thin foils were created at a thickness of a few microns and then forced to fold under capillary forces on a hydrophobic Teflon surface. In this instance, water is also used as the initiator for folding. These new silicon shapes were proposed for use in photovoltaic devices.^[12] Our current study aims to expand on the variety of designs examined in these initial novel attempts.

Methods/Materials

PDMS Film Preparation

PDMS films were prepared using Sylgard® 184 Silicone Elastomer Base mixed at a 10:1 ratio with its associated Curing Agent. Bubbles were removed from the solution by a vacuum chamber in 60 minutes then the resulting PDMS was spun coat onto silicon wafers at 2800 rpm. The spin coater used in this experiment was a modified desktop computer fan. Film thickness was tuned by adjusting the length of operation of the spin-coater and the amount of total solution applied to the silicon wafer, although ultimately, spin time has a more significant effect on film thickness. Initially, glass slides were used; however silicon substrates were more effective in being able to practically remove the resulting shapes. The prepared silicon slides were then placed in an oven to polymerize for 3 hours. Harvesting shapes from the newly prepared PDMS films was done by first lifting the film off the silicon surface then cutting out the shape using a scalpel. A common problem during the process of cutting out the different geometries was ripping and tearing in the shape's structure due to the attraction to the initial silicon surface. By removing the film in bulk and using another surface as a cutting board, this problem was minimized. To characterize the film thickness, a surface profilometer was used, which showed fairly consistent correlation with the amount of time the spin-coater was used along with the amount of solution deposited on the spinning surface.

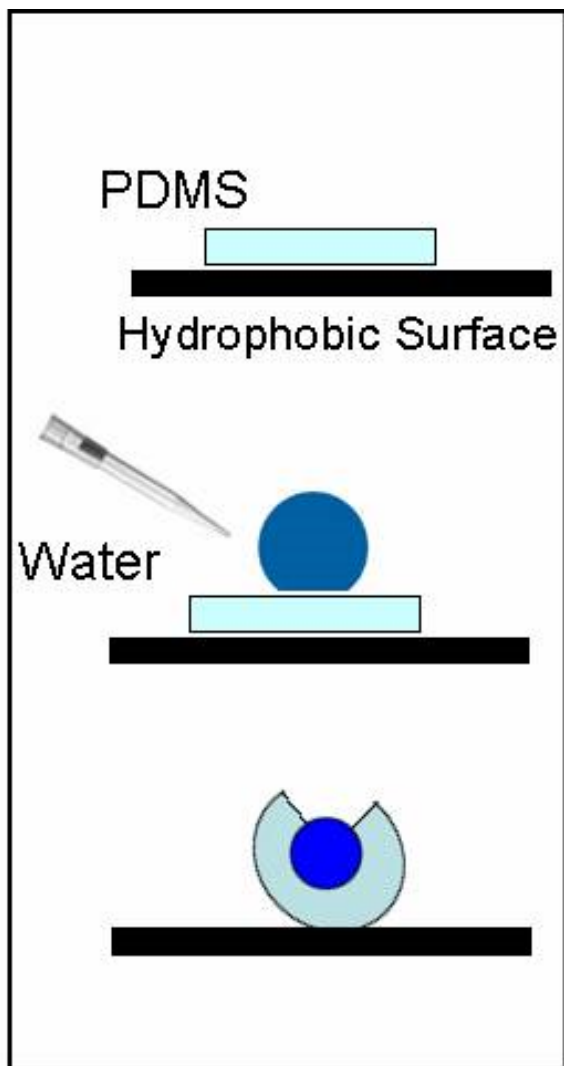


Figure 1 – Schematic of folding process, the PDMS thin film is placed onto a hydrophobic or frictionless surface layer and a drop of water is applied. Capillary forces allow the film to fold over top of the drop

PDMS Geometry Experimentation

Once the desired shapes were prepared they were placed on a hydrophobic surface with a contact angle of $\sim 130^\circ$. Three different surfaces have been used in these experiments. The first was a patterned silicon wafer with planar PPX deposited onto the surface using a Labcoter® 2 Parylene Deposition Unit. This surface was sometimes troublesome because the surface layer would become easily scratched and therefore, the PDMS films would be attracted to the surface and successful folding would be hindered. We then switched to a different surface which was a normal glass slide, first cleaned with Piranha solution, and then deposited with a self-assembled monolayer. Both hydrophobic surfaces exhibited the same issues;

however, working with cheap glass slides is more convenient than the limited supply of patterned silicon chips. The last surface was a non-hydrophobic polymer surface. This particular surface was used because of its dry properties; therefore, the surface would not attract the folding PDMS film.

The PDMS shapes deposited on the surface were filmed with a time lapse HD video camera, which took snapshots of the experimental set-up every 5 seconds. Water was pipetted onto the surface of the thin film so that capillary forces, which are dominant over bulk forces on the micro-scale, would drive self-folding into the desired 3-D shapes. Folding was driven by the resulting evaporation of water so that the edges of the polymer sheets would wrap according to the decreasing volume of water within the folding.

Poly-p-xylylene (PPX) Deposition

The deposition of a columnar poly-p-xylylene (PPX) surface onto the PDMS thin film was completed with a Labcoter 2 parylene deposition unit, a unit specifically designed for the deposition of nano-sized polymer columns. PPX was first placed into the sample holder for deposition preparation. In this study, 0.15 gram, 0.2 gram, and 0.3 gram of PPX were used to grow columnar films. It was found that 0.3 gram samples would not fold due to the thickness of the PPX columnar film. The films that were deposited were not nano-layers even though the Labcoter 2 is capable of coating nano-thick surfaces.

Oblique angle deposition method was used to deposit an angled columnar layer of PPX onto the PDMS surface at a deposition angle of $\alpha = 10^\circ$. This particular method was used because it will cause the surface to have a directionality associated with the direction of the angled PPX columns. Theoretically, this anisotropy could produce directional folding. Other deposition methods such as planar deposition, which deposits a uniform layer onto the surface, and helical deposition, which spins the substrate during coating producing helical structures,

were not sufficient because they would not induce a state of anisotropy to the surface.

PPX surface deposition begins with pyrolysis of a dimer molecule into reactive monomers, which contain free radicals. The free radical attacks the surface of the silicon substrate and form nucleation sites for the PPX to expand upward into columns. If the substrate is held at an angle to the deposition nozzle, the column growth will occur at a certain desired angle. Once the chamber is sealed with a vacuum, the evaporation will begin when the furnace reaches 690°C specific to parylenes which tend to have an evaporation temperature of 150-175°C.^[13] If the vacuum does not drop below 32 mTorr and the furnace and chamber gauge do not reach optimum temperatures of 690°C and 135°C, respectively, then the vaporizer will not begin to rise and deposition will not begin. Ideally, the vacuum should reach of a low of 10 mTorr. Once the process has been initiated, it will take roughly 3 hours. Figure 2 shows a schematic of the deposition process.

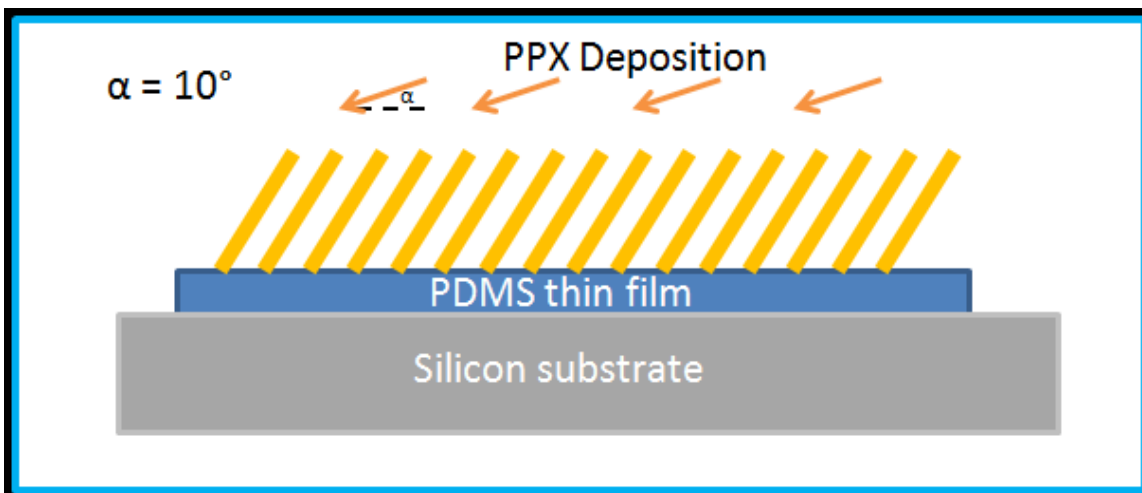


Figure 2 – Schematic of the PPX vapor deposition process. Deposition occurs at an angle of 10° with respect to the surface and produces a columnar layer of PPX as shown

Results/Discussion

The PDMS thin films created by spin-coating PDMS onto silicon wafers were wound to

be $\sim 25\text{-}40\text{ }\mu\text{m}$ thick. The thickness, which is much smaller relative to previous studies of PDMS folding, was sufficient to see the desired folding mechanics. Self-driven folding of each shape has already shown promise in creating unique and repeatable 3-D structures. The folding processes were driven by the forces of surface tension which dominate over the bulk body forces at such a small scale. The folding will occur from the moment between these surface tension forces and the force of the inner pressure from the water droplet. Moments are generated around the axes of rotation between the total pressure force and the outside edge contacting the water droplet. The force-body relationship described can be seen in Figure 3.

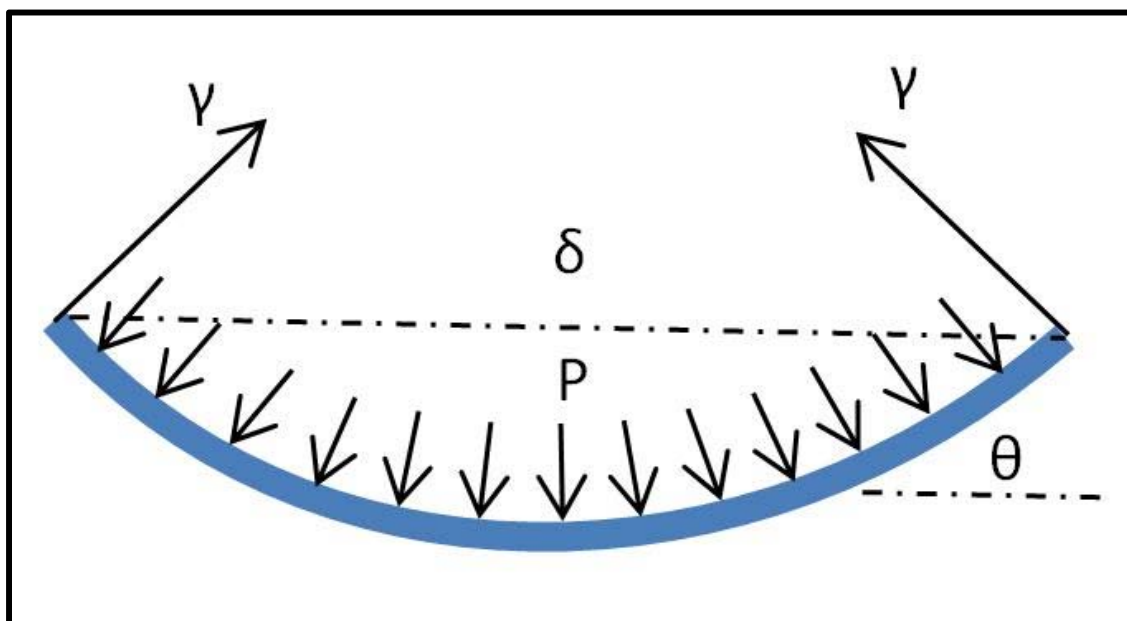


Figure 3 – Force-body diagram of the thin PDMS polymer (the blue arc). The main forces which generate the moments driving folding are γ (surface tension and P (pressure)

A variety of different designs used all showed the similar phenomena of folding of the corners toward the middle due to the nature of the water droplets used during folding. Cutting rounded shapes from the polymer films proved the most difficult due to the lack of square edges and the need to adjust the scalpel mid-cut, producing tearing occasionally. Therefore, we used a cutting technique to slowly round the corners with straight cuts. This allowed for a much more

controlled environment and resulted in less tearing of the rounded shapes. All of the shapes were designed with the intent to create a different set of three-dimensional shapes. Not all of the shapes folded as intended, further work is required to completely demonstrate the tunability of folding control. The initial sample shapes are displayed in Figure 4. These fairly simple shapes have demonstrated predictable folding mechanics, and have already been investigated in previous works.

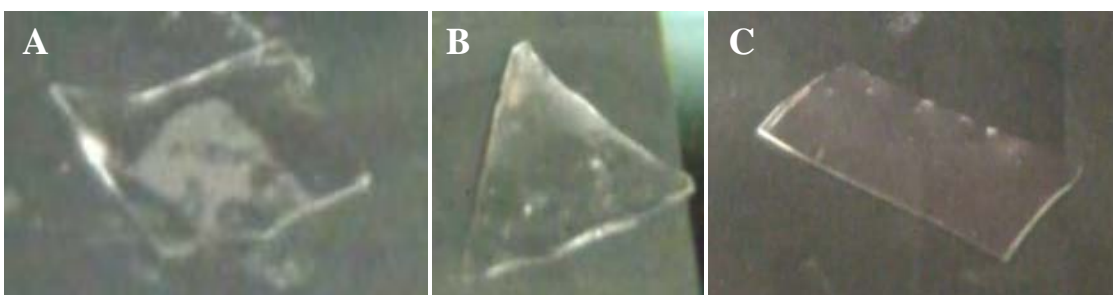


Figure 4 – (A) Square (B) Triangle (C) Rectangle, All shapes had thicknesses of $\sim 30 \mu\text{m}$

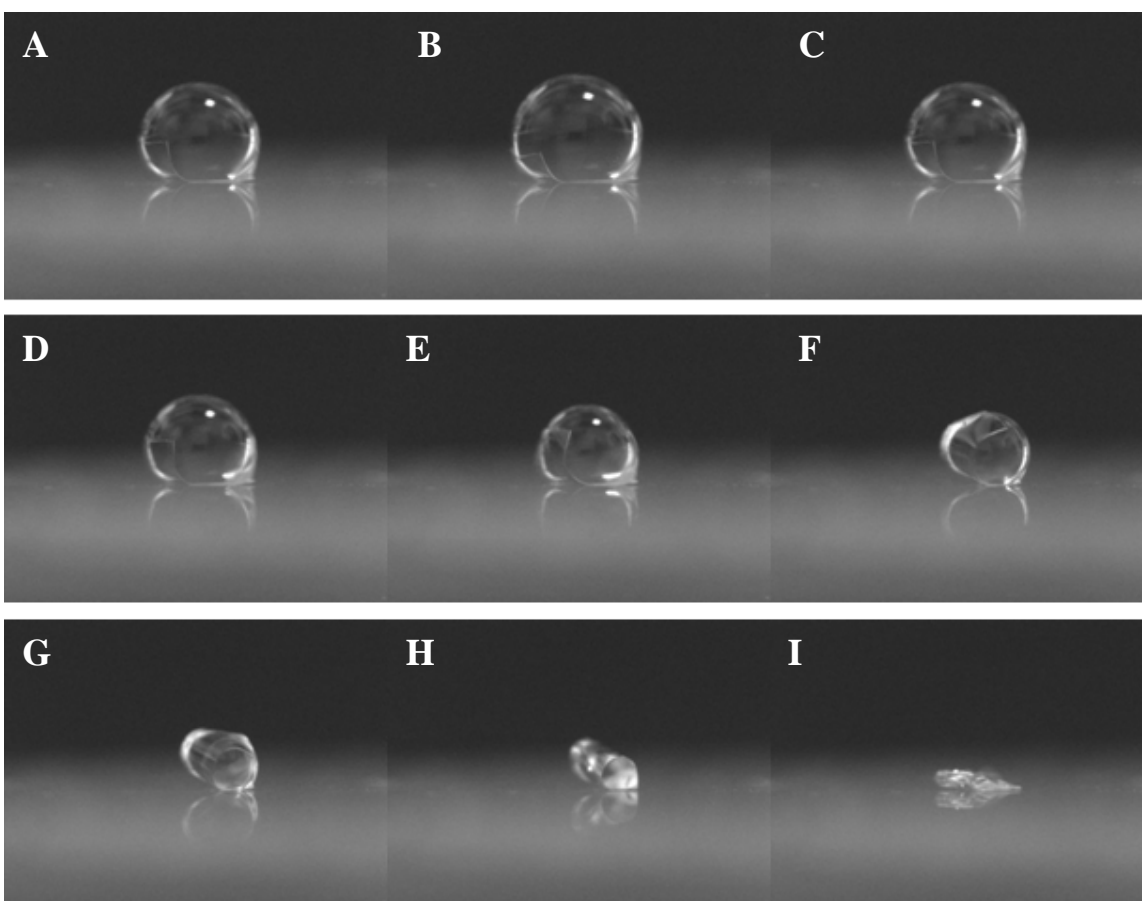


Figure 5 – Folding process of a rectangular piece of PDMS using a contact angle camera. The PDMS sheet folds from left to right.

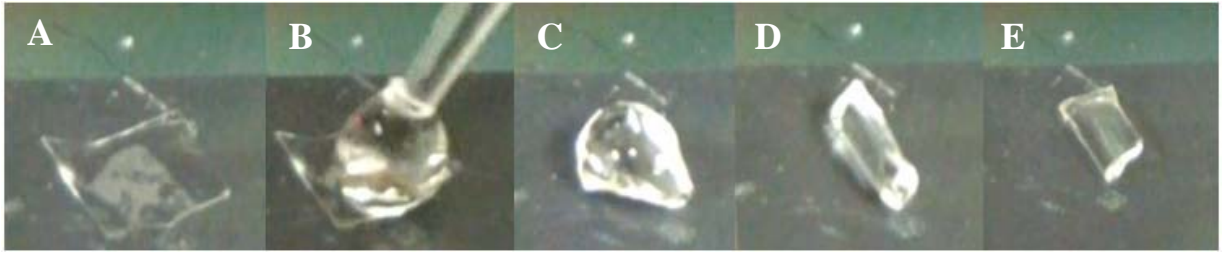


Figure 6 – Folding process of a square-shaped PDMS piece. A single water drop was applied using a pipette and folding initially occurred toward the center, but soon progressed to the shape folding over itself laterally and a tube shape resulted

As in previous studies, the simple shapes (i.e. the rectangle and triangle) displayed consistent folding processes. Rectangular shapes, with a high enough aspect ratio, immediately folded over themselves and created a tube structure. Lower aspect ratios achieved similar results, but initially folded with all four corners to the center of the PDMS sheet. Regardless of aspect ratio, every rectangular design folded similar to a piece of paper with the two ends in the folding direction meeting at one end and the other end containing the curved surface from the middle of the shape. This folding progression can be seen in figures 5 and 6. If the resulting tube structure could be sealed through UV polymerizing resins, this could be an interesting 3-D geometry for flow applications such as in the human vascular system. Figure 7 is an example of a folded rectangular PDMS sheet into a tube structure. The order of magnitude of this type of device would be on par with the dimensions of small vessels in the cardiovascular system. Similar polymers used in biomedical devices, and even hydrogel films, could be seeded with cells and folded into vascular structures.

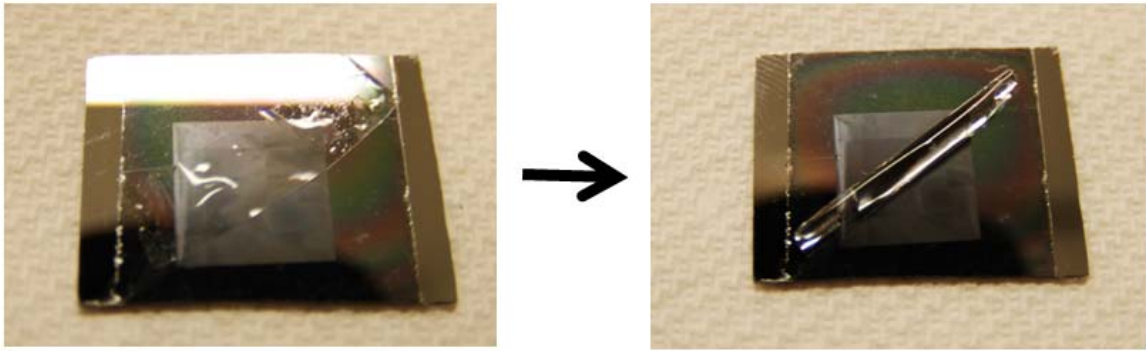


Figure 7 – Folding a large rectangle into a tube structure that has potential applications in vascular engineering practices



Figure 8 – Completely folded triangular PDMS sheet. The three corners of the triangle fold upward toward the central axis to form a pyramid shape.

The triangle folded all three of its points into a pyramid structure. However, it was initially troublesome because, on our hydrophobic surface, the points would be too attracted to the surface and only one or two would fold. This problem could be solved by using a more hydrophobic surface. The resulting geometry produced a container-like 3-D conformation as seen in Figure 8.

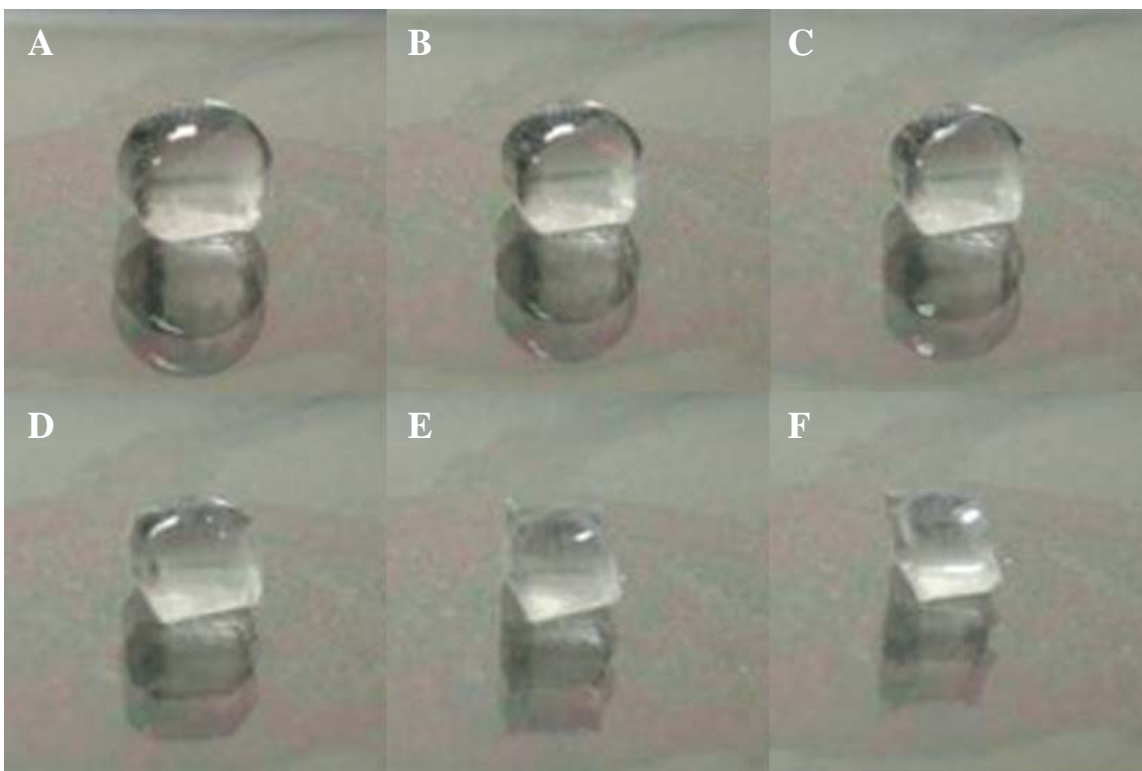


Figure 9 – Folding of the cross-shaped geometry into a box.

The cross shape was one of the more promising in terms of the 3-D geometry because it formed a perfect box (Fig. 9). This micro-sized shape could be an interesting small container in different applications where such a device would be necessary. By making one of the appendages twice as long, a full box could be achieved; however, the longer side will have more curvature than the other three, and the resulting folded shape having complete closure would be difficult to attain. The major difficulty, as the shapes tended to be more complex, was transferring the shape intact to a surface which it would be likely to fold. Electrostatic forces from the tweezers often caused the shape to be wrapped around the metal, and it proved significantly more difficult to get the shape onto the surface in question. The other concern, which should be addressed in further studies, is investigating a patterning method for creating each shape to ensure a more repeatable shape dimension. All the shapes investigated in this study were prepared manually and the overall shape was studied for its folding process. Even though exact dimensions may have been different for each trial, the ratio from shape to shape

was relatively the same.



Figure 10 – Pictures of some of the other shapes tested in this study. (A) double cross (B) "arrowhead" (C) triangular prism cut

The jigsaw-shaped piece did not behave as we predicted with the arms folding into the center giving a staggered interlocking feature. Instead, the shape folded across its y-axis as the two bottom arms came into contact with each other. This type of result would change with the scale of the central portion, since at such a small size the middle portion would be more likely to fold across. With a larger sized mid-section relative to the arms of the “jig-saw,” the middle section would remain stationary as the arms fold.

Several of the more complex shapes did not fold as we had expected and demonstrated difficulty in control of the final 3-D structure. The double-cross shape, as displayed in figure 4, folded across itself instead of each separate appendage folding into the middle. What we had intended with this geometry was to create a double box which would then fold in on itself. Even with the several difficulties confronted from this shape, it should be possible to tailor certain square geometries to meet box shape 3-D structures. Initial 2-D arrangements such as the previously discussed jigsaw, cross, and double cross do show promise in creating multi-layered 3-D shapes.

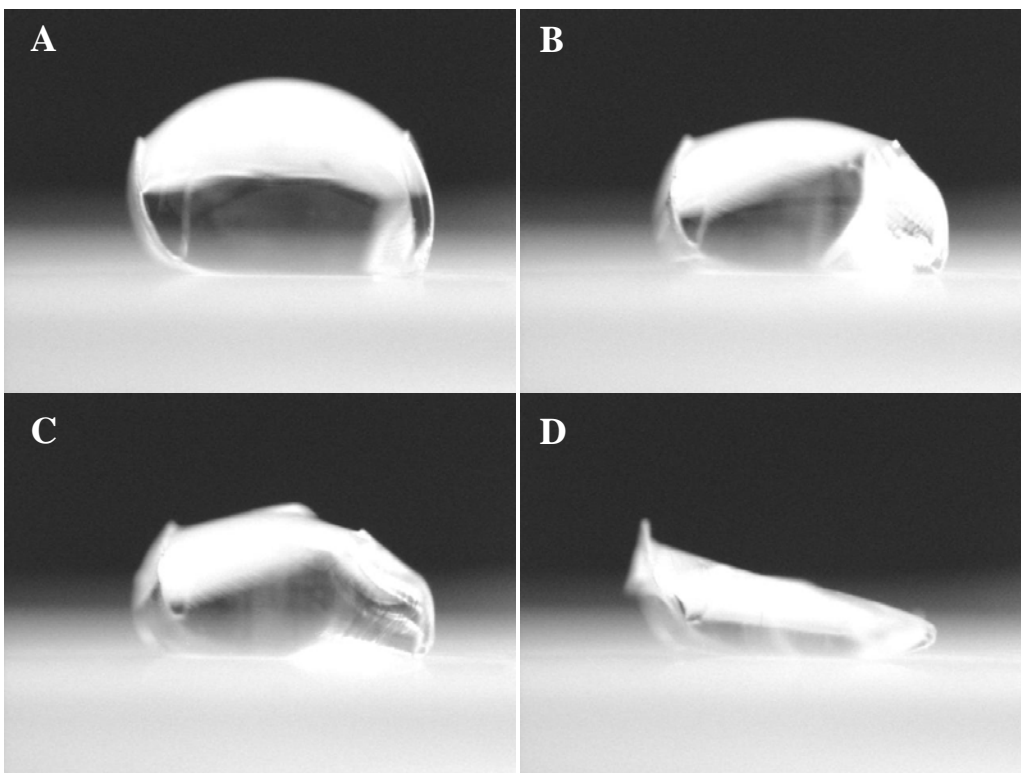


Figure 11 – A side view of the triangular prism cut shape with the rectangular edge facing the front. As the shape progresses eventually one end collapses.

Other, more unique 3-D structures were also investigated from unconventional shapes, simply to widen the possibilities posed by the folding mechanics. One of the issues with folding these designs is ensuring the edges meet in order to have a closed 3-D structure. On this note, we attempted to fold a triangular prism (Fig. 11) with moderate success. The initial planar piece consisted of a box with two triangles on either side along its width. The intent was for the shape to fold up in the center of the rectangle and have the two triangular sides close the structure off in a triangular prism arrangement. While the box did fold as expected, one side eventually collapsed as the two rectangular edges did not meet in the middle completely. With a more careful arrangement of dimensions, this type of shape is possible.

As mentioned above, curved structures were much more difficult to manually cut out of the PDMS sheets. The curved structures we did investigate, however, illustrated that curved edges exhibits a distinct control of the direction of folding. PDMS sheets with curved edges

tended to fold along those edges instead of folding along points or corners. Shaping a planar PDMS sheet with curved edges could result in directional folding of one or more surfaces of that shape. This is an important observation which may allow for more tunability of the resulting 3-D structure.

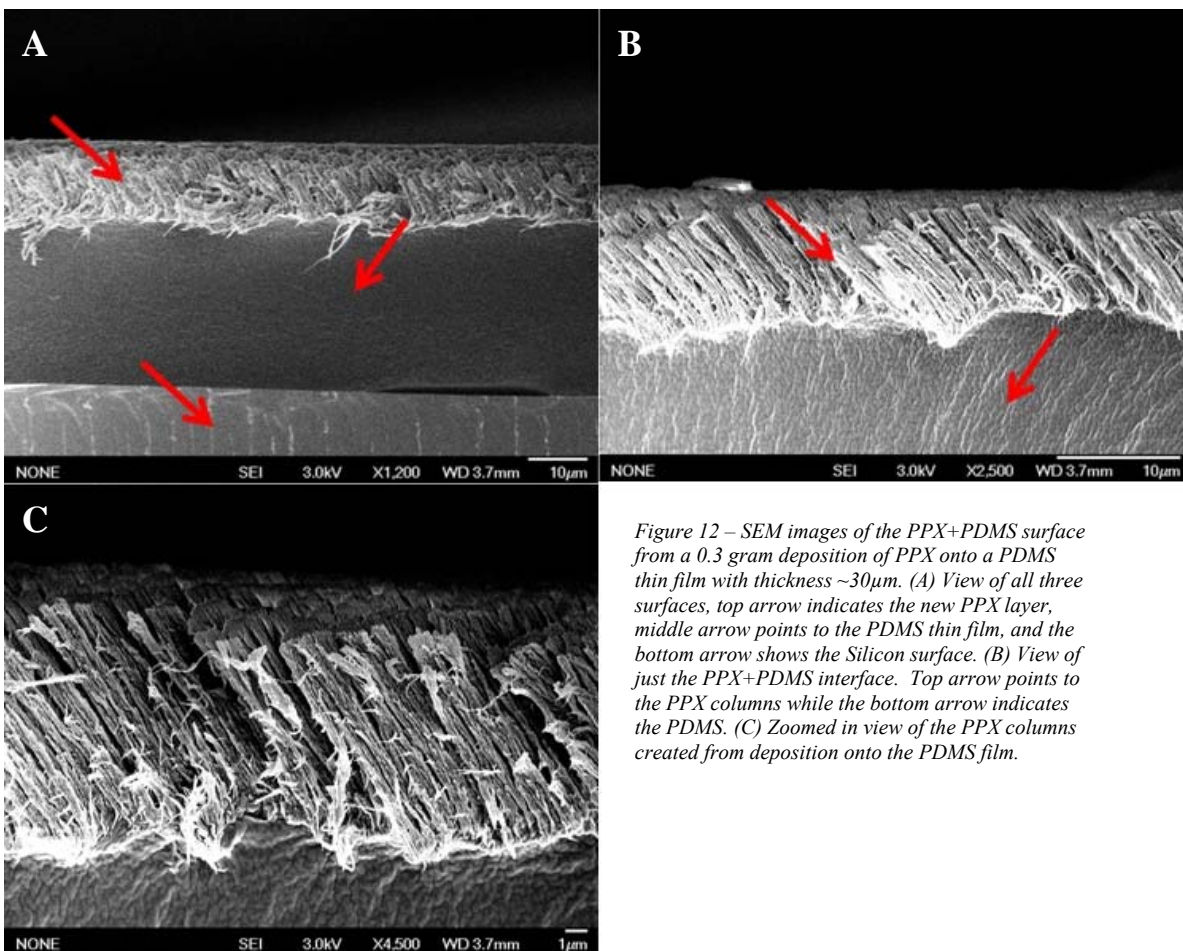


Figure 12 – SEM images of the PPX+PDMS surface from a 0.3 gram deposition of PPX onto a PDMS thin film with thickness $\sim 30\mu\text{m}$. (A) View of all three surfaces, top arrow indicates the new PPX layer, middle arrow points to the PDMS thin film, and the bottom arrow shows the Silicon surface. (B) View of just the PPX+PDMS interface. Top arrow points to the PPX columns while the bottom arrow indicates the PDMS. (C) Zoomed in view of the PPX columns created from deposition onto the PDMS film.

During the examination of a variety of different thin film shapes, there were several challenges which hindered the folding process and made it difficult to gather early results. The most significant obstacle was the attraction of the polymer layer to the hydrophobic surface. Our later switch to a more hydrophobic surface, and even a dry polymer surface, was beneficial and allowed the shape to fold as it should. Due to the attraction of the extremities of a shape's structure to the surface, incomplete folding sometimes resulted. This type of result was most

prevalent in shapes that had smaller outer protrusions such as cross-shaped designs and triangles. The micro-scale of each trial also made it difficult to handle the shapes before they were laid onto the hydrophobic surface. When cleaning the shape with ethanol, self-driven folding would occur causing it to collapse on itself. Handling each film with tweezers would cause similar issues as the small-scale PDMS structures would be more attracted to the metal and would not remove onto the surface for the experiment. This may have contributed some of the scratches on the surface as the tweezers could accidentally come into contact with the patterned surface.

The novel aspect of this project was to induce directionality to the PDMS film to fold in the direction we desired. Anisotropy is introduced using the oblique angle deposition mentioned earlier in this text to produce an angled columnar layer of PPX to the PDMS surface with a thickness of $\sim 10\text{ }\mu\text{m}$. Introducing this new layer will alter the direction, but not magnitude, of the surface tension force (Fig. 3). This will create a mismatch of the two surface tension vectors causing the folding to occur in one direction. An SEM of this new PPX layer on the PDMS substrate can be seen in Figure 12. In Figures 12-A and 12-B the top red arrows indicate the new PPX columnar layer. The middle arrow in Figure 12-A and the bottom arrow in Figure 12-B are pointing to the thin PDMS surface, which is roughly $30\text{ }\mu\text{m}$ thick. In Figure 12-A the bottom arrow indicates the Silicon surface which is clearly much smoother than the PPX-PDMS interface. The PPX-PDMS interface is not completely uniform for a number of reasons. First of all, the method at which we obtained the cross-section was

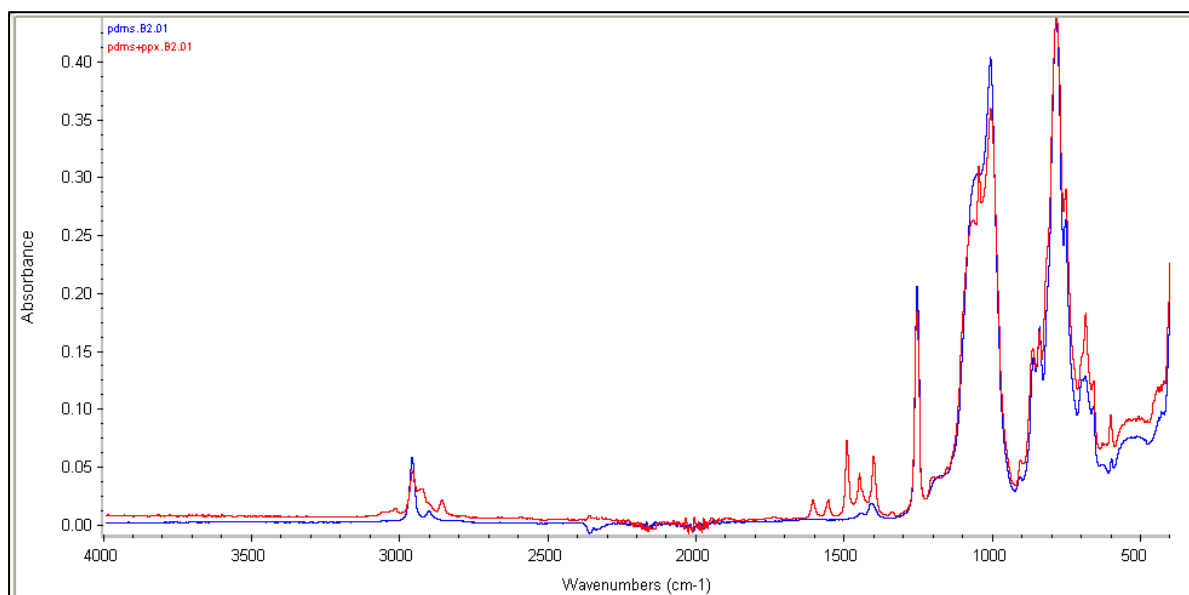


Figure 13 – FTIR spectroscopy results from a PDMS and a PDMS+PPX surface. The PDMS surface is represented by the blue curve while the PDMS+PPX is represented by the red curve.

dipping the sample into liquid nitrogen and snapping it in half to obtain a clean break. Due to the flexibility of the PDMS layer, the break produced some discontinuities in the PPX-PDMS interface. Also, the method by which we spun-coat the PDMS film onto the silicon would not produce a PDMS surface as perfect as the lower Silicon substrate.

To further confirm the presence of a PPX layer on the surface of our PDMS film we performed a FTIR spectroscopy analysis on the film which can be seen in Figure 13. The blue curve indicates the regular PDMS surface while the red curve represents PDMS+PPX. Additional spikes can be seen around 1500 cm^{-1} which indicates the new bonds produced by attachment of PPX to the bottom PDMS layer. This data confirms the presence of the anisotropic PPX layer on top of our PDMS thin film.

To compare the directionality of the folding produced by the PPX layer, multiple samples were recorded at once, as can be seen by the arrangement of samples in Figure 14. The red arrows in this figure represent the folding edge of the PDMS square as it folds across the shape to the opposite edge. As can be seen by these photos, no directionality has been introduced in this case, and it displays one of the difficulties we've encountered while

investigating this directional property. All of the square shapes in this figure have been placed to have all the PPX columns pointed in the same direction. Theoretically, each square should fold in the same manner, however, three of the squares folded in different directions, while the fourth did not fold at all. There could be a variety of reasons for this type of behavior, but most likely, the attraction of the PDMS shapes to the silicon surface is the primary cause. The films being used in these instances are on the order of $30\text{ }\mu\text{m}$, thus if forces attract edges of the films to the folding substrate, the films will likely fold regardless of the directionality present on the surface. As mentioned earlier, in the regular PDMS folding, this is a large obstacle in obtaining repeatable results.

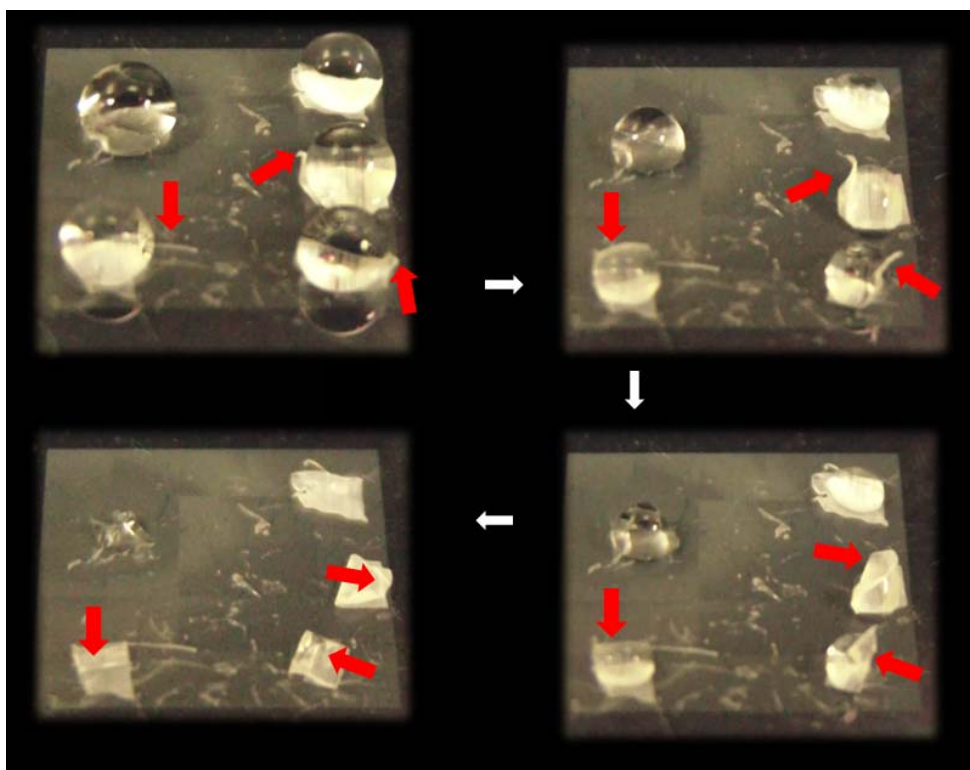


Figure 14 – Images of multiple samples of PDMS+PPX all aligned in the same direction. The red arrows indicate the folding edge.

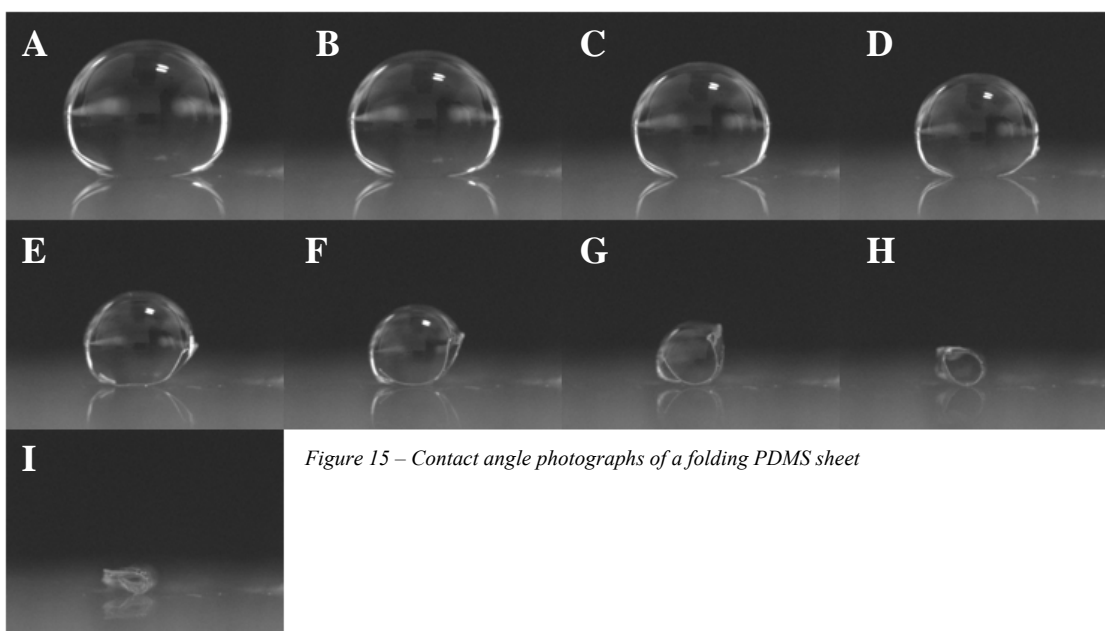


Figure 15 – Contact angle photographs of a folding PDMS sheet

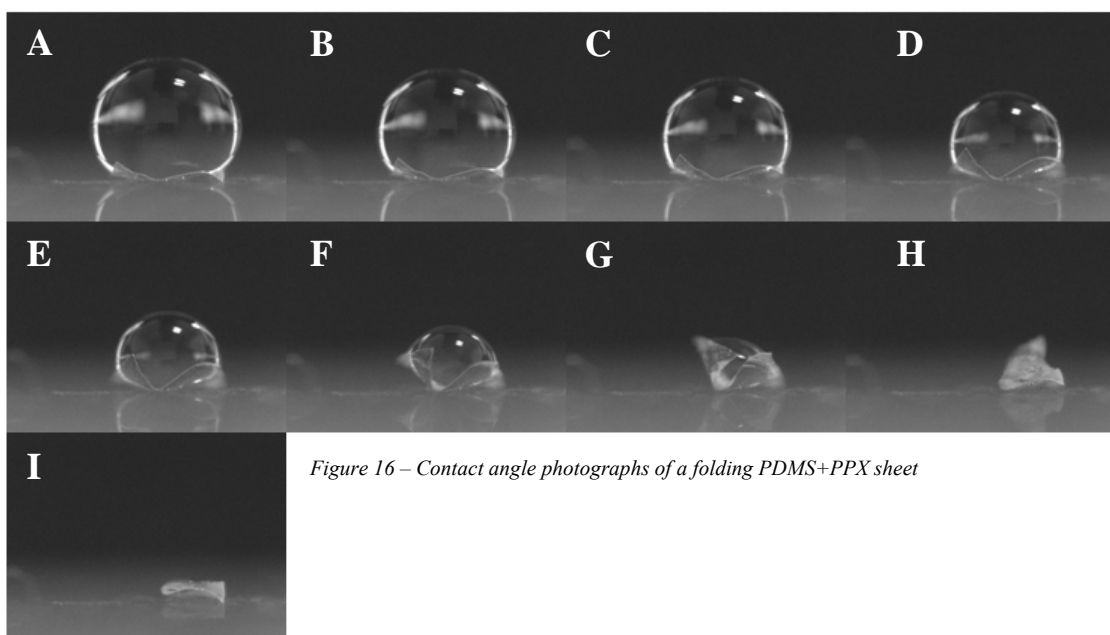


Figure 16 – Contact angle photographs of a folding PDMS+PPX sheet

In order to obtain a folding comparison between regular PDMS folding and PDMS+PPX folding, we photographed trials with a contact angle camera. In both instances, the PDMS sheet used was 2 mm x 2 mm in dimension, and the amount of water used was 15 μ L. In the PDMS-only trial (Fig. 15), we see the expected folding as described throughout this paper. The PDMS+PPX folding (Fig. 16) produced some interesting results. While the PDMS+PPX square

did fold from capillary forces, not all of the edges are in contact with the water droplet. This result is unusual due to the proposed mechanism for folding as described earlier. The leading edge should be in contact with the water droplet to drive folding. The columnar PPX layer must have some other effect on folding because the PDMS+PPX thin film folded regardless of the contact of the leading edge. The mechanisms behind these issues must be investigated further.

Conclusion

Folding of PDMS thin films has been successfully demonstrated for a variety of different 2-D geometries. Fine-tuned control of the resulting 3-D structure was not fully attained, but it should be possible with further study to make well-defined shapes out of PDMS films. The largest difficulty associated with this work was the complications of moving an increasingly complex shape due to electrostatic forces between the thin film and the tweezers used for transport. Moreover, limitations existed due to the manual methodology of creating each 2-D arrangement. A more precise method of synthesizing the shapes would allow for this increase in control because of more accurate dimensions which would produce more accurate results.

It has been successfully shown that capillary forces will dominate over bulk forces on a micro-scale, and these forces can be harnessed in applications such as soft robotics, micromachining, and biomedical devices. The next step in this study is to cure the resulting 3-D structures using a UV photocurable resin to make lasting micro-scale shapes, and to develop techniques to allow for streamlining the synthesis of thin PDMS films and allow for more repeatability. Furthermore, the possibility of shrinking this idea to the nano-level should be investigated.

Folding of PDMS+PPX columnar films is still being examined for its possible role in inducing directionality to PDMS and thin polymer folding. Anisotropy on the surface has

shown promise for controlling the behavior of water across the surface and this concept should allow for directional polymer folding. While we have found that the deposition of the PPX surface layer alters the nature of PDMS folding on hydrophobic surfaces, we have yet to obtain conclusive results concerning directionality.

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EDUCATION

THE PENNSYLVANIA STATE UNIVERSITY

College of Engineering

Schreyer's Honors College

Bachelor of Science – Engineering Science, May 2010

Minor in Bioengineering

- Dean's List, 2006-2009

**HONORS AND
AWARDS**

Schreyer's Honors College Scholar (2006-Present)

Leonhard Scholarship Program (2007-Present)

2nd Place 2005 AIChE Undergraduate Poster Competition
Poster on stimuli-responsive hydrogels

Thomas J Watson Scholarship Recipient (2006-Present)

2006 Jeff Green Scholarship

Award given by Kentucky State Legislature to graduating seniors

2005 Governor's Scholar of Kentucky

2nd Place 2004 Home Builder's Association Architectural Design Contest

PUBLICATIONS

J. D. Ehrick, S. Bachas-Daunert, S. M. Stokes, E. A. Moschou, S. K. Deo, L. G. Bachas, M. J. Madou and S. Daunert, "*Stimuli-Responsive Hydrogels Based on Hinge-Motion Binding Proteins as Recognition Elements*", Polymer Preprints 47, 1106-1107, 2006.

J.D. Ehrick, S. M. Stokes, S. Bachas-Daunert, E. A. Moschou, S. K. Deo, L. G. Bachas, and S. Daunert, "*Chemically Tunable Lensing of Stimuli-Responsive Hydrogel Microdomes*", Adv. Mat. 19, 4024-4027, 2007.

PRESENTATIONS

S. Stokes, S. Bachas-Daunert, J. D. Ehrick, E. A. Moschou, S. K. Deo, and S. Daunert "*Stimuli-Responsive Hydrogels Integrating Binding Protein Recognition Elements*", National Meeting of the American Institute for Chemical Engineers, October 31, 2005, Cincinnati, OH. 2nd Place Undergraduate Poster Session (Student): Food, Pharmaceutical & Biotechnology.

J. D. Ehrick, S. K. Deo, S. Bachas-Daunert, S. Stokes, E. A. Moschou, S. K. Khatwani, S. Daunert, and L. . Bachas,, "Stimuli-Responsive Hydrogels with Integrated Protein Recognition for Sensing Applications", Pacifichem 2005, December 15-20, 2005, Honolulu, HI.

J. D. Ehrick, S. K. Deo, S. Bachas-Daunert, S. Stokes, E. A. Moschou, S. K. Khatwani, L. G. Bachas, and S. Daunert, "Stimuli-Responsive Hydrogels with Integrated Protein Multimers for Sensing

Applications", "Nanohybrid Bioanalytical Systems", PITTCON '06, March 7-12, 2006, Orlando, FL

D. Ehrick, S. Bachas-Daunert, S. Stokes, E. A. Moschou, S. K. Deo, L. G. Bachas, and S. Daunert, "Stimuli-Responsive Hydrogels Based on Hinge Motion Binding Proteins as Recognition Elements", 232nd National Meeting of the American Chemical Society, September 10, 2006, San Francisco, CA.

ACTIVITIES

Penn State Dance Marathon Family Relations Captain

- Created the Celebration of Life video for family hour during THON
- Helped coordinate and serve as a liaison from families to the THON community

Penn State Dance Marathon Entertainment Captain

- Organized Entertainment acts for THON weekend
- Helped set up, run stage at Penn State Dance Marathon

Penn State Dance Marathon Supply Logistics Captain

- Called potential donors for supplies to aid in the production of THON
- Organized THON Raffle prizes including Pontiac G5, Trip to London, and iTouch

William and Wyllis Leonhard Engineering Scholars

- Help run the Engineering Open House for prospective students
- Network with leading engineers in the corporate world

Schreyer Honors College

- Maintain certain number of honors credits
 - Complete Senior thesis
-

WORK EXPERIENCE

Senior Thesis

August 2009-Present

Pennsylvania State University

- Tailored PDMS substrate folding to eventually construct vascular prosthetics
- Coat PDMS surface with PPX to induce directional folding

Research Assistant

May 2008-August 2008

University of Kentucky Markey Cancer Center

- Digitization of medical records for the UK Markey Cancer Center gynecologic oncology department
- Attended weekly tumor conferences and surgeries to gain exposure to medical procedures

Research Assistant

January 2005 – July 2006

University of Kentucky Department of Chemistry

- Researched the potential of stimuli-responsive hydro gels as miniaturized micro lenses in drug screening applications.
- Investigated the possibilities of printing polymers using a standard inkjet printer.

PSU Lab Assistant

April 2007- October 2007

Pennsylvania State University Department of Engineering

- Use an acoustic microscope to take images of live Hela cells and other living tissue cells.
- Utilize cell-fixing techniques using PBS.

2007 LEAP Program Mentor

Summer 2007

Pennsylvania State University, University Park, PA

- Assigned a pride of freshman to introduce to the campus
- Organized weekly activities, study sessions and attended class with group.
- Answer and aid freshman with any concerns they may have.