Fabrication Procedure for Rugged and Breathable Forms of Stretchable Electronics with Adherent and Composite Substrates

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Abstract

We introduce materials and composite designs for thin, breathable, soft electronics that can adhere strongly to the skin. In this protocol, we describe step-by-step procedure of device preparation with helpful information.

Procedure

Step 1: Preparation of substrate for temporary use in device mounting Timing: 2 hours

1. Prepare a glass slide with the dimension of 75 mm x 50 mm x 1.0mm.
2. Spin cast poly(methylmethacrylate) (PMMA) at 3000rpm for 30 seconds and cure on a hot plate at 180°C for 3 minutes.
3. Spin cast polyimide at 3000 rpm for 30 seconds and cure inside a vacuum oven at 250°C for 1.5 hours.

Step 2: Fabrication of wireless heater Timing: 2 hours

4. Deposit metals (Cr/Au, 15/100 nm) on the prepared substrate using electron beam evaporator.
5. Define open mesh architecture composed of narrow filament serpentine (FS) traces by photolithography (positive photoresist, AZ 5214). Perform wet chemical etching using Cr and Au etchant and remove photoresist with acetone

Step 3: Fabrication of RF antenna Timing: 4 hours

6. Deposit copper (Cu, 3 μm) on the substrate using electron beam evaporation.
7. Define dipole geometry with FS mesh layout by photolithography (positive photoresist, AZ 5214). Perform wet chemical etching using Cu etchant and remove photoresist with acetone.
8. Spin cast polyimide on glass slide at 3000 rpm for 30 seconds and cure inside a vacuum oven at 250°C for 1.5 hours.

Step 4: Fabrication of μ-ILED Timing: 2 days

9. Prepare AlInGaP epitaxial layer stacks by MOCVD growth on a GaAs wafer (670 nm emission wavelength; p-spreading layer (Al_{0.45}Ga_{0.55}As:C)/p-cladding layer (In_{0.5}Al_{0.5}P:Zn)/quantum well (Al_{0.25}Ga_{0.25}In_{0.5}P/In_{0.56}Ga_{0.44}P/Al_{0.25}Ga_{0.25}In_{0.5}P)/ n-cladding (In_{0.5}Al_{0.5}P:Si)/n-spreading layer (Al_{0.45}Ga_{0.55}As:Si)/n-GaAs:Si/sacrificial layer (Al_{0.96}Ga_{0.04}As)/undoped GaAs).
10. Deposit silicon dioxide (600nm) on the wafer using PECVD.
- Define arrays of L-shaped patterns (280 μm x 280 μm) by photolithography (positive photoresist, AZ 5214).
11. Immerse the wafer in buffered oxide etch (6:1 NH₄F:HF) for 3 minutes at ambient temperature. ▲CRITICAL STEP Dimension of μ-ILED is determined in this step. Under etch results in failure during ICP RIE process.
12. Rinse the wafer in a tub of DI water for 10 seconds then transfer to final rinse tub for 20 seconds.
13. Immerse the wafer in diluted hydrochloric acid solution (DI water: HCl = 1:1) for 15 seconds. Rinse the wafer in DI water then remove photoresist with acetone.
14. Open n-contact using ICP RIE (25°C, 2mTorr, 6sccm Cl₂, 3sccm H₂, 6sccm Ar, 5 minutes). Measure height profile with profilometer to confirm that n-contact is opened.
15. Define arrays of square patterns (300 μm x 300 μm) to physically distinguish μ-ILEDs by photolithography (positive photoresist, SPR 220 7.0). Immerse the wafer in n-contact etch solution (H₃PO₄: DI water: H₂O₂ = 1: 12: 13) for 30 seconds. Rinse the wafer with DI water.
16. Immerse the wafer in diluted hydrofluoric acid (DI water: HF = 1: 10) for 3 seconds to enhance subsequent undercut etching process for sacrificial layers. Remove photoresist with acetone.
17. Define n-contact pads (80 μm x 80 μm) by photolithography (AZ 5214). Immerse the wafer in diluted hydrochloric acid (DI water: HCl = 1:1) for 15 seconds and rinse with DI water.
18. Deposit n-contact metals (Pd/Ge/Au, 5/35/70 nm) using electron beam evaporation and lift-off photoresist by immersing

the wafer in acetone. 19. Define p-contact pad (80 μm x 80 μm) by photolithography (PR 5214). Immerse the wafer in buffered oxide etch (6:1 $\text{NH}_4\text{F}:\text{HF}$) for 3 minutes to open p-contact pad and rinse with water. 20. Deposit p-contact metals (Pt/Ti/Pt/Au, 10/40/40/50 nm) using electron beam evaporation and lift-off photoresist. 21. Anneal the wafer at 300°C for 30 minutes inside a glove box to generate Ohmic contacts. 22. Define anchoring pattern to enable transfer mechanism by photolithography (SPR 220 7.0) and hard bake photoresist at 130°C for 10 minutes. 23. Immerse the wafer in diluted hydrofluoric acid (DI water: HF = 1: 20) for 2 hours to undercut the sacrificial layer. Transfer wafer to tub of DI water for initial rinse for 1 minute and final rinse for 3 minutes. **▲CRITICAL STEP** The arrays of $\mu\text{-ILED}$ may float during rinsing. Softly transfer wafer to DI water tub and do not swirl the water. Step 5: Preparation of polydimethylsiloxane (PDMS) stamp for transfer printing Timing: 1 day 24. Prepare a glass slide (75 mm x 50 mm x 1.0mm). 25. Define a pattern of squares (320 μm x 320 μm) by photolithography (epoxy negative photoresist, SU-8 2050). Cure SU-8 at 150°C for 30 minutes. 26. Silanize using tridecafluoro-1,1,2,2-tetrahydrooctyl trichlorosilane (UCT Specialties, LLC). 27. Deposit PDMS (10:1) on the prepared surface and cure for 1 day at ambient temperature. Step 6: Transfer printing $\mu\text{-ILED}$ on the glass substrate Timing: 2 days 28. Define alignment marks on the prepared glass substrate (wireless heater system fabricated) for transfer printing by photolithography (AZ 5214). 29. Deposit metal (Cu, 200 nm) using electron beam evaporation and lift-off photoresist. 30. Retrieve the $\mu\text{-ILED}$ (s) using a PDMS stamp prepared using a 1:10 mixture of base to curing agent (Sylgard 184, Dow Corning). 31. Spin cast polyimide at 3000 rpm for 30 seconds on the substrate to serve as an adhesion layer. **▲CAUTION** A few minutes after spin casting, polyimide starts curing at ambient temperature and loses its tacky, adhesive surface. Transfer printing of $\mu\text{-ILED}$ s should be performed before this loss of adhesion. 32. Cure polyimide partially at 130°C for 10 minutes then remove photoresist anchor structures that remain on the $\mu\text{-ILED}$ by spraying acetone. Cure polyimide fully inside a vacuum oven at 250°C for 1.5 hours. 33. Define n-type and p-type contact pads of the $\mu\text{-ILED}$ s for metal interconnection by photolithography (SU-8 2002). Cure SU-8 at 150°C for 30 minutes. Step 7: Fabrication of electrophysiological sensor and metal interconnection Timing: 1 day 34. Deposit metals (Cr/Au, 5/60 nm) using a sputtering system. **▲CRITICAL STEP** Sputtering provides sidewall deposition that is critical for $\mu\text{-ILED}$ metal interconnection. 35. Define electrophysiological sensor and metal connect pattern for wireless heater system and $\mu\text{-ILED}$ by photolithography (AZ 5214). Perform wet chemical etching using Au and Cr etchants then remove photoresist. 36. Spin cast polyimide at 3000 rpm for 30 seconds and cure inside a vacuum oven at 250°C for 1.5 hours. 37. Deposit copper (Cu, 20 nm) using electron beam evaporation. 38. Define regions where polyimide should be etched away by photolithography (AZ 5214). Perform wet chemical etching using Cu etchant then remove photoresist. 39. Etch polyimide by reactive ion etching (March RIE, 300mTorr, 200W, 20sccm O_2 , 20 minutes). Remove copper using Cu etchant then degrease the fabricated device by immersion in acetone, isopropyl alcohol, and DI water. Step 8: Preparation of textile substrate and transfer printing fabricated system Timing: 1 day 40. Prepare textile substrate. Spin cast Silbione at 1000 rpm for 60 seconds then cure at room temperature for 1 day. 41. Stack another glass slide (75mm x 50mm x 1.0mm)/cleanroom wipe on the fabricated system and hold them with a binder clip. Next, immerse in acetone to remove PMMA. **▲CRITICAL STEP** Fabricated devices may float around inside the acetone solution without glass slide/cleanroom wipe. 42. Dry sample and

remove glass slide/cleanroom wipe. Attach water soluble tape on the surface of fabricated system. Retrieve the system by slowly removing the tape from the glass slide. 43. Attach the tape on the Silbione/textile substrate then immerse in water to remove the tape.

Figures

Figure 1

An attached device onto the skin

Figure 2

A SEM image of a biaxially stretched device