Protocol: Microfabrication of Parylene Microelectrode Arrays

Description: This document details the microfabrication protocol for Parylene microelectrode arrays (MEAs) in preparation for initial testing and then packaging.

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1 Deposit Base Parylene C

1.1 Drybake

Note: this step assumes you are working with new wafers directly taken from the box in which they were shipped in – the assumption is that these wafers are completely clean
Note: this step should be performed immediately before Parylene deposition (step 1.2)
Materials: *4" prime silicon wafer(s)*
Note: double-side polished wafers are recommended to reduce bubbles/weak adhesion of Parylene to the backside of the wafer
Equipment: *Oven or hot plate*

1. Bake wafers at 110 °C in an oven at atmosphere for at least 30 minutes (overnight is OK), or on a hot plate for >5 minutes

1.2 Deposit Parylene C

Note: this step should be performed immediately after drybake (step 1.1)
Materials: *Parylene dimer*
Equipment: *Parylene PVD*

1. Label backside of each wafer using a permanent marker with the wafer number, date, and which shelf it will be loaded on
2. Follow the Parylene SOP to operate the Parylene tool

Note: if using double-side polished wafers, Al foil is not needed under the wafers – this is only for single-side polished wafers

3. Deposit 10 µm of Parylene C on 12 4" wafers
    a. 32-33 g of dimer is typical, but amount should be verified by comparing to past Parylene runs and adjusted as needed

b. 12 wafers per batch is recommended and varying the wafer number will affect the amount of dimer required

1.3 Measure Parylene Thickness

Materials: *Parylene-coated glass slides from step 1.2*
Equipment: *Profilometer*

1. Cut a small strip of Parylene off each glass slide using a sharp razor blade
2. Measure Parylene thickness (step height from Parylene to bare glass) using a profilometer
3. Log measurements into logbook

1.4 Anneal Wafer

Note: This step is optional; it is used to pre-shrink the base Parylene layer to decrease the stress produced by adding the metal layer, to increase Parylene adhesion to the wafer, and/or to promote curling (if desired)
Note: Parylene shrinkage with each annealing step has not been fully characterized; with 3 annealing steps (base layer, step 1.4 @ 150 °C + full wafer, step 3.5 @ 150 °C + step 7 released device @ 275 °C), shrinkage is approximately 2.5% in Parylene regions
Equipment: Vacuum oven with N_2

1. Anneal the full wafer with base Parylene per the procedure in appendix A for the desired time at the desired temperature
2. Typical parameters for metal stress relaxation and adhesion: 150 °C, 4 hrs

2 Deposit and Pattern Metal

2.1 Inspect and Clean Metal Photomask

Safety: *use HF gloves, apron, and googles if using Nanostrip*
Materials: *Acetone*
IPA
Nanostrip
Sodium bicarbonate (for disposal, if no Nanostrip waste bottle available)
Equipment: *Metal photomask*
Plastic trays
Glass tank designated for Nanostrip
Teflon mask holder
Teflon-coated HF tweezers
Hot plate
IR temperature sensor

1. Blow the surface of the mask with N_2 and inspect (with a bare eye) for any debris or residue
    a. Proceed to step 4 if the mask appears clean
2. If minimal residue or debris remains, clean the mask using the solvent cleaning procedure as follows:
    a. Perform all work (except for drying) in the solvent hood
    b. Prepare 1 plastic tray each for acetone, IPA, and deioinized water

   c. Soak mask in acetone with the chrome side (with the reddish hue) facing up for >10 minutes with periodic agitation
   d. Move mask to IPA and soak for >10 minutes with periodic agitation
   e. Move mask to water and soak for >10 minutes with periodic agitation
   f. Rinse thoroughly with water, blow dry with N_2
   g. After cleaning, reinspect and proceed to step 4 if the mask appears clean
3. If stubborn residue or debris remains or cannot be removed in step 2, perform clean in Nanostrip as follows:
   a. Perform all work (except for drying) in the corrosives hood
   b. Follow procedure in Nanostrip SOP, using designated glass Nanostrip tank, Teflon mask holder, and Teflon-coated tweezers (labeled for HF)

      Note: make sure mask is always oriented with the chrome side (with the reddish hue) facing up in the mask holder to prevent scratching
4. If scratches are present in the chrome layer or other mask defects are found, repair may be possible by applying opaque tape to the glass side of the mask over the defect/scratch

2.2 DRYBAKE

Note: this step should be performed immediately before photoresist deposition (step 2.3)
Note: this step is critical for adhesion of small photoresist features (e.g. long, narrow traces)
Note: this step can be skipped if next step 2.3 is performed immediately after step 1.4 (annealing)
Equipment: Vacuum oven with N_2 (Cascade Tek or Lindberg Blue)

1. Bake wafers at 60 °C in an oven under light vacuum (35-40 cmHg) and N_2 flow (15-20 sccm) for >15 minutes

2.3 DEPOSIT PHOTORESIST

Note: this step should be performed immediately after drybake (step 2.1) or annealing (step 1.4)
Materials: AZ 5214-E photoresist
Equipment: Spin coater
Hot plate
IR temperature sensor
Wafer centering tool

1. Degas photoresist for 1 hour prior to spinning (open bottle and set it in the hood with the lights off)
2. Line the inside of the spinner lid with aluminum foil (for easier cleanup)
3. Coat 2 dummy wafers in spin coater prior to coating real wafers
   Note: this step saturates the machine with photoresist and changes the atmosphere in the spinner, leading to more consistent photoresist thicknesses between wafers

Note: the remaining steps (2.3.4 through 2.3.9) are performed one wafer at a time; repeat the following procedure once for each wafer

4. Blow wafer with clean, filtered N_2 to remove any particles on the surface
5. Place wafer onto the spinner chuck (using the wafer centering tool, if desired), center it, and engage vacuum to hold it in place
6. Dispense photoresist into a puddle on the center of the wafer

   a. Photoresist can either be dispensed using a dropper, by pouring directly out of a small amber bottle, or using a syringe (degas for >2 hr prior to loading, use >3 mL of photoresist in a polyethylene syringe)
   b. ~1.5 inch diameter puddle
   c. Use more photoresist if surface is uneven to ensure sufficient coverage
   d. If any bubbles are present in the photoresist puddle, wait for them to pop or carefully pop them with a foam swab, taking care not to touch the wafer surface
7. Spin photoresist to ~1.1 µm thickness using the following recipe:

5 s, 500 RPM, accl 8	*spreads out PR puddle*
40 s, 3200 RPM, accl 8	*defines desired thickness*

   Note: If photoresist is not within the range of 1-2 µm, the speed must be re-calibrated; photoresist thickness can be measured after development (step 2.5) is complete
8. Soft bake at 110 °C for 60 seconds
9. If photoresist is not applied correctly (e.g. if not enough photoresist is used to cover the entire wafer or a particle is stuck on the surface), remove the photoresist using the procedure in appendix D and return to step 2.1
10. Cleanup spinner and photoresist waste09

2.4 EXPOSE PHOTORESIST

Equipment: *Mask aligner*
Metal photomask
Hot plate
IR temperature sensor
Plastic tray

1. Load metal photomask into the mask aligner

Note: all steps (2.4.2 through 2.4.7) are performed one wafer at a time; repeat the following procedure once for each wafer

2. Load wafer into the mask aligner and center the mask pattern on the wafer
3. Expose wafer through metal photomask in hard contact mode at 42 mJ/cm^2
   a. 12.5 mW/cm^2 x 3.4 s recommended
   b. Other lamp settings and timing can be used as long as the exposure dose remains the same (e.g. 12.5 mW/cm^2 x 3.4 s = 42 mJ/cm^2)
4. Bake at 110 °C for 63 seconds (image reversal bake)
5. Rest wafer for >3 minutes to cool down
6. Flood expose wafer (expose with no mask) at 280 mJ/cm^2
   a. 12.5 mW/cm^2 x 23.3 s recommended
   b. Other lamp settings and timing can be used as long as the exposure dose remains the same (e.g. 12.5 mW/cm^2 x 23.3 s = 280 mJ/cm^2)
7. Place wafer immediately into DI water bath after flood exposure for at least 2 minutes to prevent overheating
   a. Wafer can move directly from the water bath to the developer bath in step 2.5 or it can be dried prior to development
8. Clean up mask aligner and fume hood

2.5 Develop Photoresist

Materials: *AZ 340 developer*
Equipment: *Corrosives fume hood*
Plastic trays

1. Perform chemical work with developer in corrosives fume hood

Note: all steps (2.5.1 through 2.5.6) are performed one wafer at a time; repeat the following procedure once for each wafer

2. Develop wafer in developer bath (1:4 ratio of AZ 340 developer to DI water) for 18 seconds with mild agitation
    a. A typical recipe for the 1:4 ratio is 40 mL developer to 160 mL of DI water
    b. Use the tray(s) designated for developer, ensuring they are clean before use
    c. Development time may need to be adjusted based on age of photoresist and developer and environmental conditions, but should be within the range of 16-19 seconds
3. After development, move wafer quickly to a water bath, then flush 3× with DI water
4. Blow wafer dry with N_2
5. Inspect developed features under microscope and develop for additional time if needed
6. If photoresist is not patterned correctly (e.g. if the exposure dose is not correct, if it has been overdeveloped, or it has been scratched), remove the photoresist using the procedure in appendix D and return to step 2.1
7. If photoresist is patterned correctly, clean up trays and fume hood area

2.6 Measure Photoresist Thickness

Materials: *Developed photoresist-coated wafers from step 2.5*
Equipment: *Profilometer*

1. Measure photoresist thickness (step height from photoresist pattern to Parylene surface) using a profilometer
2. Log measurement in logbook

2.7 Descum Wafer

Note: this step should be performed immediately before metal deposition (step 2.8)
Equipment: *RIE or Asher*

1. Descum (clean) wafers in the RIE or Asher using the following recipe:
   100 mT, 100 W, 50 sccm O_2, 5 minutes

2.8 Deposit Metal

Note: this step should be performed immediately after descum (step 2.6)
Materials: *Titanium*
Platinum
Gold
Equipment: *E-beam evaporator*

1. Deposit the metal stackup (20 nm Ti (adhesion layer) + 25 nm Pt (prevents Ti/Au interaction) + 150 nm Au + 25 nm Pt) at 1.5-2 Å/s; typical rates are 1 Å/s for Ti, 1 Å/s for Pt, and 2 Å/s for Au
    a. Wait 30 minutes between different types of metal to allow crucible to cool down

2.9 Pattern Metal via Liftoff

Materials: *NMP rinse*
IPA
Foam swab (optional)

Equipment: *Hot plate*
IR temperature sensor
Glass dishes designated for liftoff
Sonicating bath
Stereoscope
Solvents fume hood

1. Perform chemical work in solvents fume hood
2. Prepare one bath of NMP rinse at 60 °C (on hot plate, in glass dish labeled for liftoff)
3. Prepare one bath of NMP rinse, one bath of IPA, and one bath of DI water at room temperature (in glass dishes labeled for liftoff)
    a. The IPA and water dishes should be shallow to allow for easier stereoscope inspection

Note: all steps (2.9.4 through 2.9.12) are performed one wafer at a time; repeat the following procedure once for each wafer

4. Soak wafer in 60 °C NMP rinse for 10-20 minutes with periodic mild agitation until metal begins to visibly lift off of wafer
5. Hold the NMP bath (with the wafer inside) above the sonicating bath and intermittently touch the water surface for intermittent sonication until metal appears to fully lift off
6. Once liftoff appears to be complete, move NMP bath back to the hot plate and move the wafer to a room temperature NMP bath for >5 minutes
    a. Do not allow wafer to dry, as this will cause lifted-off metal to permanently stick to the wafer surface
7. Lift wafer out of the room temperature NMP bath, rinse with NMP in a squeeze bottle, and move to an IPA bath
    a. Do not allow wafer to dry, as this will cause lifted-off metal to permanently stick to the wafer surface
8. Inspect the wafer for any remaining metal while submerged in IPA under a stereoscope
    a. If any undesired metal remains (metal that has not yet been lifted off or metal flakes sitting on the surface), move wafer back to the warm NMP bath and repeat process from step 2.9.5
    b. If any stubborn metal remains after repeating sonication, a foam swab can be used to gently dislodge metal from the wafer surface
9. Lift wafer out of the IPA bath, rinse with IPA in a squeeze bottle, and move to a DI water bath for >3 minutes
    a. Do not allow wafer to dry, as this will cause lifted-off metal to permanently stick to the wafer surface
10. Re-inspect the wafer for any remaining metal while submerged in water under the stereoscope
    a. If any undesired metal remains (metal that has not yet been lifted off or metal flakes sitting on the surface), move wafer back to the warm NMP bath and repeat process from step 2.9.5
11. Rinse wafer with DI water 3 times, and blow dry with N_2

12. Inspect metal features under microscope and return to step 2.9.5 if any metal or photoresist remains
13. Clean up chemicals and dishes
    a. Dispose of NMP and IPA in solvent waste bottle
    b. Glass dishes should be rinsed clean with acetone, IPA, and DI water

3 DEPOSIT TOP PARYLENE C

3.1 DESCUM WAFER

Equipment: *RIE or Asher*

1. Descum (clean) wafers in the RIE or Asher using the following recipe:
   100 mT, 100 W, 50 sccm O_2, 5 minutes

3.2 SILANIZATION

Note: this step should be performed within 12 hours of Parylene deposition (step 3.3)

Materials: *A-174 Silane*

Equipment: *Glass dishes designated for A-174*
Aluminum foil
Crystalizing dish labeled for A-174
Wafer cassette designated for A-174
Fume hood

1. Prepare a mixture of 900 mL DI water, 900 mL isopropanol, and 9 mL A-174 silane in a large glass beaker (volume ratio of A-174:IPA:DI water is 1:100:100)
   a. This volume is used for batches of 12 wafers; smaller quantities using the same ratio can be used for smaller batches
2. Gently stir the mixture for 30 seconds, cover the beaker with aluminum foil, and let sit for at least 2.5 hours, but no more than 24 hours
3. Transfer the A-174 mixture into a crystalizing dish
4. Soak wafers face up or in a wafer cassette in the A-174 mixture for 30 minutes (wafers must be fully submerged)
5. Remove the wafers and place on TexWipe (cleanroom wipers) in the fume hood face up and air dry for 30 minutes
6. Rinse the wafers thoroughly with IPA for 30-60 s (squeeze bottle preferred)
7. Blow dry with N_2
8. Clean up chemicals (solvent waste) and clean dishes in IPA and DI water

3.3 DEPOSIT PARYLENE C

Note: this step should be performed within 12 hours after silanization (3.2)

Materials: *Parylene dimer*

Equipment: *Parylene PVD*

1. Follow the Parylene SOP to operate the Parylene tool
2. Deposit 10 µm of Parylene C on 12 4” wafers

a. 32-33 g of dimer is typical, but amount should be verified by comparing to past Parylene runs and adjusted as needed
b. 12 wafers per batch is recommended and varying the wafer number will affect the amount of dimer required

3.4 Measure Parylene Thickness

Materials: *Parylene-coated glass slides from step 3.3*
Equipment: *Profilometer*

1. Cut a small strip of Parylene off each glass slide using a sharp razor blade
2. Measure Parylene thickness (step height from Parylene to bare glass) using a profilometer
3. Log measurements into logbook

3.5 Anneal Wafer (Optional)

Note: if many days between 3.3 and this step, repeat descum (step 3.1)
Equipment: *Vacuum oven with N_2*

1. Anneal the full wafer per the procedure in appendix A for 4 hours at 150 °C

4 Pattern Parylene (Step 1 - top open features and edge)

4.1 Inspect and Clean Etch Photomask 1

Safety: *use HF gloves, apron, and googles if using Nanostrip*
Materials: *Acetone*
IPA
Nanostrip
Sodium bicarbonate (for disposal, if no Nanostrip waste bottle available)
Equipment: *Etch photomask 1*
Plastic trays
Glass tank designated for Nanostrip
Teflon mask holder
Teflon-coated HF tweezers
Hot plate
IR temperature sensor

1. Blow the surface of the mask with N_2 and inspect (with a bare eye) for any debris or residue
    a. Proceed to step 4 if the mask appears clean
2. If minimal residue or debris remains, clean the mask using the solvent cleaning procedure as follows:
    a. Perform all work (except for drying) in the solvent hood
    b. Prepare 1 plastic tray each for acetone, IPA, and deioinized water
    c. Soak mask in acetone with the chrome side (with the reddish hue) facing up for >10 minutes with periodic agitation
    d. Move mask to IPA and soak for >10 minutes with periodic agitation
    e. Move mask to water and soak for >10 minutes with periodic agitation
    f. Rinse thoroughly with water, blow dry with N_2

   g. After cleaning, reinspect and proceed to step 4 if the mask appears clean
3. If stubborn residue or debris remains or cannot be removed in step 2, perform clean in Nanostrip as follows:
   a. Perform all work (except for drying) in the corrosives hood
   b. Follow procedure in Nanostrip SOP, using designated glass Nanostrip tank, Teflon mask holder, and Teflon-coated tweezers (labeled for HF)

      Note: make sure mask is always oriented with the chrome side (with the reddish hue) facing up in the mask holder to prevent scratching
4. If scratches are present in the chrome layer or other mask defects are found, repair may be possible by applying opaque tape to the glass side of the mask over the defect/scratch

4.2 DRYBAKE

Note: this step should be performed immediately before photoresist deposition (step 4.3)
Equipment: Vacuum oven with N_2

1. Bake wafers at 60 °C in an oven under light vacuum (35-40 cmHg) and N_2 flow (15-20 sccm) for >15 minutes

4.3 DEPOSIT PHOTORESIST

Note: this step should be performed immediately after drybake (step 4.1)
Materials: AZ 12XT-20PL-15 photoresist
Edge bead removal solvent (optional)
Equipment: Spin coater
Hot plate
IR temperature sensor
Wafer centering tool (optional)
Edge bead removal shield (optional)

1. Degas photoresist for >1 hour prior to spinning (open bottle and set it in the hood with the lights off)
2. Line the inside of the spinner lid with aluminum foil (for easier cleanup)
3. Coat 2 dummy wafers in spin coater prior to coating real wafers
   Note: this step saturates the machine with photoresist and changes the atmosphere in the spinner, leading to more consistent photoresist thicknesses between wafers

Note: the remaining steps (4.3.4 through 4.3.10) are performed one wafer at a time; repeat the following procedure once for each wafer

4. Blow wafer with N_2 to remove any particles on the surface
5. Place wafer onto the spinner chuck (using the wafer centering tool, if desired), center it, and engage vacuum to hold it in place
6. Dispense photoresist into a puddle on the center of the wafer
   a. Photoresist can either be dispensed using a dropper, by pouring directly out of a small amber bottle, or using a syringe (degas for >2 hr prior to loading, use >3 mL of photoresist in a polyethylene syringe)
   b. ~1.5 inch diameter puddle
   c. Use more photoresist if surface is uneven to ensure sufficient coverage

   d. If any bubbles are present in the photoresist puddle, wait for them to pop or carefully pop them with a foam swab, taking care not to touch the wafer surface
7. Spin photoresist to 15 µm thickness using the following recipe (aiming for 1.5× "Top" Parylene thickness):

10 s, 500 RPM, accl 5	*spreads out PR puddle*
45 s, 2000 RPM, accl 8	*defines desired thickness*

Note: If photoresist is not within the expected thickness range, the speed must be re-calibrated; photoresist thickness can be measured after development (step 4.5) is complete

8. Remove outer ~5 mm of photoresist using a swab and edge bead removal solvent
   a. Open spinner lid and lower edge bead removal (EBR) shield (black plastic cylinder) over wafer without touching the wafer
   b. Place magnet over the lid sensor to override the interlock
   c. Fill a small glass beaker with EBR solvent
   d. Soak a large foam swab in the EBR solvent and blot away excess solvent
   e. Place the swab on the edge of the wafer at the 3 o'clock position such that the swab is only in contact with the edge bead (no more than 5 mm away from the edge of the wafer)
   f. Spin the wafer using the following recipe:

5 s, 200 RPM, accl 4	*time to position swab*
40 s, 750 RPM, accl 4	*EBR time*

   g. Reposition the swab if needed during the first 5 seconds (low speed), then leave the swab in contact with the wafer for 20 seconds
   h. Allow the wafer to spin for the remaining 20 seconds to dry
   i. Repeat step 4.3.8e through i if necessary until the edge bead has been removed
9. Soft bake at 110 °C for 3 minutes
10. If photoresist is not applied correctly (e.g. if not enough photoresist is used to cover the entire wafer or a particle is stuck on the surface), remove the photoresist using the procedure in appendix D and return to step 4.2
11. Clean up spinner and photoresist waste

4.4 Expose Photoresist

Equipment: *Mask aligner*
Etch photomask 1
Plastic tray

1. Load etch photomask 1 into the mask aligner

Note: all steps (4.4.2 through 4.4.4) are performed one wafer at a time; repeat the following procedure once for each wafer

2. Load wafer into the mask aligner and align the metal layer to the mask pattern
3. Expose wafer through etch photomask 1 in soft contact mode at 185 mJ/cm^2
   a. 10 mW/cm^2 x 18.5 s recommended
   b. Other lamp settings and timing can be used as long as the exposure dose remains the same (e.g. 10 mW/cm^2 x 18.5 s = 185 mJ/cm^2)
4. Post exposure bake at 90 °C for 1 minute
5. Place wafer immediately into DI water bath after exposure for at least 2 minutes to prevent overheating

   a. Wafer can move directly from the water bath to the developer bath in step 4.5 or it can be dried prior to development
6. Clean up mask aligner and fume hood

4.5 Develop Photoresist

Materials: *AZ 726MIF developer*
Equipment: *Corrosives fume hood*
Plastic trays: general use (unlabeled) and designated for developer

1. Perform chemical work with developer in corrosives fume hood

Note: all steps (4.5.2 through 4.5.6) are performed one wafer at a time; repeat the following procedure once for each wafer

2. Develop wafer in developer bath (undiluted) for 75 seconds with mild agitation
   a. Use the tray(s) designated for developer, ensuring they are clean before use
   b. Development time will need to be adjusted based on age of photoresist and developer and environmental conditions
3. After development, move wafer quickly to a water bath, then flush 3× with DI water
4. Blow dry with N_2
5. Inspect developed features under microscope and develop for additional time if needed
6. If photoresist is not applied correctly (e.g. if the exposure dose is not correct, if it has been overdeveloped, or it has been scratched), remove the photoresist using the procedure in appendix D and return to step 4.2
7. If photoresist is patterned correctly, clean up trays and fume hood area

4.6 Measure Photoresist Thickness

Materials: *Developed photoresist-coated wafers from step 4.5*
Equipment: *Profilometer*

1. Measure photoresist thickness (step height from photoresist pattern to Parylene surface) using a profilometer
2. Log measurement in logbook

4.7 Etch Parylene

Equipment: *DRIE or RIE*

1. Etch through the thickness of the top Parylene layer (down to the metal layer for any exposed metal features) on each wafer using the DRIE (procedure in appendix B) or the RIE (procedure in appendix C)

4.8 Remove Remaining Photoresist

1. Strip remaining photoresist off each wafer per the procedure in appendix D

5 Pattern Top Parylene (Step 2 - edge only)

1. Repeat step 4 using etch photomask 2 and etch through any remaining Parylene (thickness of the base Parylene)

6 Release Devices

Equipment: *Scalpel*
Sharp tweezers
Microscope

1. To remove a single device:
    a. Place a droplet of water at the device edge (near one of the handling tabs)
    b. Looking through a microscope, use a scalpel to gently lift the edge of the device, allowing the water to wick between the Parylene and the wafer
    c. Peel the device off the wafer using sharp tweezers, holding on to the handling tab only, allowing water to continue wicking underneath the device as its lifted off
        i. Add more water as needed
2. To remove all devices on a wafer:
    a. Submerge the wafer in water
    b. Devices should begin to lift off on their own, or you can peel the devices off individually while submerged using sharp tweezers or a scalpel

7 Post-Process Annealing

Equipment: *Vacuum oven with N_2*
Materials: *Ceramic plates*

1. Sandwich release devices between clean ceramic plates
2. Anneal the released devices per the procedure in appendix A for 48 hours at 200 °C
3. Anneal the released devices on a hotplate set to 275 °C (180 °C/hr ramp) and set in vacuum chamber
    a. Set 25-30 sccm nitrogen flow
    b. Ramp for 1.5 hrs, bake for 3 hrs
    c. Turn off hotplate and let cool for 1-2 hrs
4. Remove devices

8 Post-Process Cleaning

Note: this step is recommended to remove any remaining scum on electrode sites and improve impedance values
Materials: *Prime silicon wafer(s) or soda lime wafer(s)*
Kapton tape
Equipment: *Asher*

1. Attach released devices to a clean carrier wafer (Si or glass) with the electrode sites exposed using small pieces of Kapton tape
2. Clean devices in the Asher using the following recipe:
   125 mT, 100 W, 30 sccm O_2, 5 minutes

APPENDICES

A. WAFER ANNEALING PROCEDURE

1. Place wafer(s) in a vacuum oven, close, and evacuate chamber to 70 cmHg or greater vacuum
2. Purge chamber with N_2 to 20-30 cmHg, then re-evacuate to 70 cmHg or greater
3. Repeat step 2 twice (three total N_2 purges)
4. Leave the vacuum valve open and open the N_2 valve until 10-15 sccm of N_2 are flowing into the chamber
   a. N_2 is not necessary for this step, but will prevent O_2 buildup in the chamber if there is a vacuum leak
5. Bake wafers (under vacuum and N_2 flow) for desired time and temperature, typically this will be 150 °C for 4 hours

B. PARYLENE ETCHING PROCEDURE (DRIE)

Equipment: DRIE

1. Etch wafers in the DRIE through the patterned photoresist using the procedure developed in Meng et al, 2008 [1]
2. After each step, inspect wafers for any remaining Parylene in the etched areas and continue etching as needed
3. If no photoresist remains, stop etching, remove photoresist via the procedure in appendix D, and re-pattern a new photoresist layer for the current mask pattern, starting from the drybake step

C. PARYLENE ETCHING PROCEDURE (RIE)

Equipment: RIE

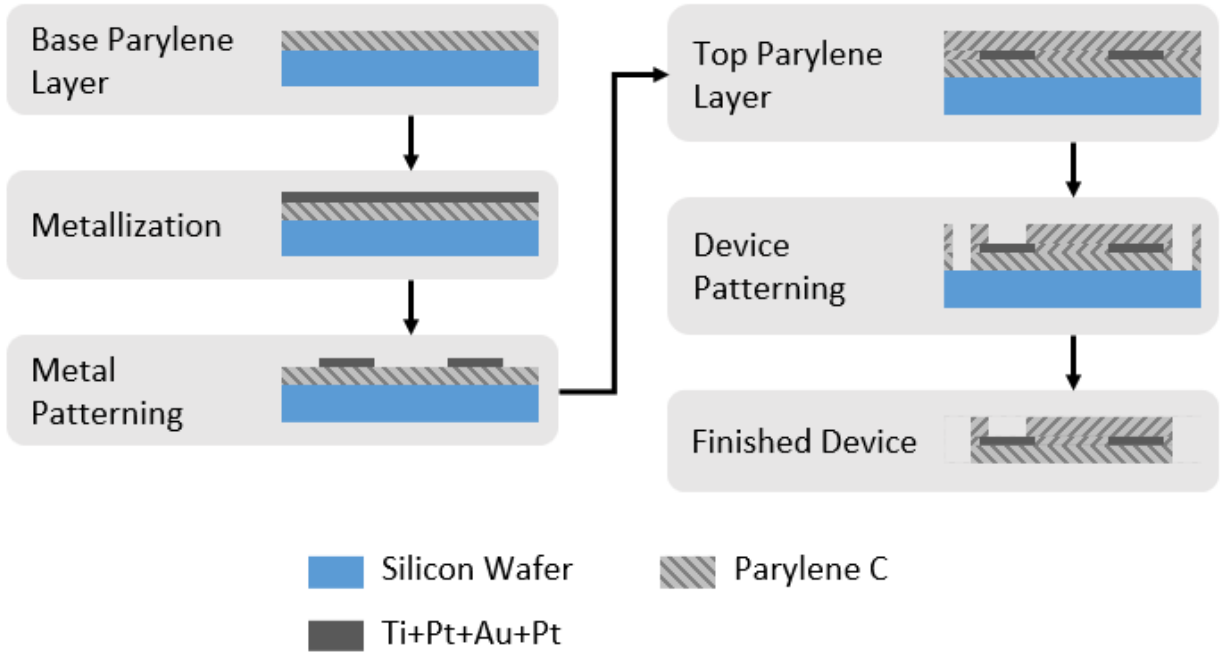
1. Etch wafers in the RIE through the patterned photoresist using the following parameters:
   a. 150 mT, 150 W, 50 sccm O_2
   b. Multiple wafers can be etched at one time (if the chamber is large enough)
   c. Perform in two or more steps of 15 minutes or less, rotating the wafer(s) 90-180 degrees with each step
2. After each step, inspect wafers for any remaining Parylene in the etched areas and continue etching as needed
   a. Etch rate varies depending on equipment used and number of wafers loaded in the machine, but should be on the order of 0.15-0.20 µm/minute
3. If no photoresist remains, stop etching, remove photoresist via the procedure in appendix D, and re-pattern a new photoresist layer for the current mask pattern, starting from the drybake step

D. Photoresist Stripping Procedure

Materials: *Acetone*
IPA
Equipment: *Plastic trays*

1. Soak wafer in an acetone bath for 30-60 seconds with mild agitation to remove the majority of photoresist
2. Move wafer to a second acetone bath and soak for >3 minutes with periodic mild agitation
3. Move wafer to an IPA bath and soak for >3 minutes with periodic mild agitation
4. Move mask to a water bath and soak for >1 minutes with periodic mild agitation
    a. Watch out for devices lifting off of the wafer at this stage, and skip the next step if it will result in loss of devices
5. Rinse gently with water, blow dry with N_2

E. Process Flow Diagram



F. Material Sources

Note: Standard materials (e.g. acetone, DI water, cleanroom wipes, etc.) are not listed

Material	**Supplier**
CR-7 chrome etchant	Transene, Danvers, MA
Parylene dimer	Specialty Coating Systems, Indianapolis, IN
AZ 12XT-20PL-15 photoresist	AZ Electronic Materials, Branchburg, NJ
AZ 5214 E photoresist	AZ Electronic Materials, Branchburg, NJ
AZ 340 developer	AZ Electronic Materials, Branchburg, NJ
AZ 726MIF developer	AZ Electronic Materials, Branchburg, NJ
Edge Bead Removal (EBR) solvent	AZ Electronic Materials, Branchburg, NJ
NMP Rinse	AZ Electronic Materials, Branchburg, NJ

Titanium	Provided by USC cleanroom
Platinum	Provided by USC cleanroom
Gold	Provided by USC cleanroom
Nanostrip 2X	CMC Materials, Santa Ana, CA

G. EQUIPMENT MODELS

Note: Standard equipment (e.g. tweezers, microscopes, N_2 gun, scale, etc.) are not listed

Equipment	**Model #**	**Supplier**
Vacuum oven with N_2	TVO-2	Cascade Tek Inc., Longmont, CO
	VO914A	Lindberg/Blue M, New Columbia, PA
Profilometer	DektakXT	Bruker, Billerica, MA
Spin coater	WS-400B-6NPP Lite	Laurell Technologies, North Wales, PA
Hot plate	PMC 730 Dataplate	Barnstead/Thermolyne, Dubuque, IA
	1000-1	Electronic Micro Systems, Sutton Coldfield, UK
Sonicating bath	3510	Branson Ultrasonics, Danbury, CT
DRIE	Plasmalab 100	Oxford Instruments, Bristol, UK
RIE	PlasmaPro 80	Oxford Instruments, Bristol, UK
	Series 85	Technics, Pleasanton, CA
Asher	CV200RFS	Yield Engineering Systems, Fremont, CA
Mask aligner	Model 200	OAI, San Jose, CA
E-beam evaporator	Mark 40	CHA Industries, Livermore, CA
	PRO Line PVD 75	Kurt J. Lesker, Jefferson Hills, PA
Parylene PVD	PDS 2010 Labcoter	Specialty Coating Systems, Indianapolis, IN

H. REFERENCES

1. E. Meng, P. Y. Li, and Y.-C. Tai, "Plasma removal of Parylene C," *J. Micromechanics Microengineering*, vol. 18, no. 4, p. 045004, 2008, doi: 10.1088/0960-1317/18/4/045004.
2. B. Thielen and E. Meng, "Characterization of thin film Parylene C device curvature and the formation of helices via thermoforming," *J. Micromechanics Microengineering*, vol. 33, no. 9, p. 095007, 2023, doi: 10.1088/1361-6439/acdc33.
3. B. J. Kim, B. Chen, M. Gupta, and E. Meng, "Formation of three-dimensional Parylene C structures via thermoforming," *J. Micromechanics Microengineering*, vol. 24, no. 6, p. 065003, 2014, doi: 10.1088/0960-1317/24/6/065003.
4. B. J. Kim and E. Meng, "Micromachining of Parylene C for bioMEMS," *Polymers for Advanced Technologies*, vol. 27, no. 5, pp. 564-576, doi: 10.1002/pat.3729.
5. J. Ortigoza-Diaz, K. Scholten, and E. Meng, "Characterization and Modification of Adhesion in Dry and Wet Environments in Thin-Film Parylene Systems," *J. Microelectromechanical Syst.*, vol. 27, no. 5, pp. 874–885, 2018, doi: 10.1109/JMEMS.2018.2854636.