Evaluation of Hydrophilic Properties of Polydimethylsiloxane for Possible Microfluidic Sweat Sensor Applications

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Abstract: Sweat contains similar health indicators as blood. Consequently, sweat collection for medical diagnostic purposes is an attractive prospect as it doesn't require needles and can reveal information about electrolyte, hydration, and pH levels in the body. Models of sweat sensors range from rigid structures to more flexible designs that incorporate RFID chips and pH sensitive ionogel indicators. The utility of polydimethylsiloxane's (PDMS) qualities such as chemical inertness an induced hydrophilic surfaces might prove beneficial to microfluidic sweat sensors that could require fewer components, enhance fluid flow, and still maintain desired function. This paper details the initial experiments that primarily focused on measuring water droplets through digital images and contact angle measurement. This project was an undergraduate student research requirement of Central Michigan University's (CMU) Ronald E. McNair Scholars program; it was intended to further develop skills related to laboratory technique and academic writing under the guidance of an experienced research mentor. Scanning electron microscopy was explored as an additional means to observe hydrophilic surface properties. Contact angle analysis revealed that repeated exposure to moisture over time reduced the quality and lifetime of hydrophilic PDMS surfaces.

Introduction:

Sweat sensor research is an expanding field due the promise of developing non-invasive health monitoring systems[1-3]. Sweat contains many of the same health indicators found in blood such as pH levels, electrolytes, and proteins[1-3]. Development of efficient sensing designs could reduce the need for uncomfortable needles and holds the potential for collecting information about a person's state of health while they exercise. Some models forgo electronic components in favor of simple pH reactive dyes in gel matrices[1]. Other designs incorporate sweat based batteries and RFID components intended to transmit data to smart phones and computers[2, 3]. The electrolytes found in sweat can serve as a form of "battery" that activates electronic sensors to generate readings[2, 3]. Durability, flexibility, and comfort have been issues faced by sweat sensor designers as commercial models tend to be rigid and uncomfortable[1-3]. In order to improve the comfort and ease of application for living subjects, recent sensor designs were miniaturized so as to be more easily integrated into head bands and adhesive bandage materials[1-3]. Literature sources noted their respective designs performed reliably when compared to commercial sweat sensors[1-3]. Despite their promising performance, the above-mentioned arrays required complex processing and construction—including small circuit elements and laser-cut structural components[1-3].

A polymer known as polydimethylsiloxane (PDMS) might be well-suited to the current body of work as it has demonstrated durability, flexibility and cost-effectiveness in microfabrication projects[4-6]. It has been heavily employed throughout analytical chemistry, Lab-On-a-Chip (LOC) technologies, and microfluidics experiments[4-6]. PDMS initially found popularity in analytical chemistry due to its porousness and absorbency during chemical separation experiments[5]. These properties were ideal for separating and collecting analytes; chemical treatments made it possible to release the samples captured by the PDMS for in-depth analysis[4]. Its biocompatibility and ease of molding through photolithographic processes offered a means to fabricate devices containing micron-scale features while avoiding dangerous chemicals used to etch glass and plastic substrates[5-7]. Microfluidic devices, in particular, range in utility from DNA analysis to ink-jet laser printing[4-7]. The Photolithographic processes involved in their fabrication employ of light-reactive chemicals called photoresists[6, 7]. In particular, negative photoresists harden when exposed to UV radiation. With a proper mask, a mold can be produce microchannels to desired shapes[6, 7]. After the mold is complete it is then a simple matter of preparing and later separating the PDMS from the mold for use[6, 7]. However, PDMS offers other beneficial traits beyond non-toxicity and ease of molding such as the ability to attract water after exposure to oxygen-based plasma.

PDMS is naturally hydrophobic and tends to repel water[5, 8 & 10]. When exposed to oxygen-based plasma, it can temporarily become hydrophilic, inducing water to spread out over the surface of a sample[8-10]. As a water attracting quality could be most beneficial in devices intended for directing fluid flow, much study has been conducted to extend the hydrophilicity in PDMS[8-10]. Methods for evaluating hydrophobic recovery included extended baking times, coating with 2hydroxethyl methacrylate (HEMA), and immersion in water and hexadecane[7-10].

Samples either baked for 14 days before exposure or were treated with HEMA. Hydrophobicity, in non-HEMA samples, reappeared after 14 days while HEMA-treated samples appeared to indefinitely retain their hydrophilic surfaces[8, 9]. Normally, PDMS starts to regain its hydrophobicity in as little as several hours[8-10]. Despite the return of hydrophobic properties, the literature indicates that PDMS never fully regains complete hydrophobicity[8-10]. It is believed that excess crosslinking agent (low molecular weight groups) and undeveloped PDMS contribute to hydrophobic recovery by their attraction to plasma exposed surfaces from the inner layers of the polymer[9]. This led to two main questions which will be discussed below.

First, could hydrophilic PDMS channels offer possibilities for microfluidic sweat sensors consisting of only a few components as opposed to the more complex arrays discussed earlier? The first question conjured a second, more pressing question: Would hydrophilic channel walls be the main driving force for drawing liquid through the devices or would simple capillary forces stimulate sweat movement in the channels? We wanted to study the hydrophobic and hydrophilic properties of PDMS to more clearly answer these questions and assess the practicality of integrating hydrophilic surfaces in PDMS into microfluidic arrays. The work described in this paper was the focus of an undergraduate research project affiliated with the Ronald E. McNair Scholars program. It was based on sweat sensor research being conducted by a faculty member in the electrical engineering department at CMU. One of the requirements for McNair Scholars participants was to participate in a summer-long research project under the guidance of a faculty advisor. The purpose of the summer project was to provide undergraduate students with the opportunity to gain further experience in various aspects of research. The work was mainly carried out at Kaya Lab located in the CMU's School of Engineering and Technology. The procedures and results of the summer's project are presented in the proceeding sections.

Materials:

The materials required for the span of this project included those that served to fabricate testing samples and the equipment involved in running experiments.

PDMS Slides and Soft-lithography

Sylgard 184 PDMS was the main focus material that served to construct the actual samples that were exposed to oxygen plasma. A plasma cleaner generated the plasma that induced hydrophilicity. The nature of the proposed project required SU-8 photo resist, SU-8 developer, a spin coater, and a mask aligner; all such resources were part of the process required to fabricate a suitable molds and samples devices as detailed in previous literature[5, 6]. Examples of each machine can be seen in Fig. 1 below.

Figure 1: Images of a) plasma cleaner; b) PDMS baking oven; c) spin coater; d) mask aligner.

Fig.1 offers pictures of the equipment employed during the investigation of hydrophilic PDMS. The plasma cleaner that induced hydrophilic behavior in PDMS can be seen in Fig. 1a). It functioned by bathing prepared samples with oxygen plasma in a vacuum setting; the plasma cleaner generated plasma by a magnetic field via a wire coil that surrounded the plasma chamber. Fig.1b) shows the oven that was intended for the PDMS curing process. Fig. 1c) shows the spin coater that served to coat glass slides with PDMS. It would have also been part of the photolithographic portions of the fabrication process also requiring the use of a mask aligner shown in Fig. 1d). Additional materials included tape, petri dishes, knives, and hole-punches for creating entry ports into the devices.

Experimental

Much of the work focused on observing moisture droplets on glass slides coated with PDMS. The first portion of this work relied on images captured via a digital camera over a series of days to observe any potential patterns in fluid behavior on diminishing hydrophilic surfaces. Testing branched out to employ a contact angle meter to more quantitatively that measured the contact angle meter progressively over a series of days.

A SEM session investigated any potential surface differences between pristine and plasma-exposed PDMS. Scanning electron microscopy required the deposition of gold and chromium to react with the electron beam and produce images of any potential surface features. SEM work was intended to explore PDMS' topographical properties as suggested in the literature[8].
The fabrication and performance evaluation of both pristine and hydrophilic PDMS microchannels was intended as a more direct means of testing the viability of hydrophilic surfaces in microfluidic sweat sensors. The channels would have mimicked the environment found in the sensors being developed in Kaya Lab and demonstrated just how fluids would have moved in devices constructed from both material types. Fig. 2 provides a side-view of one of type of channels that the project sought to test.

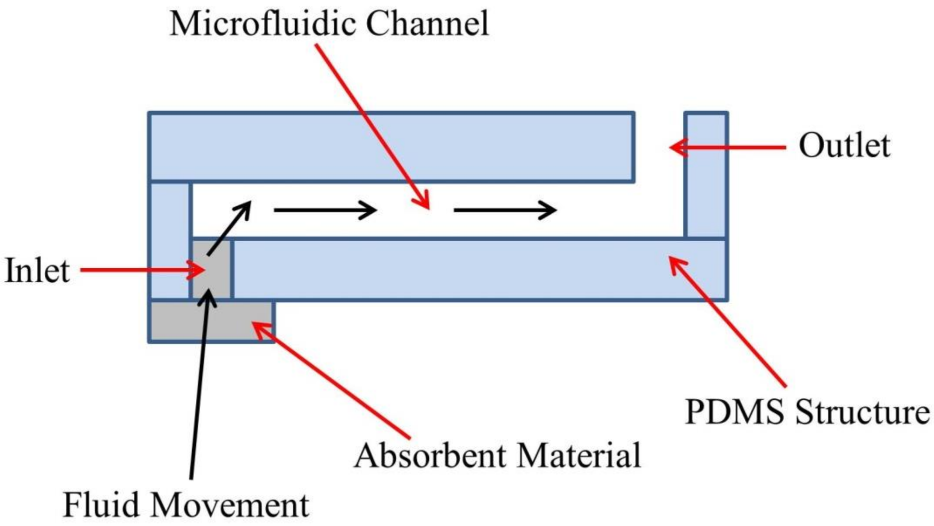

Figure 2: A cut view of the proposed device concept.

As illustrated in Fig.2, the channel was designed with a simple entrance for fluid into the chamber and an exit hole at the top to allow air to escape. The channel design accommodated a moisture-absorbent material for wicking moisture in from a fluid reservoir below. The arrows and labels were added to clarify fluid direction during ideal testing responses. Due to time constraints and issues with the mask aligner, device testing had to be reserved for a later time. SEM, images of droplets, and contact angle meter evaluations comprised the majority of the testing conducted during the summer.

Methods:

To gain a deeper insight into which property is mainly responsible for attracting fluid through PDMS channels it was necessary to evaluate the behavior of both hydrophobic and hydrophilic PDMS structures.

Fabrication

For a more in-depth description of the photolithographic process, it is recommended to consult two sources in the bibliography[5, 6]. The procedures for glass slides fabrication are presented in the subsequent paragraphs.

PDMS on Glass Slides

PDMS coated slides were deemed an effective sample for evaluating hydrophobic recovery of PDMS over time. PDMS was mixed at a 1:10 ratio of curing agent to PDMS and then degassed for approximately 20-30 minutes. 1” by 3” glass slides were covered with degassed PDMS by a spin coater (Laurell Technologies Corporation Model: WS 400 BZ-6NPP/LITE(REV.MS)) to evenly distribute the PDMS over the surfaces of the slides. The slides were spun at 1000 RPM for 30 seconds to a thickness close to 50 µm. After spin coating, the samples were baked on a hot plate (Thermolyn (120V, 750W) Model: HP-A1915B) set to 95º C for a time between 17-35 minutes until completed; the variation in time appeared to be due to a combination of the number of glass slides placed on the hot plate and apparent temperature variations on the surface of the hot plat itself within +/- 5º C. Fig.3 provides images of the equipment and material used at various stages of the slide fabrication process.

Figure 3: Stages of PDMS slide preparation a) mixing, b) degassing, c) spincoating, and d) baking.

Oxygen Exposure

The PDMS coated slides required a simple plasma treatment procedure. A Harrick Plasma Cleaner PDC-32G supplied the necessary plasma in its room air configuration. According to the manual, the plasma cleaner operated in the MHz range at a pressure ranging from 300-1500 mTorr. PDMS samples were treated at the High setting of 18 W. Fig. 4 below provides images of the cleaner during use.

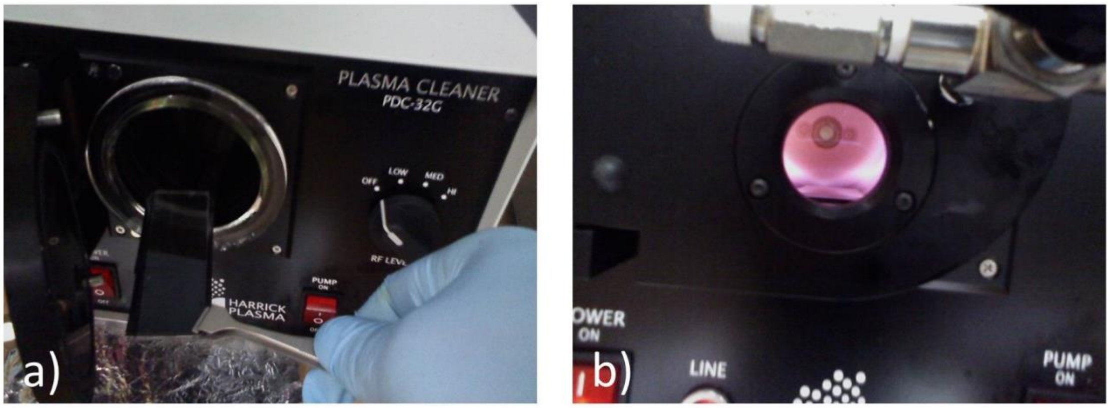

Figure 4: Plasma cleaner operation as a) sample is loaded into cleaner and b) plasma cleaner is active.

As can be seen in Fig. 4a), the sample was loaded into the chamber from the front before being closed and a vacuum pump is activated at a rate of 1.4 m^3/h to attain the desired level of vacuum. Fig. 4b) demonstrates the plasma treatment of a PDMS sample. The pinkish color of the plasma was due to the small volume oxygen that served as the base of the plasma itself.

Testing

The first portion of testing involved the implementation of PDMS-coated slides for observing the effects of plasma treatment and the resulting hydrophobic recovery. Fig. 5 below offers two images of the camera set up. The basic concept for this work was the use of an elevated, mobile stage that would facilitate close-up images of water beads on the surfaces of treated and untreated PDMS slide samples. A baring slide along with a text book provided a suitable elevated, mobile surface while allowing the camera to remain stationary. The camera used for capturing images was a PENTAX Optio W80 digital camera.

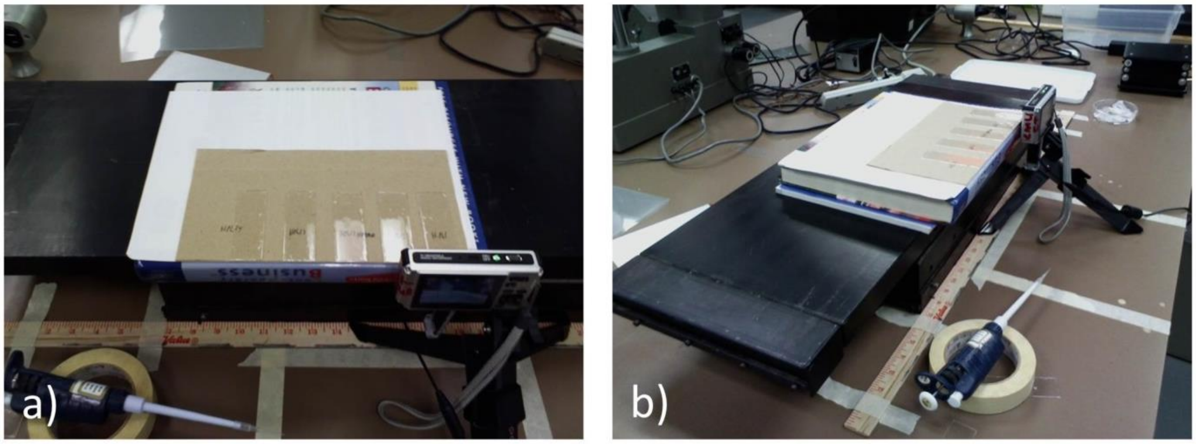

Figure 5: Views of the droplet image capture station from a) top view and b) ¾ view.

As shown in Fig. 5, the slides were arranged in a linear order. The tests themselves required pictures to be taken daily over a 4 day period. On the first day, 4 PDMS slides were bombarded with Oxygen plasma and then laid out next to the untreated PDMS slide. Then, an image was captured of the hydrophobic slide and the fresh, hydrophilic slide. Then on the subsequent days, images were added for one additional slide. This technique provided a means to capture any consistent interactions between droplets and the sample surfaces. One of the main reasons behind this testing was to observe if the hydrophilicity could be altered by interactions between the water molecules and the PDMS coated slides. The premise was that a comparison between previously non-hydrated slides and slides where droplets had already been placed would reveal some noticeable differences between the shapes and behaviors of the moisture droplets; such differences would have supported the possibility of an influence upon hydrophobic recovery.
A second method employed for charting hydrophobic recovery involved the use of a Tantec Contact Angle Meter. The meter relied on the half-width of the droplet for measuring the angle of the water droplet. For the purpose of testing, 4-microliter droplets were deposited onto three separate areas of each slide sample with a 5-microliter syringe. The three droplets served as a means to verify accuracy of the readings. The tests were carried out in two forms.

The first set of contact angle data was collected over a period of one week. During this time period, 1 untreated sample and 4 plasma-treated slides were evaluated over a 4-day time span that began with the day of initial plasma-exposure. Each of the four days, the angle measurements were recorded the slides adding an additional sample until all of the slides were included in the test on the final day. After the first round of testing, a second variety of tests were conducted.

The next phase of contact angle measurement involved a single untreated PDMS slide and two plasma-exposed samples. Measurements were recorded at the time that moisture droplets were deposited onto the surfaces of the slides and then 4 minutes after to observe any potential changes.

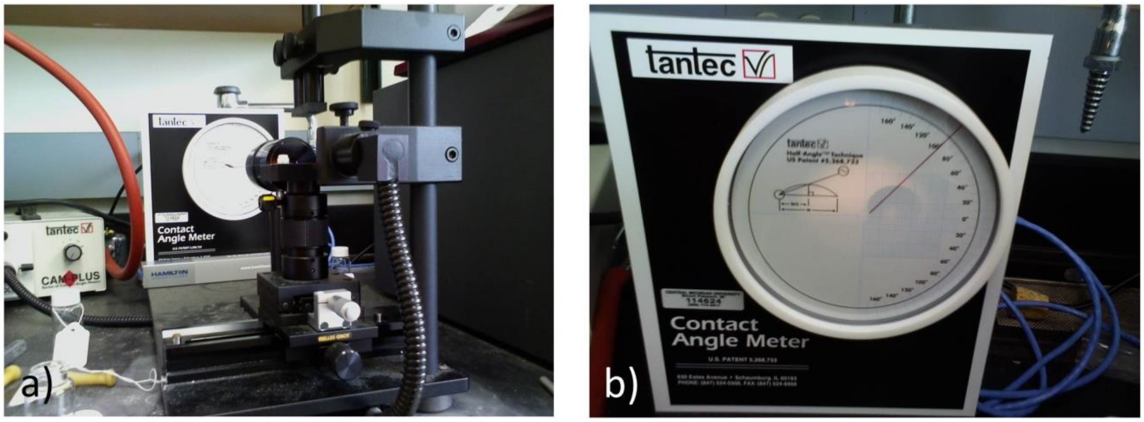

Figure 6: Views of a) the contact angle meter and b) a droplet being measured.

The Scanning Electron Microscopy (SEM) session was intended to examine the results and surface features as described in the research literature[8]. Before the SEM could scan the surfaces of the PDMS samples, coated with approximately 7 nm of gold/palladium in an Anatech 6.2 USA Hummer Sputtering System. Fig. 7 offers images of the sputter coater itself and the process for the samples in Fig 7a) & 7b) respectively. The sputter coater was set to 120 s, with 15 mAmp current, and 118 mTorr of pressure. After the sputter coating was completed, the samples were ready for evaluation in the SEM.

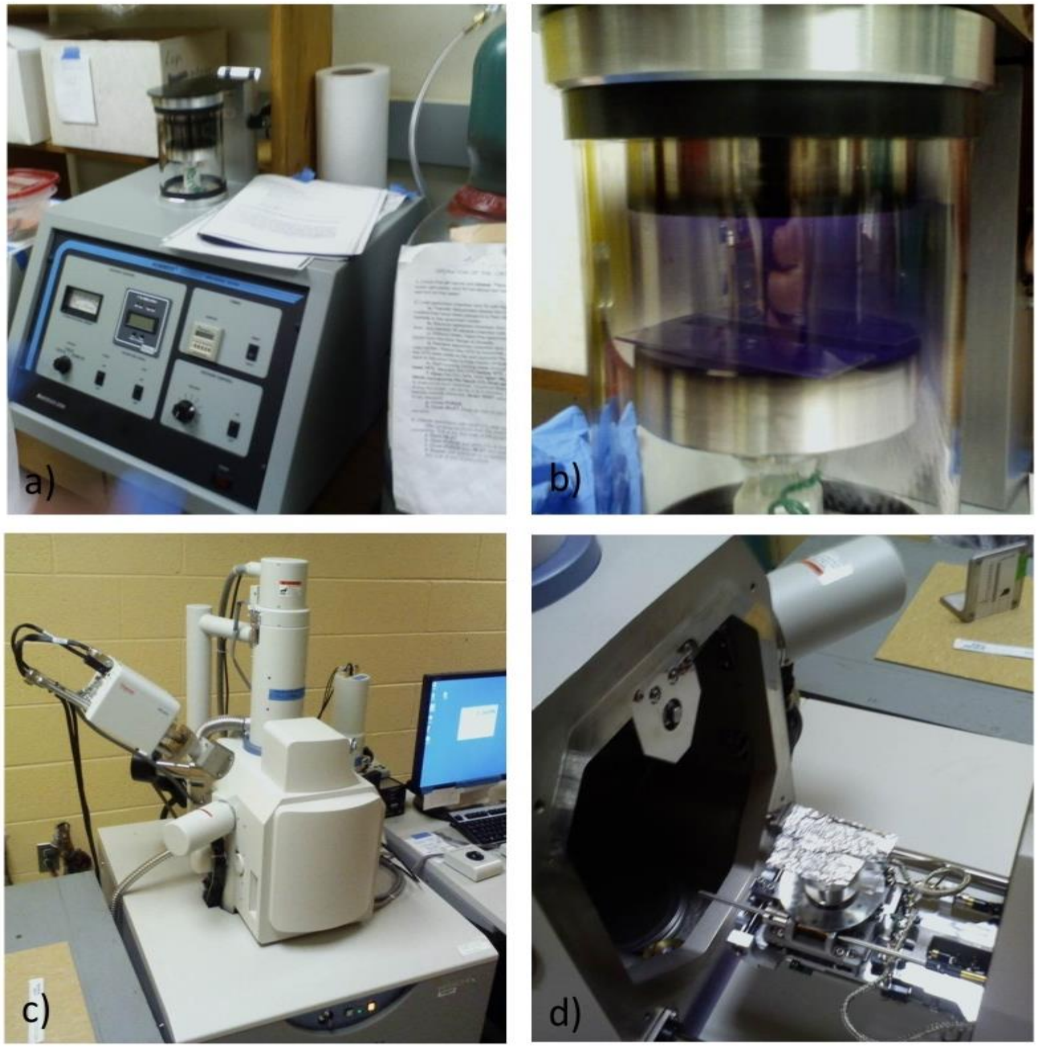

Figure 7: Views of a) the sputter coater, b) PDMS slides during the sputter coating process, c) the SEM itself, and d) the samples being loaded into the SEM.

A Hitachi S-3 400N scanning electron microscope was employed during the tests detailed in this paper. The SEM itself can be seen in Fig. 7c) &7d). Fig. 7c) is the SEM before the scans commenced and Fig. 7d) provides an illustration of the two samples as they were loaded into the SEM. It operated under the following settings: 5 kV & 116µA-124µA. Both samples were scanned at magnifications of 1000 X and 20000X for any visible topography. According to the literature, there should have been visible signs of some surface features in both samples. The results of the scans are included below for further discussion.

Results

Scanning Electron Microscope

The results from the SEM session yielded inconclusive results. Discernable features were not present in either the untreated sample or plasma exposed sample. In the literature, both forms of PDMS possessed discernable surface features. Fig. 8 shows the images taken from both sample types. As can be seen, there appears to be little difference between both sets of images. It was speculated that the thickness of the gold/palladium coating could have obscured any surface features of the samples. The electron beam penetrates 10 nm into the surface of the sample while the sputtered coating covered 7 nm of this height. In the literature, only gold was used for sputter coating, but no mention was made of the thickness of the metal itself. A consultation with the staff of CMU's SEM lab revealed that common sputter material heights ranged between 5nm-10nm, so it is uncertain whether or not a thinner coating would have improved the visibility of the PDMS topography. Furthermore, the literature indicated a sputtering pressure of 37 mTorr while the coating done during this work was conducted at 118 mTorr.

Another potential source of variation may have been the power settings between the plasma cleaner used in Kaya Lab and that listed in the literature. The literature described a power of 150 W and an RF of 13.56 MHz. The plasma used in this work had a power setting of 18 W and only listed the RF in the MHz range. The pressure for the plasma cleaner was 200 mTorr while the literature indicated a pressure of 74 mTorr. Another deviation between the trial and the literature was that the initial trial required 1 minute of plasma treatment while the paper suggested 15 min. The above differences, however, fail to account for the lack of visible features in the untreated PDMS slides.

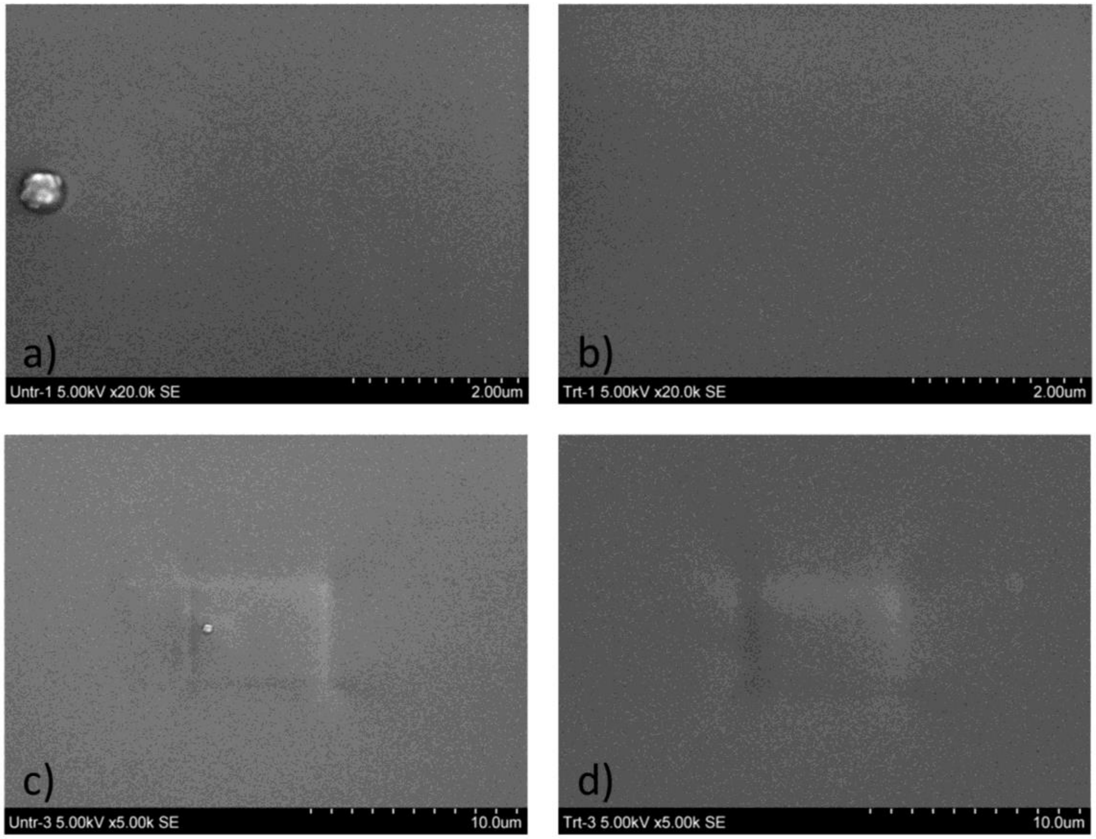

Figure 8: Images of both hydrophobic and hydrophilic PDMS samples at 20000x a) & b) and 5000 x c) & d).

Fig. 8 c) & d) provided an example of the effects of the SEM's electron beam on the polymer itself. The electron beam scans an area in a rectangular fashion. The interaction between the PDMS and the electron beam results in the impressions demonstrated in Fig. c) & d). The deeper side of the shape was caused by the electron beam contacting one side of the scanning area for a moment longer than the other areas before sweeping the section for images. One possible alternative to SEM might be an Atomic Force Microscope that does not rely on sputter coating to bring out visible surface features. Another alternative might be a lower voltage, high resolution, SEM that uses carbon vapor deposition which would produce a thinner layer than sputtering.

Droplets Images and Contact Angle Meter

The digital images and contact angle measurements of droplets revealed relatively consistent behavioral trends. The hydrophobic PDMS yielded readings ranged from 97º-106º. This was in line with the literature[8]. The measurements for plasma treated PDMS produced different profiles with respect to each form of test. The results were presented Fig. 9 -11 and Tables 1-4 below.

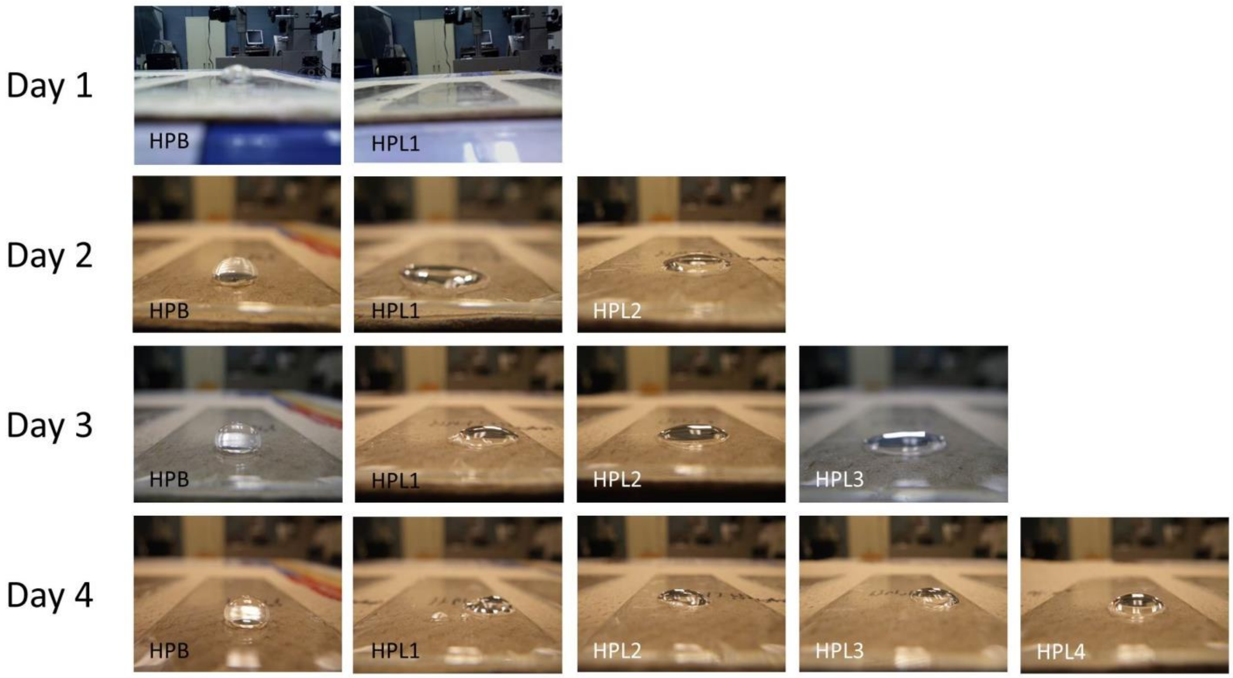

Figure 9: Sequential images of moisture interaction with PDMS slides during week 1

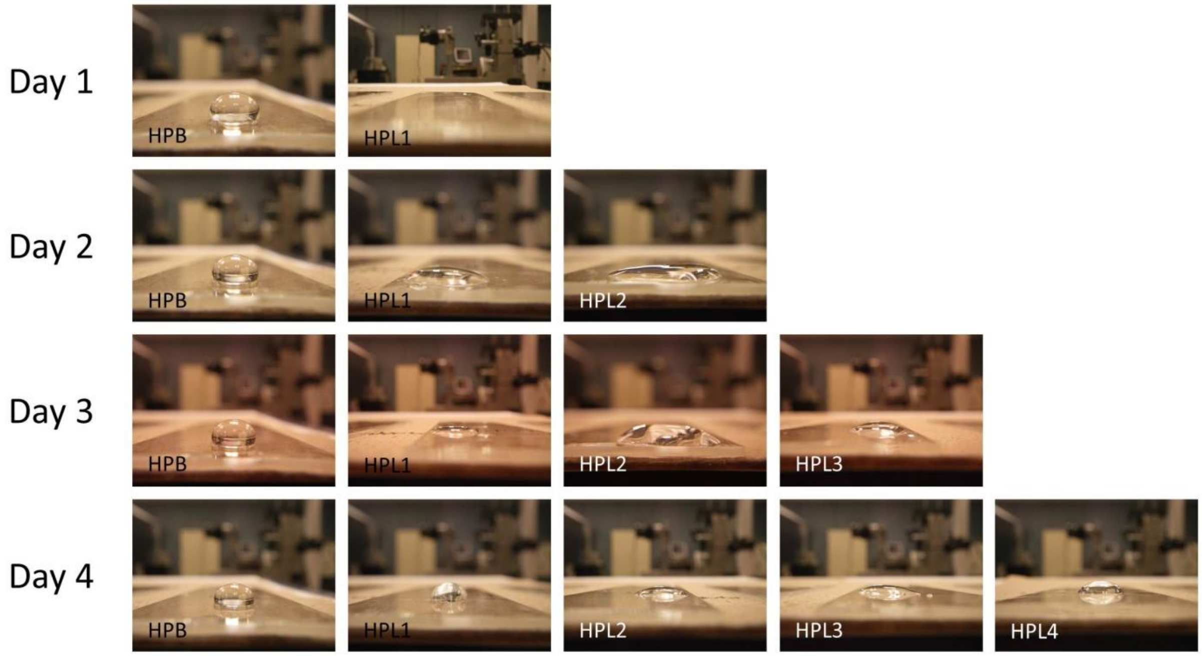

Figure 10: Sequential images of moisture interaction with PDMS slides during week 2

Fig.9 & 10 present the images data gathered during the first two weeks of observing hydrophobic recovery. The images illustrate the interaction of the moisture droplets on the PDMS over the progression of testing days. HPB and HPL were simple abbreviations for hydrophobic and hydrophilic respectively; the number referred to the samples having droplets applied to them on a particular day. Day 1 reflected the water's interaction with the samples on the day of plasma bombardment. The water on the plasma-treated slides spread out over the surface indicating full hydrophilic induction. Day 4 consisted of all of the samples having moisture droplets deposited onto their surfaces to observe any notable differences in the moisture behavior/appearance. On the remaining days of testing, Fig. 9 & 10 revealed a relatively consistent droplet appearance. Deviations that did appear, such as in HPL1 and HPL4 during week 2, could be attributed to minor variations in the thickness of the PDMS after spin coating. It is suspected that the thickness discrepancy could have also contributed to droplet “roll back” from the point of droplet placement that caused some droplets to appear farther away than others.

Contact angle measurement offered a more quantitative degree of measurement than digital imagery. Tables 1-4 contain the results of the four methods of contact angle evaluations conducted during this project. In all tables, the numbers presented reflect the averages of three readings each. Furthermore, Fig.11 clearly plots the trends present in the experimental data.

Table 1. Average Contact Angle Values: Initial Trials

Contact Angle (◦)				
*Sample	Day 1	Day 2	Day 3	Day 4
HPB	99	98	97	99
HPL1	0	84	31	90
HPL2	x	27	39	41
HPL3	x	x	34	40
HPL4	x	x	x	38

* HPB: Hydrophobic & HPL: Hydrophilic + sample number

The testing protocol for collecting the data placed in Table 1 resembled that employed for the digital images. Data was gathered progressively over a series of four days to observe any potential interaction between the moisture and its influence on the hydrophobic recovery itself. As can be seen in Table 1, the measurements for the untreated slides were relatively constant while the four hydrophilic slides provided some inconsistent readings. HPL1 showed the greatest variation in readings fluctuating from 84º to 31º up to 90º. HPL2 & 3 revealed a steadier pattern of contact angle increase by 14º and 6º respectively over the course of testing days. HPL4 was only measured on the fourth day of trials, but it was within 3º of the final values from samples HPL2 & HPL3.

Table 2. Average Contact Angle Values for 4 Minute Intervals

Contact Angle (◦)								
*Sample	Day 1		Day 2		Day 3		Day 4	
	Time (Min)		Time (Min)		Time (Min)		Time (Min)	
	0	4	0	4	0	4	0	4
HPB	101	100	102	102	103	103	106	105
HPL1	0	0	28	27	44	41	79	71
HPL2	0	0	27	25	32	28	86	82

* HPB: Hydrophobic & HPL: Hydrophilic + sample number

Table 2 contains the data for the tests requiring measurements taken at the time of droplet deposition and then after a 4 minute delay. Very little change was observed in the untreated slides on each day of angle measurement. Despite the lack of immediate change, the numbers suggest a gradual increase of contact angle by 6º during the week. The hydrophilic slides appeared to yield a slight decrease in contact angle after each 4 minute period. The average decrease in contact angle fell within the range of 2º-8º degrees. While the daily droplet measurements indicated contact angle degradation, the readings over the four days of experiments indicated an overall increase in contact angle.

Table 3. Average Contact Angle Values: 24 & 30 Hours After Plasma Treatment

Time (Hrs)	Sample #	Contact Angle (◦)
24	1	19
	2	18
30	1	33
	2	25
	3	24
	4	26

*Averages of 7 Droplets

Table 4. Average Contact Angle Values: 24-48 Hours After Plasma Treatment

Time (Hrs)	Sample #	Contact Angle (◦)
24	1	13
	2	15
27	1	45
	2	29
30	1	74
	2	54
	3	17
	4	19
48	1	82
	2	79
	3	33
	4	37

*Averages of 7 Droplets

Tables 3 & 4 provide the contact angle measurements from the last two weeks of testing. Table 3 corresponds to the third week of testing and reflects the data gathered at 24 hours and 30 hours after plasma treatment exposure. Two plasma-treated samples were evaluated with a contact angle meter and then reevaluated six hours later with the addition of two more treated samples to observe how moisture interactions may alter the hydrophilic properties of PDMS over time. The process was expanded in the fourth week as reflected by the data in Table 4. During final testing week, the time intervals were expanded to 24, 27, 30, and finally 48 hours proceeding plasma exposure. Readings for the first two slides were taken at the 24 and 27 hour intervals. Then, the first two slides were tested with the addition to two more slides at 30 and 48 hours to check for any patterns in contact angle change. Tables 3 & 4 both appear to indicate steady increases over the 30 and 48 hour periods of evaluations. The total data from all contact angle experiments was plotted in Fig. 11 below.

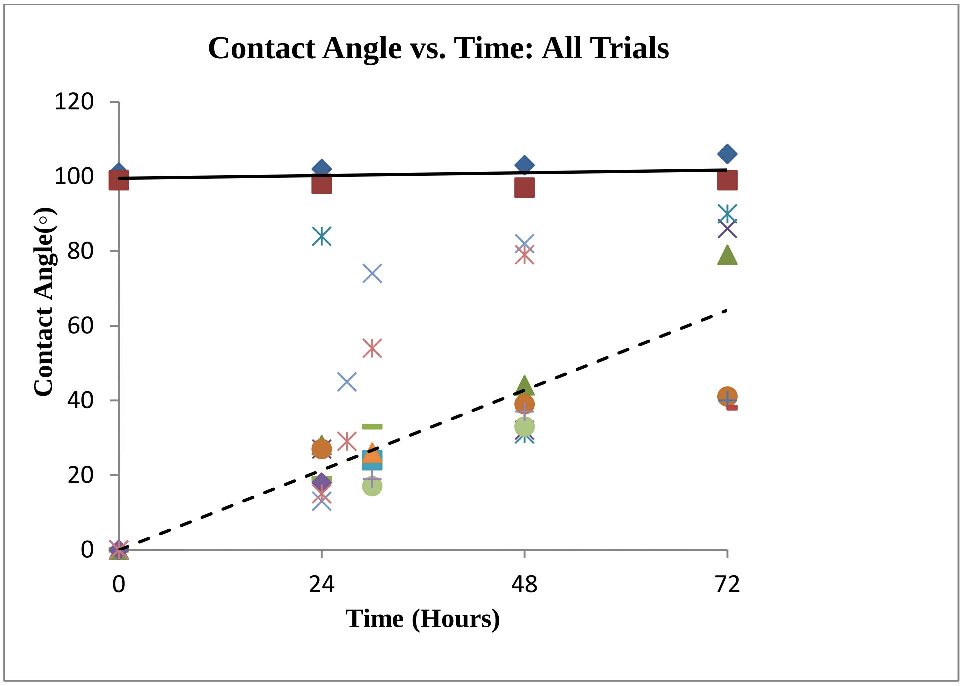

Figure 11: Contact angle measurements with respect to time for all trials conducted

Fig. 11 provides a comparison for both the control and hydrophilic sample data taken from Tables 1-4. The control samples demonstrated a relatively stable pattern indicating little change for the duration of the experiments. Conversely, plasma treated samples from the four weeks of trials indicated an overall increase in hydrophobic surface properties. The overall trend for the hydrophilic sample data shows an increase in contact angle measurement with respect to time. The increase in contact angle shown in Fig. 11 shows a recovery of the hydrophobic properties in the PDMS surfaces and a resulting decline in hydrophilicity.

Discussion:

This paper focused on the applications of hydrophilic PDMS surfaces to sweat sensing devices. The work encompassed PDMS processing, digital imagery, and contact angle measurement. The goal of the work was to gain insight into the applicability of plasma treated surfaces to enhance the performance of sweat sensors or to even exploit hydrophilic surfaces as a primary driving mechanism for directing fluid flow through the sensors. Literature sources have indicated that a common method for moving fluids through sweat sensors employed absorbent materials like thread and cloth to exploit capillary action[1-3]. If hydrophilic surfaces proved effective, they could serve as a passive form of pump in a potentially simper design. Profiling the interactions between the polymer surface and moisture was the first step.

Some inconclusive results appeared during the trials. A different form of SEM or an Atomic Force Microscope might provide a clearer insight into the effects of plasma on PDMS surface topography. Sources of reading variations most likely include uneven PDMS height on the surface of the slides due to spin coating, evaporation, dust contamination, swelling due to and alcohols forming in the PDMS itself. Another possible cause in the deviations might be surface reorganization due to dipolar interaction between the oxygen atoms in the PDMS molecules and the hydrogens in the water molecules. Further studies may help to isolate the causes from the above-mentioned possibilities.

The experimental data did, however, reveal a trend in hydrophobic recovery as time and multiple moisture treatments were administered to PDMS surfaces. What the data seems to suggest is that repeated exposure of plasma treated exposure to water droplets consistently decreased the quality and duration of hydrophilic surfaces. This pattern appeared consistently for all four trials despite minor differences in the methods for each test. A regular decline in hydrophilic surface quality due to repeated moisture exposure could impact potential designs seeking to incorporate such surface properties. This could have particular relevance to sweat sensors operating in humid environments and the lifespan/reusability of hydrophilic microfluidic devices in a laboratory setting.

The next likely step in this work would be to test hydrophilic PDMS microfluidic channels and compare them to their hydrophobic counter parts to compare fluid flow. This work could be expanded to incorporate thread to evaluate hydrophilic surfaces alone and integrated with a wicking mechanism to observe any potential design benefits. For imaging purposes, fluorescent fluids would probably be the best collect clear images of fluid flow. The images could then be analyzed with software such as MATLAB and Image J to profile the possible flow speeds and further quantify the interactions between moisture and plasma treated PDMS.

Impact on Engineering Education

This research encouraged an expanded understanding of engineering through the investigation of biomedical sweat sensors. During the course of this work, various types of sweat sensing devices were researched (electronic, chemical, and combination of the two). In addition, it allowed an opportunity to gain experience with equipment such as a contact angle meter and a scanning electron microscope. The qualitative and quantitative testing led to further learning about the interactions between PDMS and moisture droplets through reading and consultation with the staff/faculty in the Biology and Chemistry departments on CMU’s campus. This resulted in an understanding of the effects of repeated moisture exposure to plasma treated PDMS surfaces; such insights can be applied to future sweat sensor designs and research. Furthermore, the summer-long project provided an environment to build upon previously acquired research experiences under the guidance of expert faculty members. Such tutelage led to an improved understanding of experimental protocols, general lab technique, and research writing standards.

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