Protocol: Packaging and Assembly of Parylene MEAs

Description: This document outlines the procedure for packaging Parylene polymer microelectrode arrays (pMEAs) to external connectors and recording system. The overall process consists of interconnecting thin-film metal on Parylene to a custom printed circuit board (PCB) followed by securely integrating Omnetics connectors to the PCB substrate.

Note: Standard equipment and materials (e.g. tweezers, microscopes, DI water, cleanroom wipes, N_2 gun, scale, etc.) are not listed in materials lists.

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1 PCB Preparation

1.1 PCB Requirements

Materials: *PCB – custom*
Stencil – custom

1. FR-4 board base material.
2. Surface finish of pads of 20-30 microinches of electroless nickel immersion gold (ENIG).
   a. Traditional 1-3 microinches of ENIG finish results in low yield Au wire ball bonds.
   b. Other surface finishes, such as electroless nickel electroless palladium immersion gold (ENEPIG), may be suitable.

1.2 Ultrasonic Cleaning Bath

Equipment: *Sonicating Bath*
Materials: *PCB – custom*

1. If PCBs come panelized, separate each PCB from panel.
2. Prepare IPA ultrasonic bath. Soak PCB for 10 minutes.
3. Prepare DI water bath. Soak PCB for 10 minutes. Rinse 3× with DI water.
4. Blow dry thoroughly.

1.3 Mother PCB to Daughter PCB Connection

Note: this step is only necessary for Rat A and Rat B MEAs

This step establishes an electrical connection between the Daughter and Mother PCBs. The Daughter PCB provides a fixed offset the Parylene C MEA, determined by the PCB thickness, to: (1) allow enough space between adjacent assemblies for external headstage connections and (2) preserve the separation distance required between adjacent implanted MEAs for the electrode sites/shanks to reach the desired brain targets. Daughter PCBs host a pad array on the front face to interface Parylene pMEA to the PCB on the front face, and on the bottom face for connecting to Mother PCB. Mother PCBs host two pad arrays on the front face for (1) connecting to the Daughter PCB and (2) attaching Omnetics connectors, and on the bottom face for attaching Omnetics connectors. Figure 1.1 shows a 3D model of the assembled PCBs with interconnected MEA.

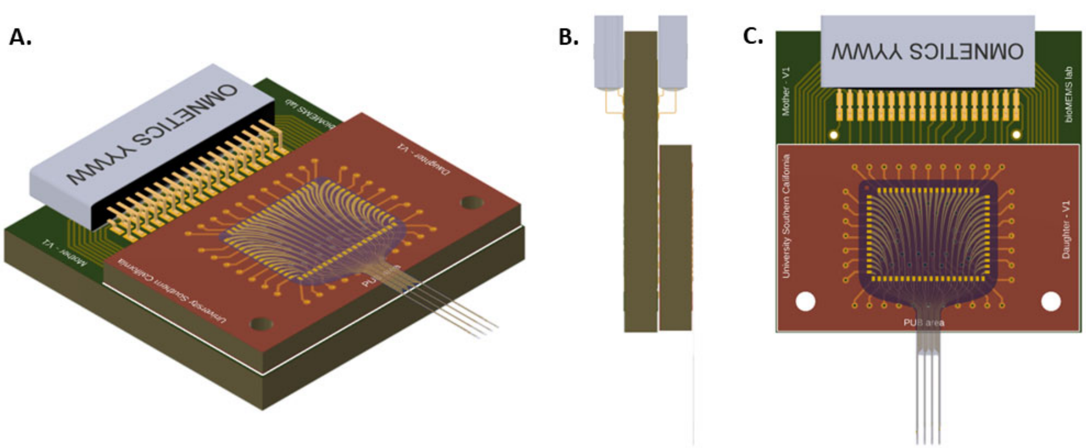

Figure 1.1. 3D model of packaged Parylene C MEA showing the Daughter and Mother PCBs

Figure 1.2 shows the dimensions of the mating pads for Mother and Daughter PCBs. It is recommended that the pads in Mother PCB are larger than the ones in Daughter PCB.
Note: have yet to verify what is the smallest pad dimensions that would result in high yield interconnection.

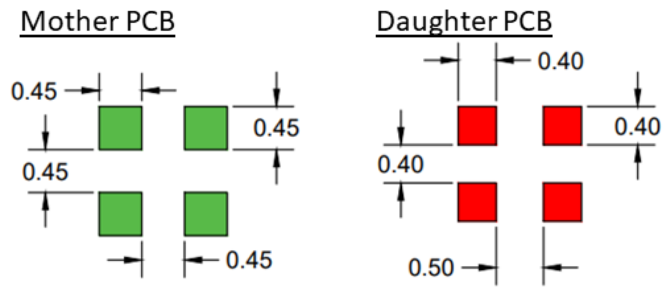

Figure 1.2. Mating pads dimensions for Mother and Daughter PCBs

Equipment: *Hotplate*
Stencil setup – custom made
Materials: *PCB – custom*
Stencil – custom
Lead-free solder paste
Lead-free flux remover
Flux

1. If PCBs are panelized, separate each PCB from panel.
2. Prepare IPA ultrasonic bath. Soak PCBs for 10 minutes.
3. Prepare DI water bath. Soak PCB for 10 minutes. Rinse 3x with DI water.
4. Blow dry thoroughly.
5. Apply lead-free solder paste on mating pads of Mother PCB:
   i. Place Mother PCB on Stencil setup (Figure 1.3A).
   ii. Insert alignment pins in alignment holes.
   iii. Align stencil to the Mother PCB through alignment pins and use tape on the edges to fix it – verify alignment under microscope (1.3B).
   iv. Remove pins.
   v. Dispense solder paste on one end of stencil close to the apertures.
   vi. Using a plastic flexible card, spread the paste evenly and make sure each aperture gets filled – verify under microscope (Figure 1.3C).
   vii. Remove tape and lift stencil (Figure 1.3D).
   viii. Bake solder paste with the following parameters:
      a. 2 min at 100 °C.
      b. 2 min at 160 °C.
      c. 2 min at 210 °C.
      d. 2 min at 265 °C - solder paste should visibly reflow at this temperature.
      e. Cool down to room temperature on hotplate ~ 5 min.
   ix. Inspect if solder paste has solidified under the microscope (Figure 1.3E).
6. Reapply solder paste to Mother PCB following step 5 (Figure 1.3F).
7. Align Daughter PCB to Mother PCB via alignment holes.

8. Reflow solder paste by baking with the following parameters and by pressing on Daughter (top) PCB:
    - i. 2 min at 100 °C.
    - ii. 2 min at 160 °C.
    - iii. 2 min at 210 °C.
    - iv. 3 min at 265 °C.
    - v. Cool down to room temperature on hotplate ~ 5 minutes. Apply even pressure on Daughter PCB for 2 minutes during cooling.
      Note: very important to constantly apply even pressure from 200 °C (step 8.iii) until it cools below 160 °C (step 8.v). Figure 1.4 shows the difference during step 8 with (A) and without () pressure applied on Daughter PCB.
9. Verify if electrical connection is made by probing at least 5 electrodes at different locations, yielding 100%.
    - i. If < 100% yield, repeat from step 6.

   Note: use a thin thread of wire bundle to probe the pads on top of Daughter PCB – avoid damage.
10. Verify there are no electrical shorts by probing the larger pads in Mother PCB.
    - i. If there is any shorting, repeat from step 6.
11. Clean mated PCBs:
    - i. Ultrasonic bath of lead-free flux remover.
    - ii. Ultrasonic bath of IPA for 5 minutes.
    - iii. Ultrasonic bath of water for 5 minutes.
    - iv. Blow dry.

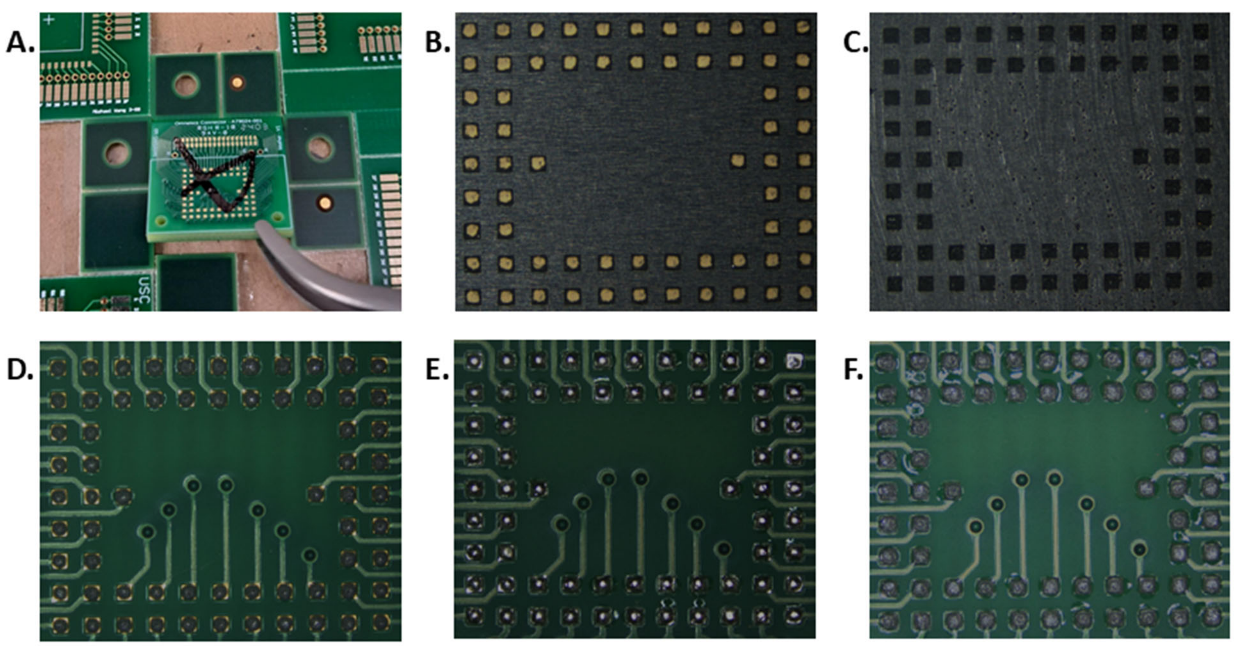

Figure 1.3. Preparation of Mother PCB. (A) PCB placed on stencil set up. (B) Mating ENIG pads through stencil. (C) Mating ENIG pads coated with solder paste through stencil. (D) Solder paste on mating pads. (E) Reflowed solder paste on mating pads. (F) 2nd layer of solder paste on mating pads.

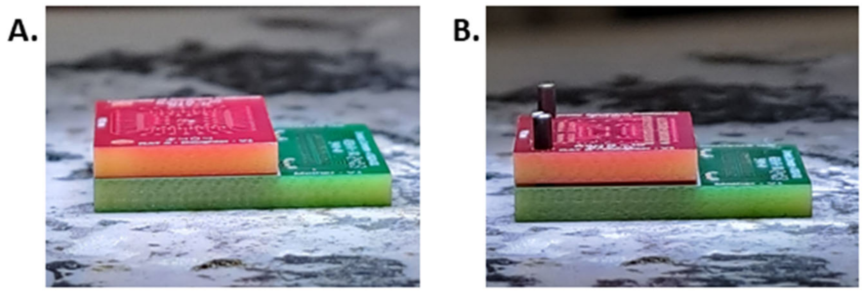

Figure 1.4. Sideview of interconnected Mother-to-Daughter PCBs with (A) and without (B) pressure applied on Daughter (red) PCB. Assembly without applied pressure (B) resulted in failure as evidenced by the separation visible between the two boards.

2 Omnetics Connector Attachment

The purpose of this step is to establish an electrical connection between the PCB substrate and Omnetics connectors which are used for external connection to the headstage of the recording system.

2.1 Solder Paste

Materials: *Solder paste*
Equipment: *Dispenser*
Solder paste syringe

1. Let solder paste sit at room temperature for 30 minutes before use for easier flow.
2. Connect dispenser and attach solder paste syringe in the adapter.
3. Using the stereoscope or microscope, coat front and back contact pads on the PCB with a line of solder paste.

2.2 Reflow

Materials: *Omnetics connector*
Equipment: *Soldering iron*
Hot air gun

1. Place and align Omnetics connector on PCB pads either manually under the stereoscope or using an alignment fixture.
2. Set soldering iron set to 650 °C. Touch each accessible Omnetics surface mount leg to reflow solder paste.
3. Set hot air gun to 350°C and 50 air flow. Bring the gun close to the Omnetics connector until visible reflow occurs.
4. For two-sided PCBs, flip PCB and repeat steps 1-3 to attach the Omnetics connector to the back side.
5. Carefully blow dry with N_2 gun.

3 Interconnection Strategies for Bonding Parylene devices to PCBs

Integrating electronic packaging for flexible polymer MEAs is critical for the overall performance of penetrating neural interfaces. In this protocol, we describe two low temperature ultrasonic bonding approaches tailored to the specific needs of MEAS: PUB bonding and ball bonding through vias/rivets.

3.1 Polymer Ultrasonic on Bump (PUB) Bonding

This procedure is for bonding polymer MEAs to rigid PCBs. In this technique, ultrasonic welding is performed using a standard bonder tool sized to match the pad size [1]. Flat metal contact/bond pads are joined via a coined bump through the MEA via a 'waffle' tool. This forms permanent bonds and is typically destructive to the pads on the MEA.
PUB bonding is recommended for the following applications:

1. Traditional planar thin film fabricated MEAs of a Parylene-metal-Parylene structure.
2. Bonding pads with pitch and widths ranging from 100 µm x 70 µm to 400 µm x 210 µm [1].

**PUB bonding was reported to achieve highest yield and lowest resistance when compared to three other fine pitch interconnection strategies (wire bonding, conductive epoxy and anisotropic conductive film) [1].*
We refer the reader to PUB Bonding Subprotocol with detailed instructions on the procedure for PUB bonding. We also refer the reader to the Parylene MEA microfabrication protocol.

3.2 Ball Bonding through Vias/Rivets

This procedure is for bonding MEAs to rigid PCBs where the electrode face is not in direct contact with the pads on the PCB substrate. At the pad sites, Au balls are ultrasonically bonded through vias in the MEA. This is expected to form permanent mechanical bonds at low temperature (60 °C) while reducing bonding area [2].
Ball bonding through vias/rivets (through holes) is recommended for the following applications:

1. MEAs where electrode face is opposite from the surface in contact with PCB.
    a. Metal pads with vias lead to more elaborate fabrication protocols of the MEAs. A detailed description of MEAs with vias at the pad sites is under construction.
2. Bonding pads with a minimum pitch and width of 100 µm x 200 µm.

We refer the reader to Rivet Bonding Subprotocol with detailed instructions on the procedure for rivet bonding.

3.3 Overfill

Materials: *EpoTek MED 302*
Equipment: *Syringe barrel*
Luer stub 23 gauge
Dessicator

1. Prepare EpoTek MED 302 using a scale for accuracy:

a. Two-part epoxy, 10 parts to 4.5.
2. Pour epoxy into a syringe barrel and degas in a vacuum bell jar for 10 minutes. Once degassed, remove trapped air.
3. Replace the tip cap with a luer stub 23 gauge for precision dispense.
4. Connect dispenser and attach syringe in adapter.
5. Dispense epoxy over MEA.
6. Let epoxy rest at room temperature for 1 hour.
7. Cure epoxy in oven at 60-65 °C for 3 hours.

4 Wire Lead Attachment

The purpose of this step is to attach ground/reference external wires to the PCB board.

4.1 Connect Wires

Materials: *Stainless steel wire*
Equipment: *Stainless steel scissors*
Soldering iron

1. Cut 8 cm long sections of stainless steel and remove ~ 2cm of insulation from both ends using a stainless steel scissors.
2. Thread stainless steel wire through ground/reference plated-through hole (PTH) (Figure 4.1) in PCB board until insulation is nearly touching PTH.
3. Solder wires to ground/reference PTH.
4. Trim excess stainless steel wire from the back of PCB.

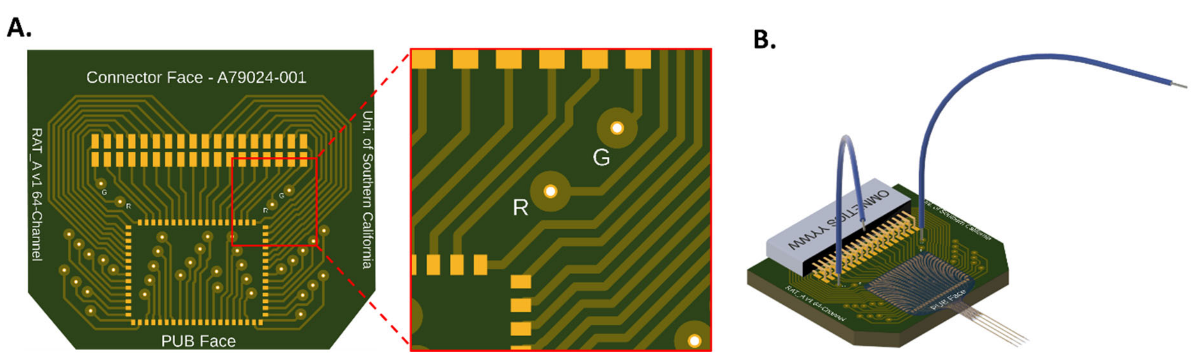

Figure 4.1. A. CAD model of PCB. G and R indicate 'ground' and 'reference' plated-through holes (PTHs). B. CAD model of assembled MEA, PCB, Omnetics connectors and ground wires.

5 Final Insulation/Coating

Materials: *EpoTek MED 302*
Equipment: *Scale*
Desiccator

1. Prepare EpoTek MED 302 according to manufacturer instructions using a scale for accuracy.
    a. Two-part epoxy, 10 parts to 4.5.
2. Degas for 1 hour in a desiccator.

3. Coat the top surface of PCB with a thick layer of epoxy.
    a. Ensure the ground/reference wires are straight - use tape if necessary.
4. Cure epoxy overnight at room temperature
5. Repeat steps 5.2-5.5 on the back surface of PCB.

APPENDICES

A. MATERIAL SOURCES

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

Material	**Supplier**
Printed Circuit Board (PCB)	Rush PCB, Milpitas, CA
Stainless steel wire - Catalog #790900	A-M Systems, Sequim, WA
EPO-TEK MED-302	Epoxy Technology, Billerica, MA
Omnetics connector A79024-001	Omnetics, Minneapolis, MN
Solder paste – Catalog#4900P	MG Chemicals
Lead-free flux remover	Chemtronics, Kennesaw, GA

B. EQUIPMENT MODELS

Note: Standard equipment (e.g. tweezers, microscopes, N2 gun, scale, dessicator, etc.) are not listed

Equipment	**Model #**	**Supplier**
Sonicating bath	1510	Branson, Brookfield, CT
Ball bonder	626	Hybond, Escondido, CA
Wedge bonder	527A	Hybond, Escondido, CA
'Waffle' tool	7145 series	Small Precision Tools,
Luer stub 23 gauge blunt needle	NC9400183	Fisher Scientific, Hampton, NH

REFERENCES

[1] J.J. Yoo and E. Meng, "Bonding methods for chip integration with Parylene devices," *J. Micromechanics and Microengineering*, Feb. 2021, doi: 10.1088/1361-6439/abe246.
[2] Y. Wang, et al., "Flexible multichannel electrodes for acute recording in nonhuman primates," *Microsyst. Nanoeng.*, July 2023, doi: 10.1038/s41378-023-00550-y.