Microfluidic Channels in Polymethyl-methacrylate by Opitmizing Aluminum Adhesion

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Abstract—**A study has been performed to determine the optimum surface treatment to adhere an aluminum hard mask to a polymethyl-methacrylate (PMMA) wafer substrate for the production of microfluidic channels.**

The initial process parameters of the PMMA reactive ion surface treatment included oxygen plasma, sulfur hexafluoride plasma and argon plasma designs of experiments. However, a soak in tetra methyl ammonium hydroxide (TMAH) proved to provide the most adhereable surface for an aluminum deposition. It is hypothesized that the TMAH soak allowed for the removal of the surface layer of the PMMA wafer substrate.

The aluminum hard mask was deposited by evaporation after the wafers were surface treated with TMAH. Using contact photolithography, the aluminum was patterned and the PMMA wafer substrate was etched isotropically in propalene glycol mono methyl ether acetate (PGMEA) for the creation of microfluidic channels.

Success of this project is based on the quality of the aluminum evaporated film and the transparency of the PMMA wafer substrates after the isotropic etch in PGMEA.

I. Introduction

MICROFLUIDIC channels have been studied for their use in bio-MEMS related fields. These include sensors, fluid transport, DNA analysis and blood cell observation. PMMA is an ideal candidate as a substrate material because of its transparency at the visible wavelength as well as its availability and cost effectiveness. Aluminum was chosen as the hard mask for the PGMEA etch to create isotropic channels in the PMMA substrates for its availability, cost effectiveness and quality of process control. Because the melting temperature of PMMA is around 100°C, sputtering aluminum was not advised. Aluminum wet etch (phosphoric acid, acetic acid and nitric acid) does not attack PMMA. Please see Figure 1 for a drawing of the finished product of this project.

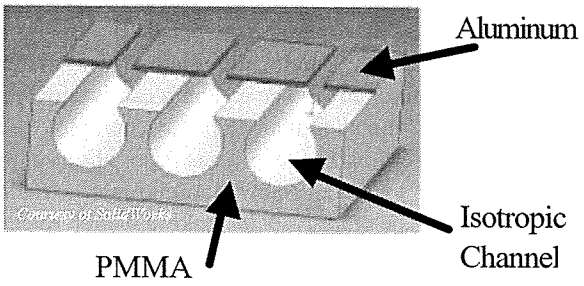

Figure 1: Computer Rendered Concept

Initially, the Drytek Quad, a reactive ion etch tool was used to try to treat the surface of the PMMA wafers using a design of experiements that included oxygen gas, SF_6 gas and argon gas from 1 - 10 minutes from 150 - 600 Watts.

It was noted that the time between reactive ion surface treatment and aluminum deposition when varied did not change the result. The PMMA substrates endured a high heat deformation at high powers and times of reactive ion surface treatment. The initial transparent PMMA wafers became non-uniformly opaque in the radial direction at every power and time reactive ion surface treatment. Aluminum depositions after a reactive ion surface treatment in all cases resulted in a non-reflective, film that did not pass the tape test.

The tape test is conducted after the metal deposition as a preliminary check to see whether or not the metal will adhere to the substrate and not be removed during an etch of the substrate. This test was advised by Dr. W. Grande and Tina Prevost. Please see Figure 2 for an actual picture of the aluminum film on a reactive ion treated PMMA surface. Please note that all wafers using every gas at various powers and times resulted in this.

This work is a design requirement for a B.S. degree in Microelectronic Engineering at the Rochester Institute of Technology (RIT), Rochester, NY. The results of the project were first presented as part of the 22nd Annual Microelectronic Engineering Conference, May 2004 at RIT.

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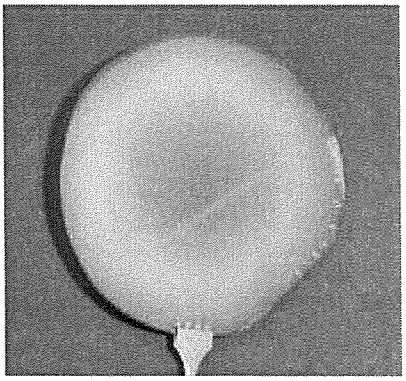

Figure 2: Aluminum on Reactive Ion treated PMMA

II. THEORY

A. *Reactive Ion Surface Treatment*

Under vacuum, the PMMA wafers are subjected to plasma using a forming gas at a certain power for a certain amount of time. The gas molecules bombard the surface of the PMMA, theoretically allowing for an aluminum thin film deposition layer that is uniform, and is reliable throughout processing.

B. *TMAH Soak Surface Treatment*

The PMMA wafers were cut from a sheet and grinded to be the shape of a four inch silicon wafer for process manufacturing ease. The wafers came packed in a paper protective packaging that adhered to both sides of the wafer, which needed to be removed prior to processing. It is theorized that the 20 minuted soak in the basic photoresist developer, 0.21 N TMAH removed the layer that adhered the protective layer to the PMMA substrates as well as cleaned the surface of the PMMA substrates.

C. *Aluminum Evaporation*

As current flows through the tungsten baskets, the aluminum pellets melt and aluminum molecules are released into the atmosphere inside the bell jar. As the aluminum molecules make contact with the PMMA wafers, they solidify and adhere. A low pressure and high currents are required for a thick, uniform aluminum film. Any air (carbon, nitrogen, oxygen) or alien molecules in the path of the aluminum molecules may create an aluminum film that may not stick or a very thin film. Aluminum film thickness and uniformity is also a function of the distance between source and substrate. The farther the source is from the substrate, the film is thinner and more uniform. The closer the source is from the substrate, the thicker the film but at a cost of non-uniformity.

III. PROCESS

The process for making Microfluidic channels in PMMA resulted in ignoring development in reactive ion surface treatments and using TMAH.

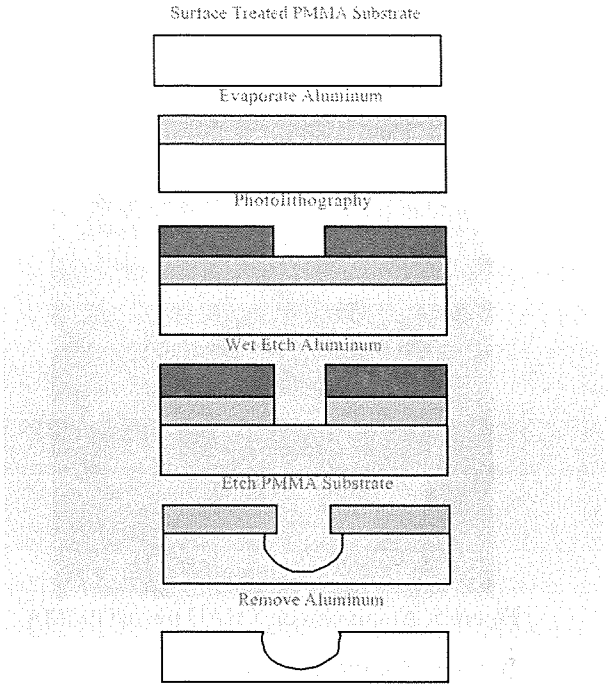

Figure 3: Microfluidic Channel Process

A. *Surface Treatment*

The PMMA wafer substrates were soaked in 0.21 N TMAH for 20 minutes then spin rinse dried. Note that using compressed air decreases the cleanliness of the wafer surface.

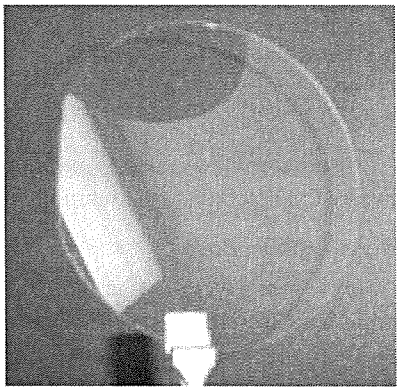

Figure 4: TMAH treated PMMA

B. *Aluminum Evaporation*

The wafers were put into a turret that revolved and

rotated about the top of the CHA Evaporator bell jar, approximately 27 inches above the source. The CHA Evaporator was pumped down to a pressure of 5 E -6 Torr. Tungsten baskets were used to hold 4 aluminum pellets in two current sources. Sixty Amps ran through each tungsten basket melting the aluminum at 660°C for an evaporation rate up to 19 Angstroms per second and a thickness of 1.5 um.

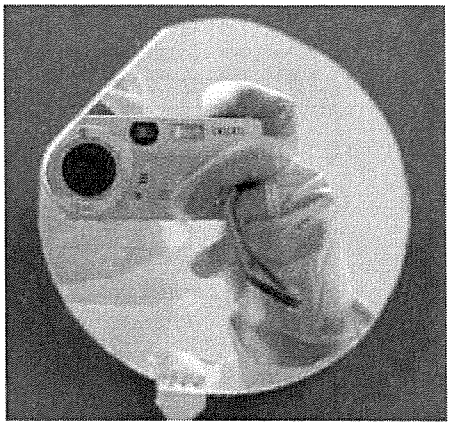

Figure 5: Aluminum on TMAH treated PMMA

C. Contact Photolithography

The wafers were coated with Shipley 812 photoresist at 4500 RPM for 45 seconds and proximity pre-baked at 90°C for 3 minutes. Using the Karl Suss contact aligner, the wafers were exposed with a dose of 160 mJ/cm^2. The wafers were then proximity Post Exposure baked for 3 minutes at 90°C and developed using MF- CD 26, 0.26 N TMAH for 60 seconds.

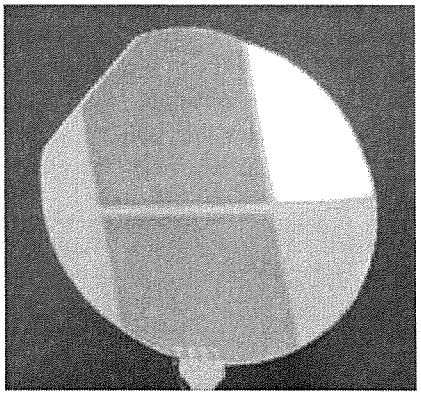

Figure 6: Photoresist on Aluminum on PMMA

D. Wet Aluminum Etch

The wafers were put into a bath of nitric, acetic and phosphoric acid to pattern the aluminum in the areas were the photoresist did not exist and expose the PMMA.

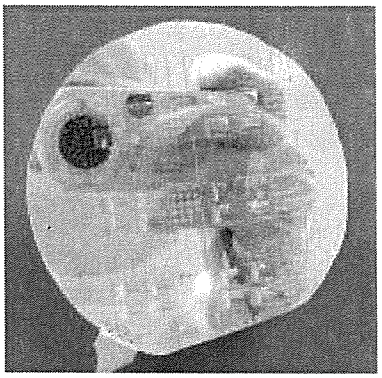

Figure 7: Patterned Aluminum on PMMA

E. PMMA Etch in PGMEA

The wafers were soaked in PGMEA for approximately three hours with an etch rate of 1000 Angstroms per minute. The Phillips 525 Scanning Electron Microscope (SEM) was used in observing the wafers before and after the aluminum was finally removed. The SEM was used at an accelerating voltage of 5 kV with a spot size of 500 nm and the wafers were sputtered with gold to increase surface conductivity and the reduce PMMA charging.

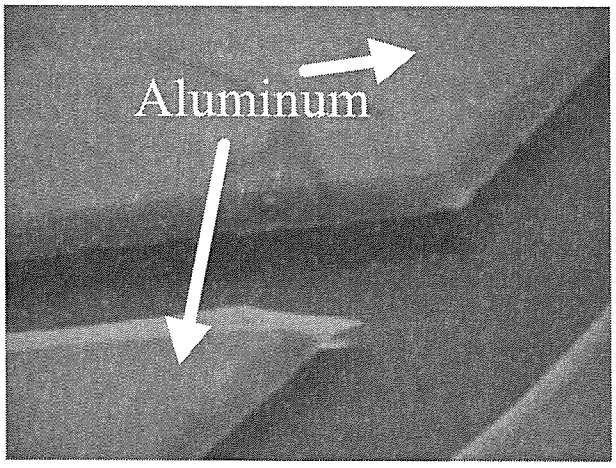

Figure 8: SEM of Aluminum on PMMA

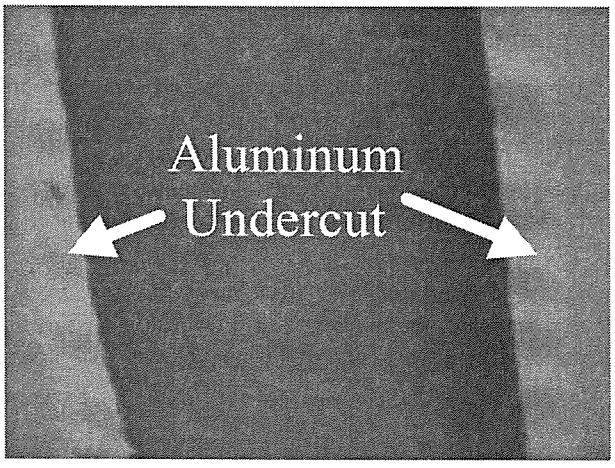

Figure 9: SEM of Aluminum on PMMA

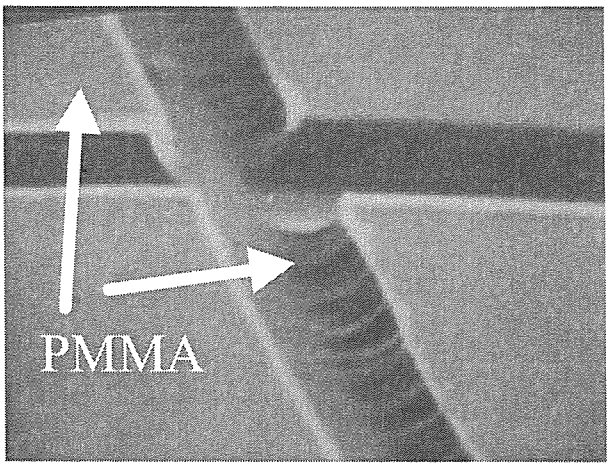

Figure 10: SEM of PMMA Channels

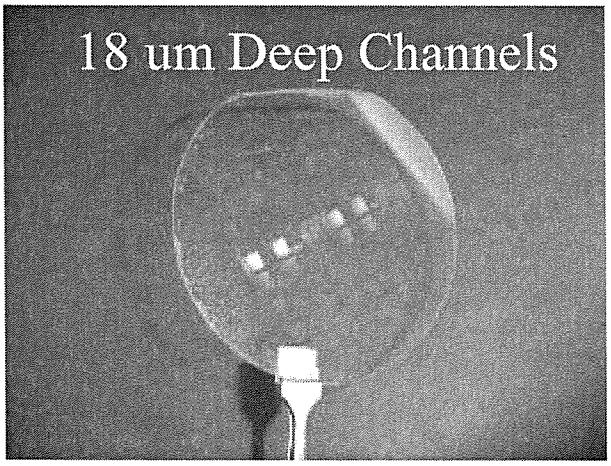

Figure 11: Microfluidic Channels in PMMA

IV. Results and Discussion

A. *PMMA Surface Quality*

As seen from Figures 4 - 11, the surface of all films; aluminum, photoresist and PMMA remain spotless, pristine and uniform. The PMMA remains transparent throughout the experiment and the line edge roughness is minimal on the aluminum.

B. *Aluminum Adhesion*

As seen in Figures 8 – 10, the PGMEA etched the PMMA isotropically in all directions without lifting up the aluminum film. The aluminum film at the edges is undercut and overlaps in the absence of PMMA. This shows that the aluminum not only stuck to itself but also the PMMA substrate.

V. Conclusion

Microfluidic channels were made by etching isotropic channels in poly methyl methacrylate by optimizing aluminum adhesion. Reactive ion surface treatment was shown to thermally manipulate the PMMA substrate, while soaking the PMMA wafers in 0.21 N tetra methyl ammonium hydroxide for 20 minutes proves to clean the wafer well prior to the aluminum deposition. Propalene glycol monomethyl ether acetate is shown to isotropically etch PMMA and aluminum is proved to serve as a protective etch mask for PMMA when the substrate is properly treated.

Acknowledgments

The author thanks Tina Prevost for great assistance and cooperation and Dr. W. Grande for project guidance. The author would also like to acknowledge the RIT Semiconductor and Microsystems Fabrication Laboratory staff for technical assistance and equipment support. Special thanks to Bruce Tolleson and Dr. L. Fuller.

George W Woodruff III, originally from Penn Yan and Lowville, New York, received a B.S. degree in Microelectronic Engineering from the Rochester Institute of Technology in 2004. He obtained co-op work experience at Analog Devices Inc. in Cambridge, MA, NanoPower Inc. in Rochester, NY, and Ferro Electronic Materials, in Penn Yan, NY, and has done MEMS Gear and Pressure sensor research as well as Titanium Silicide research at RIT. He is currently pursuing a Ph.D. degree in Microsystems Engineering at RIT.