CNM2 Electrostatic MEMS (4-layer) Runsheet

For further questions about this SOP, please contact Dr. Yusha Bey: jasmall@ucdavis.edu

Note: Please contact staff or senior lab users for proper equipment and chemical training before attempting this runsheet on your own.

Equipment manuals are available for your reference, but they are not a substitute for training.

Purpose

Detailed fabrication process of a four-layer MEMS cantilever beam DC contact switch. The first layer defines the bottom metal layers. The second layer defines the anchor region for the cantilever. The third layer defines the contact dimple of the cantilever. The fourth layer defines the geometry of the cantilever beam.

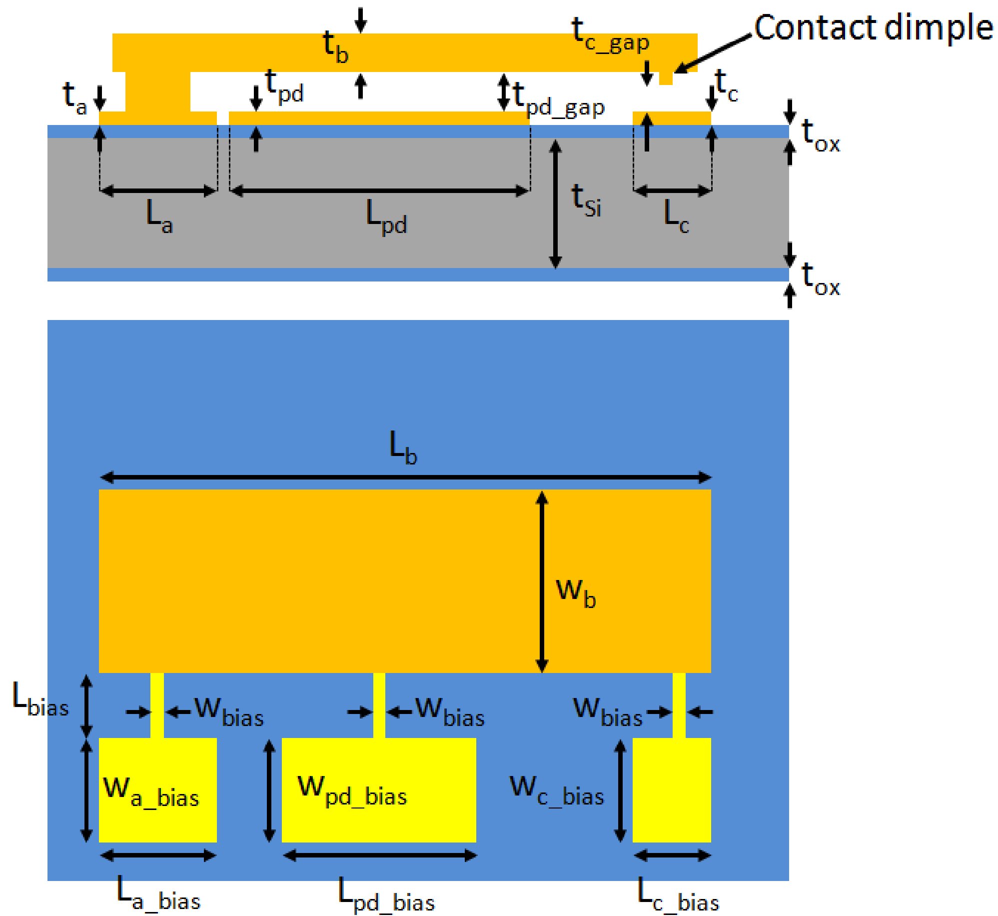
Equipment

Training required	Training not required
Karl Suss MA-4	Carl Zeiss Optical
Solitec Spinner Hotplate	Water sonicator
Lesker Sputterer	Power Supply (Electroplating), DC cables with alligator clip adaptation
Electroplating Benches	Glass Beakers and deep evaporation dishes
Technics RIE 800	Hotplate with integrated thermocouple feedback
Tousimis Critical Point Dryer	Binder clips, threaded Teflon rod, kapton tape, razor blades
Dektak 3030 Profilometer	Carl Zeiss Optical

Materials

SOP training required	Training not required
Hydrogen peroxide	Toluene, acetone, methanol, isopropyl alcohol
Sulfuric acid	S1813, S1827, HMDS
Transene gold etchant TFA	CD-26 developer, PRS-3000
Transene chromium etch 1020AC	Chromium and gold targets for Lesker Sputterer

Typical Device Dimensions



Parameter	Value	Parameter	Value
Silicon dioxide thickness (t_{ox}) [µm]	0.2 - 0.5	Contact pad length (L_c) [µm]	50 - 100
Silicon substrate thickness (t_{Si}) [µm]	300 - 600	Contact pad width (w_c) [µm]	50 - 100
MEMS beam thickness (t_b) [µm]	4 - 8	Contact pad thickness (t_c) [µm]	0.2 - 0.3
MEMS beam width (w_b) [µm]	50 - 100	DC Bias line width (w_{bias}) [µm]	30 - 50
MEMS beam length (L_b) [µm]	300 - 500	DC Bias line length (L_{bias}) [µm]	50 - 100
Contact dimple thickness (t_d) [µm]	0.2 - 0.3	DC Bias line thickness (t_{bias}) [µm]	0.2 - 0.3
Contact dimple width (w_d) [µm]	3 - 5	Anchor bias width (w_{a_bias}) [µm]	100 - 200
Contact dimple length (L_d) [µm]	3 - 5	Anchor bias length (L_{a_bias}) [µm]	100 - 200
Pull-down gap height (t_{pd_gap}) [µm]	1 - 3	Anchor bias thickness (t_{a_bias}) [µm]	0.2 - 0.3
Contact gap height (t_{c_gap}) [µm]	0.8 - 2.7	Pull-down bias width (w_{pd_bias}) [µm]	100 - 200
Actuation pad length (L_{pd}) [µm]	100 - 200	Pull-down bias length (L_{pd_bias}) [µm]	100 - 200
Actuation pad width (w_{pd}) [µm]	50 - 100	Pull-down bias thickness (t_{pd_bias}) [µm]	0.2 - 0.3
Actuation pad thickness (t_{pd}) [µm]	0.2 - 0.3	Contact bias width (w_{c_bias}) [µm]	100 - 200
Anchor length (L_a) [µm]	50 - 100	Contact bias length (L_{c_bias}) [µm]	100 - 200
Anchor width (w_a) [µm]	50 - 100	Contact bias thickness (t_{c_bias}) [µm]	0.2 - 0.3
Anchor thickness (t_a) [µm]	0.2 - 0.3		

Process

1) **Begin with 500 nm oxidized layer, low resistivity (1-10 ohm-cm), <100> orientation, P-type (Boron doped), silicon substrate (50 mm X 25 mm X 0.5 mm) (Figure 1).**

Figure 1 Bare oxidized silicon substrate.

2) **Clean substrate**
   a. *Clean samples:*
      i. Soak sample for 5 minutes in a glass beaker filled with ***toluene*** placed in a water sonicator. Use enough ***toluene*** to completely submerge the sample. Once the time has elapsed, transfer wet sample directly to ***acetone*** filled glass beaker.
      ii. Soak sample for 5 minutes in a glass beaker filled with ***acetone*** placed in a water sonicator. Use enough ***acetone*** to completely submerge the sample. Once the time has elapsed, transfer wet sample directly ***methanol*** filled glass beaker.
      iii. Soak sample for 5 minutes in a glass beaker filled with ***methanol*** placed in a water sonicator. Use enough ***methanol*** to completely submerge the sample. Once the time has elapsed, transfer wet sample directly to ***isopropyl alcohol*** filled beaker.
      iv. Soak sample for 5 minutes in glass beaker filled with ***isopropyl alcohol*** placed in a water sonicator. Use enough ***isopropyl alcohol*** to completely submerge the sample.
      v. Thoroughly rinse sample for 60 seconds with deionized water gun over the sink.
      vi. Use nitrogen gun to blow dry the sample (Do not let water evaporate from sample. Rewet if necessary).
      vii. Perform a 10 minute piranha clean: ***Hydrogen Peroxide (30%): Sulfuric Acid (98%)*** (1:1). **Perform this procedure per the Standard Operating Procedure**.
      viii. Carefully and thoroughly rinse the sample for 60 seconds with the deionized water gun over the sink.
      ix. Use nitrogen gun to blow dry the sample (Do not let water evaporate from sample. Rewet if necessary).
      x. Dehydration bake: 150 Celsius for 5 minutes on an open hotplate (**Solitec Hotplate**).

3) 1st Lithography (Pull-down electrode, Source, Drain)

a. *Allow substrate to cool to room temperature if previous step was a dehydration bake.*
b. *Spincoat* (**Solitec Spinner**) ***S1813 positive photoresist*** **(Figure 2)**:
   i. 4000 rpm ***HMDS*** for 15 seconds
   ii. 4000 rpm ***S1813*** for 45 seconds
   iii. Thickness: ~1.3 micrometers
c. *Remove the edge bead*
   i. This can be performed with a ***razor blade***.
   ii. Use the vacuum of the spinner chuck to hold the sample in place.
   iii. Scrape the edge bead off of the sample.
d. *Soft Bake* (**Solitec Hotplate**)*:*
   i. 115 Celsius for 60 seconds on a hotplate.
e. *Allow substrate to rest for 60 seconds between bake step and exposure step.*
f. *Exposure energy* (Assumed power density: 18 mW/cm^2)*:*
   i. ~150 mJ/cm^2 (**Karl Suss MA-4 Mask Aligner**)
   ii. The time will vary as the power density changes over time.
g. *Develop* **(Figure 3)***:*
   i. Fill a glass beaker with ***CD-26 developer***. Use enough developer to completely submerge the sample. Use constant and gentle agitation for 20-30 seconds.
   ii. Quench the development by immediately submerging the sample in a second glass beaker filled with deionized water.
   iii. Thoroughly rinse with deionized water gun for 60 seconds over the sink.
   iv. Use nitrogen gun to blow dry the sample (Do not allow water to evaporate from the sample. Rewet if necessary).
h. *Inspect and photograph under microscope* (**Carl Zeiss Optical**)*:*
   i. Make changes or redo process if necessary
i. *Perform step height analysis* (**Dektak 3030 Profilometer**)
j. *Plasma ash*
   i. 7 sccm O_2, 50 watts, 150 mT, 30 seconds (**Technics RIE 800**).

Figure 2 Substrate coated with 1.3 µm of S1813 positive photoresist.

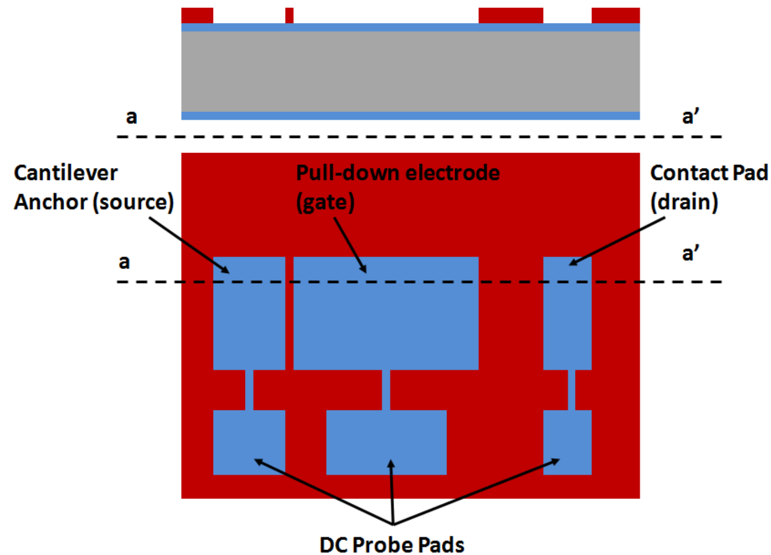


Figure 3 Photolithography step for patterning the bottom metal contacts.

4) **Liftoff (To pattern the bottom metal)**
   a. *DC Sputter Deposition* (**Lesker Sputterer**) *of metal* (**Figure 4**):
      i. Base pressure 1-3 E-6 T (2-3 hour pump down).
      ii. Enable substrate rotation.
      iii. Deposit 50 nanometers of ***chromium***, 300 W, 20 mT, Ar, rotation.
      iv. Deposit 200-300 nanometers of ***gold***, 300 W, 20 mT, Ar, rotation.

   b. *Water sonication* (**Figure 5**)*:*
      i. Soak sample for 5 minutes in a glass beaker filled with ***acetone*** placed in a water sonicator. Adjust this step as needed in order to make sure the liftoff is complete. Use enough ***acetone*** to completely submerge the sample. Transfer wet sample directly to glass beaker filled with ***acetone***.
      ii. Soak sample for 5 minutes in a second glass beaker filled with ***acetone*** placed in a water sonicator. Use enough ***acetone*** to completely submerge the sample.
      iii. Thoroughly rinse with deionized water gun for 30-60 seconds over the sink.
      iv. Use nitrogen gun to blow dry the sample (Do not allow water to evaporate from the sample. Rewet if necessary).
      v. Inspect under microscope (**Carl Zeiss Optical**). If liftoff is complete, proceed to the next step. Otherwise repeat the previous acetone steps until the liftoff is complete.
      vi. Soak sample for 5 minutes in a glass beaker filled with ***methanol*** placed in a water sonicator. Use enough ***methanol*** to completely submerge the sample. Transfer wet sample directly to the next ***methanol*** filled glass beaker.
      vii. Soak sample for 5 minutes in a second glass beaker filled with ***methanol*** placed in a water sonicator. Use enough ***methanol*** to completely submerge

the sample. Transfer wet sample directly to the next ***isopropyl alcohol*** filled glass beaker.

viii. Soak sample for 5 minutes in a glass beaker filled with ***isopropyl alcohol*** placed in a water sonicator. Use enough ***isopropyl alcohol*** to completely submerge the sample. Transfer wet sample directly to next ***isopropyl alcohol*** filled glass beaker.

ix. Soak sample for 5 minutes in a second glass beaker filled with ***isopropyl alcohol*** placed in a water sonicator. Use enough ***isopropyl alcohol*** to completely submerge the sample.

x. Thoroughly rinse sample for 60 seconds with deionized water gun over the sink.

xi. Nitrogen blow dry (Do not allow the water to evaporate from the sample. Rewet if necessary).

xii. Dehydration bake: 110 Celsius for 10 minutes on a hotplate (**Solitec Hotplate**) .

c. *Inspect and photograph under microscope* (**Carl Zeiss Optical**)

   i. This can be performed after the ***acetone*** step to make sure the metal has been thoroughly removed.

d. *Step height analysis* (**Dektak 3030 Profilometer**)

   i. Verify and record the thickness of the metal layer.

Figure 4 Substrate coated with 50 nm of chromium and 200-300 nm of gold using Lesker Sputter deposition.

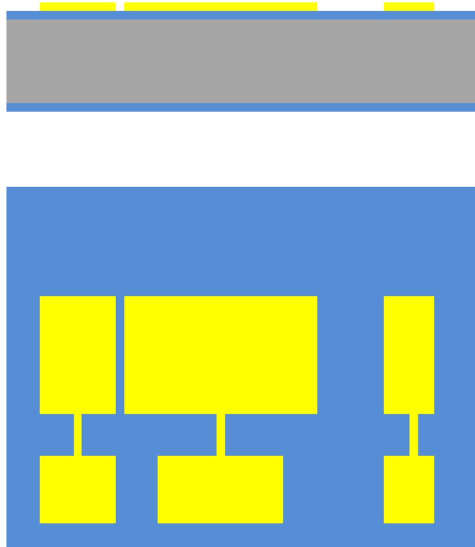


Figure 5 Final patterned bottom metal contacts after liftoff processing.

5) **2nd and 3rd Lithography (MEMS cantilever anchor points and contact dimple)**
   a. *Plasma RIE* (**Technics RIE 800**)*:*
      i. 2 sccm of oxygen, open argon line, 300 watts, 150-200 mT, for 60 seconds.
   b. *Spin coat* (**Solitec Spinner**) *S1813 positive photoresist* (**Figure 6**):
      i. **No HMDS!!!**
      ii. 4000 rpm ***S1813*** for 45 seconds
      iii. Thickness: ~1.3 micrometers
   c. *Remove the edge bead*
      i. This can be performed with a **razor blade**.
      ii. Use the vacuum of the spinner chuck to hold the sample in place.
      iii. Scrape the edge bead off of the sample.
   d. *Soft Bake:*
      i. 115 Celsius for 60 seconds on a hotplate **(Solitec Hotplate)**
   e. *Allow substrate to rest for 1 minute between the softbake step and the exposure step.*
   f. *Perform alignment for cantilever beam contact dimple lithography.*
   g. *Exposure energy* (Assumed power density: 18 mW/cm^2)*:*
      i. Shallow exposure for contact dimple
      ii. ~15 mJ/cm^2 (**Karl Suss MA-4 Mask Aligner**).
      iii. ~10 % of the exposure energy should only develop ~20 % of the photoresist yielding an approximate 230 nm contact dimple (Please see Jun-Bo Yoon, et al. *"Multilevel microstructure fabrication using single-step 3D photolithography and single-step electroplating"*, 364).
   h. *Inspect and photograph under microscope* (**Carl Zeiss Optical**)
      i. Make changes or redo if necessary.
   i. *Perform alignment for cantilever beam anchor point lithography.*
   j. *Exposure energy* (Assumed power density: 18 mW/cm^2)*:*
      i. Deep exposure for anchor.

ii. ~150 mJ/cm^2 (**Karl Suss MA-4 Mask Aligner**)

k. *Develop* (**Figure 7**)*:*

i. Fill a glass beaker with ***CD-26 developer***. Use enough developer to completely cover the sample. Submerge the sample and gently agitate for 20-30 seconds.

ii. Stop the development by immediately submerging the sample in a second glass beaker filled with deionized water.

iii. Rinse the sample gently and thoroughly for 60 seconds with deionized water gun over the sink.

ii. Use the nitrogen gun to blow dry the sample (Do not let water evaporate from sample. Rewet if necessary).

l. *Inspect and photograph under microscope* (**Carl Zeiss Optical**) *:*

i. Make changes or redo if necessary

m. *Step height analysis* (**Dektak 3030 Profilometer**)

n. ***No Plasma Ash!!!***

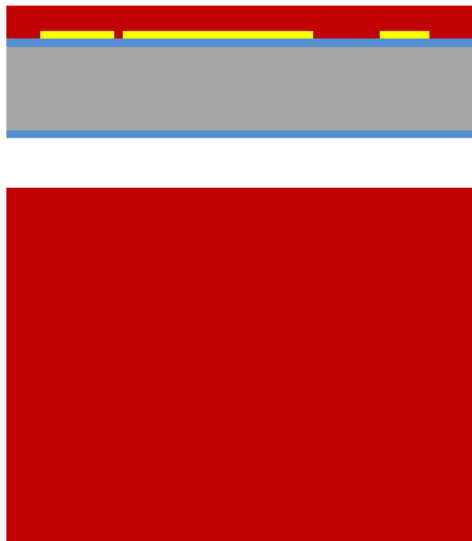


Figure 6 Substrate coated in photoresist.

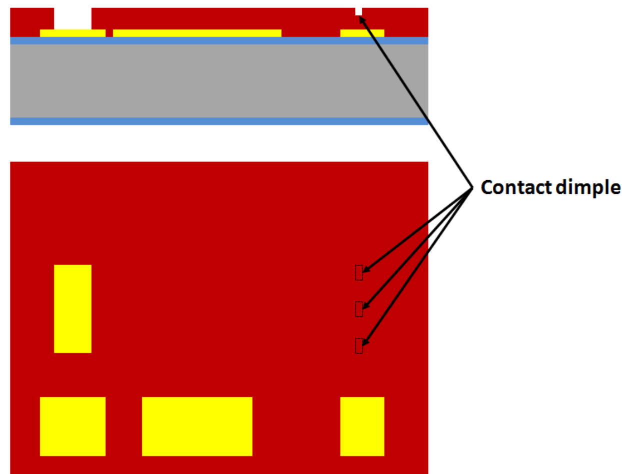


Figure 7 Photolithography for patterning the MEMS cantilever anchor and contact dimple.

6) **Metal seed layer (Electroplating seed layer)**
   a. *DC Sputter* (**Lesker Sputterer**) *deposition of metal* (**Figure 8**):
      i. Base pressure 1-3 E-6 T.
      ii. 20-30 nanometers of chromium, 300 W, 20 mT, Ar, rotation
      iii. 150 – 200 nanometers of gold, 300 W, 20 mT, Ar, rotation

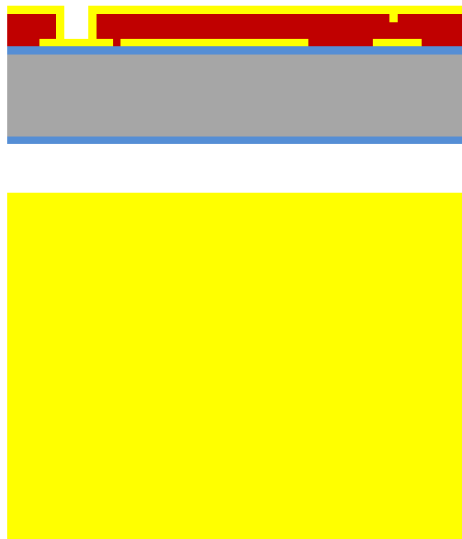


Figure 8 Sample coated in 20-30 nm of chromium and 150-200 nm of gold after DC sputter deposition.

7) **4th Lithography (Electroplating mold for creating MEMS Cantilever)**
   a. *Spin coat **S1827** positive photoresist* (**Figure 9**):
      i. **No HMDS!!!**
      ii. 2000 rpm ***S1827*** for 30 seconds
      iii. Thickness: ~4.1 micrometers
   b. *Remove the edge bead*
      i. This can be performed with a ***razor blade***.
      ii. Use the vacuum of the spinner chuck to hold the sample in place.

iii. Scrape the edge bead off of the sample.

c. *Soft Bake:*
   i. 105 Celsius for 4 minutes on a ***hotplate*** **(Solitec Hotplate)**

d. *Allow sample to rest for 1 minute between the softbake and exposure step.*

e. *Perform necessary alignment for the cantilever beam.*

f. *Exposure energy* (Assumed power density: 18 mW/cm^2)*:*
   i. ~378 mJ/cm^2 (**Karl Suss MA-4 Mask Aligner**)

g. *Develop* **(Figure 9)***:*
   i. Fill a glass beaker with ***CD-26 developer***. Use enough developer to cover the sample. Submerge the sample and gently agitate for 30-40 seconds.
   ii. Quench the development by immediately submerging the sample in a second glass beaker filled with deionized water.
   iii. Rinse the sample gently and thoroughly for 60 seconds with deionized water gun over the sink.
   iv. Use the nitrogen gun to blow dry the sample (Do not let water evaporate from sample. Rewet if necessary).

h. *Inspect and photograph under microscope* (**Carl Zeiss Optical**)*:*
   i. Make changes or redo if necessary

i. *Step height analysis* (**Dektak 3030 Profilometer**)

j. *The entire sample should have a layout similar to* **Figure 10.** *Where the devices to be plated will be the "active" region that is completely submerged in the plating solution. While the electrical connection region will be completely outside of the solution. The electrical connection region is where the metallic* ***binder clip*** *will have a direct ohmic connection with the sample. It is critical that the photoresist is completely developed from this area.*

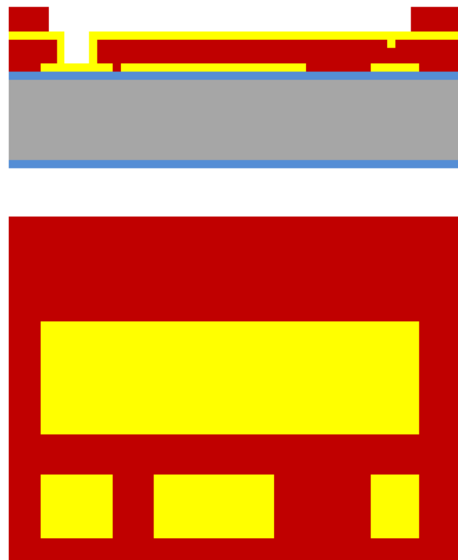


Figure 9 Photolithography to create electroplating mold.

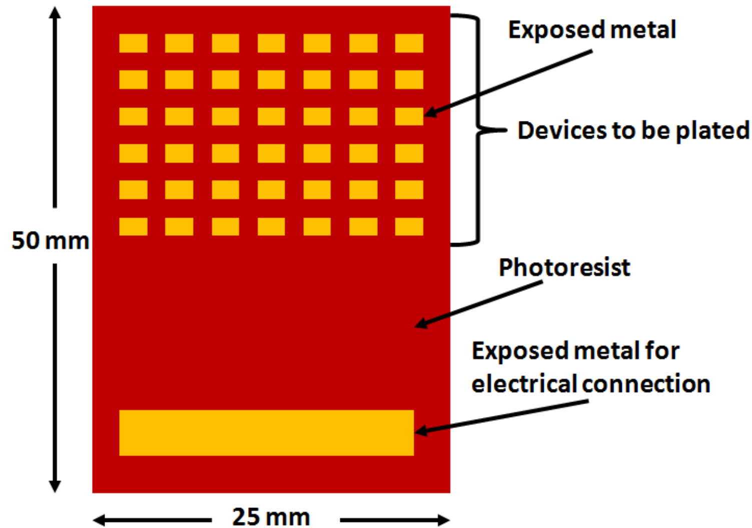


Figure 10 Example layout of sample to be electroplated.

8) **Gold Electroplating (Figure 10):**

a. *Plasma Ash*
   i. 7 sccm O_2, 50 watts, 150 mT, 10 seconds (**Technics RIE 800**).

b. *Use **Transene Sulfite Gold - TSG-250** (http://transene.com/tsg-250/)*
   i. Temperature: 60 Celsius
   ii. Current density: 2 amperes per square foot (ASF)
   iii. 6 – 7 pH
   iv. Anode: Stainless steel
   v. Agitation: None
   vi. Tank: 2 liter glass beaker
   vii. Deposition rate: ~100 nanometers/minute
   viii. Deposit to 4-5 μm thick

c. *Electroplating*
   i. When sputtering the seed layer, the sidewalls of the wafer also get coated. **Use *kapton tape* to isolate these regions from the solution.** Otherwise the deposition rate will decrease dramatically due to this unintentionally exposed area.
   ii. Attach the ***binder clip*** to the sample so that the sample hangs down from the ***binder clip***.
   iii. Attach the second ***binder clip*** to the ***stainless steel anode***.
   iv. Attach the third ***binder clip*** to the ***teflon coated thermocouple***.
   v. Hang the sample, the ***stainless steel anode***, and the ***teflon coated thermocouple*** from the ***teflon threaded rod***, with the surface to be plated facing the ***stainless steel anode***. Hang the two so they are approximately 1 inch apart, and parallel.
   vi. Immerse the cathode and anode in the plating solution. The top edge of the wafer and top edge of the ***stainless steel*** should poke out above the surface a little bit. **The binder clip and the open electrical contact area on your sample should never be submerged!!!** Otherwise the deposition rate will be greatly reduced.

vii. Attach the ***alligator clips*** of the ***power supply*** to the anode (***stainless steel sheet***) and cathode (MEMS sample). To reiterate, it is critical that there is a place for the ***binder clip*** to attach to the wafer that is not coated with photoresist! You need a good contact region to make an electrical connection to the seed layer. This should be designed in as part of your mask (**Figure 10**), otherwise you may need to try to use ***acetone*** on a swab to open up a little region at the edge of the wafer to make contact.
viii. **Make sure the electrical connection to the power supply is the right way around!!! Negative terminal (cathode): sample, Positive terminal (anode): stainless steel plate.**
ix. The completed set up should look similar to the picture below (**Figure 11**).
x. Decide what current you want to operate at. It is recommended that you operate at 2 $Amps/ft^2$ of plating current density at the cathode. This current density deposits approximately 100 nm/min. Ensure that your calculated area is as precise as possible. Also, ensure all metal regions that are **NOT** to be plated are either isolated by ***kapton tape*** or not submerged in the solution. **If the backside of your sample is bare silicon, this will get electroplated. Isolate the entire backside with *kapton tape*.**
xi. Set up the power supply.
xii. After the plating time is complete, turn off the power supply (**Figure 12**).

d. *Rinse sample thoroughly and gently for 60-90 seconds with deionized water gun over the sink.*
e. *Use nitrogen gun to blow dry the sample (Do not allow the water to evaporate from the surface. Rewet if necessary) .*
f. *Inspect and photograph under microscope* (**Carl Zeiss Optical**)
g. *Step height analysis* (**Dektak 3030 Profilometer**)

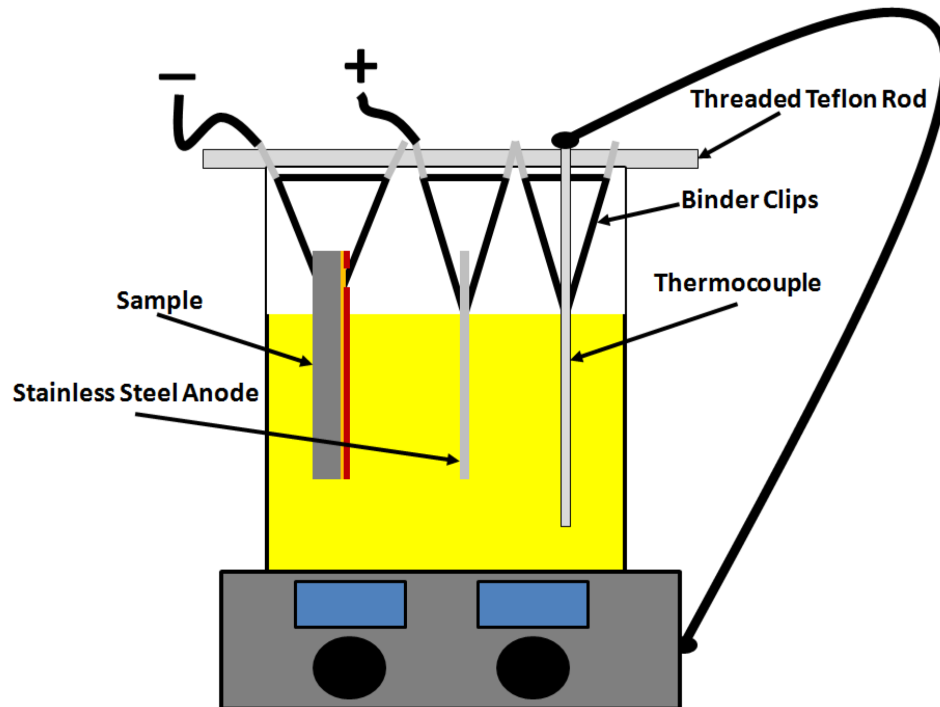


Figure 11 Complete electroplating setup with electrical connections and temperature feedback.

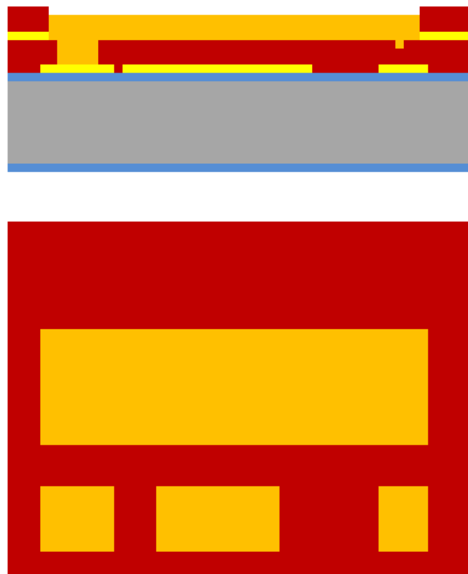


Figure 12 Electroplated MEMS cantilever and DC probe pads.

9) Strip Photoresist

a. *Strip photoresist* (Assumed power density: 18 mW/cm^2)*:*

i. Flood UV exposure at ~1200mJ/cm^2 (**Karl Suss MA-4 Mask Aligner**).

ii. Fill glass beaker with ***CD-26*** developer. Use enough to cover the sample. Submerge sample in ***CD-26*** developer until photoresist is completely removed (**Figure 13**).

iii. Rinse sample gently and thoroughly for 60 seconds with deionized water gun over the sink.
iv. Use nitrogen gun to blow dry the sample (Do not let water evaporate from sample. Rewet if necessary).
v. Inspect sample under microscope (**Carl Zeiss Optical**) and repeat cleaning steps if necessary.
vi. Step height analysis (**Dektak 3030 Profilometer**)

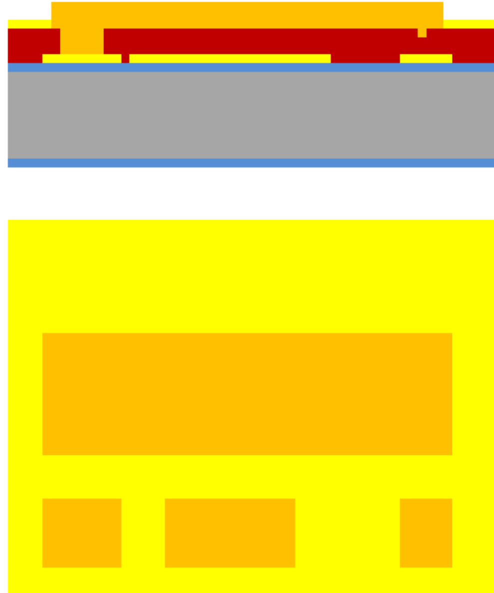


Figure 13 Stripping of photoresist electroplating mold.

10) Wet etch Cr/Au seed layer (Figure 14):

a. *Plasma RIE* (**Technics RIE 800**)*:*
   i. 2 sccm of oxygen, 7 sccm of argon, 300 watts, 150 mT, for 60 seconds
b. *Gold wet etch* (http://transene.com/au-etchant/)*:*
   i. Fill glass beaker with ***Transene Gold Etchant TFA***. Use enough solution to cover the sample. Submerge the sample and gently agitate for 30-40 seconds. Periodically stop and rinse the sample with deionized water over the sink every 10-15 seconds to observe the progress of the etch.
   ii. When desired etch time has elapsed, quench the etch by immediately submerging the sample in a second glass beaker filled with deionized water.
   iii. Rinse sample gently and thoroughly for 60 seconds with deionized water gun over sink.
   iv. Use nitrogen gun to blow dry the sample (Do not allow the water to evaporate from the surface. Rewet if necessary).
c. *Inspect etch under microscope* (**Carl Zeiss Optical**) *and, if necessary, repeat until all the gold is removed from the exposed areas.*
d. *Inspect under microscope and photograph gold wet etch* (**Carl Zeiss Optical**)
e. *Plasma RIE* (**Technics RIE 800**)*:*
   i. 2 sccm of oxygen, argon, 300 watts, 150 mT, for 60 seconds
f. *Chromium wet etch* (http://transene.com/cr/)*:*

i. Fill a glass beaker with ***Transene Chromium Etch 1020AC***. Use enough solution to cover the sample. Submerge and gently agitate the sample for 30-45 seconds.
ii. When desired etch time has elapsed, quench the etch by immediately submerging the sample in a second glass beaker filled with deionized water
iii. Rinse sample gently and thoroughly for 60 seconds with deionized water gun over sink.
iv. Use nitrogen gun to blow dry the sample (Do not allow the water to evaporate from the surface. Rewet if necessary.).
v. Inspect etch and, if necessary, repeat until all the chromium is removed from the exposed areas. Reduce the etch time in order to avoid significant undercutting.

g. Inspect sample under microscope and photograph chromium wet etch (**Carl Zeiss Optical**)

h. *Perform step height analysis* **(Dektak 3030 Profilometer)**
i. As a general rule of thumb: electroplated gold etches approximately 4 times faster than sputtered gold. Please plan accordingly.

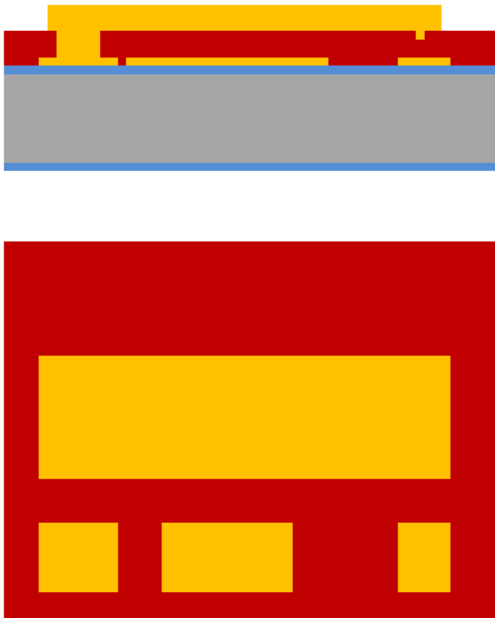


Figure 14 Wet etch of metal seed layer.

11) Sample Dicing (if necessary)

a. *Coat a protective layer of **S1813** on the sample.*
b. *Perform the standard softbake process step.*
c. *Perform standard dicing steps.*

12) Release MEMS Cantilever

a. Strip photoresist and clean sample (**Figure 15**)*:*
i. Preheat ***PRS-3000*** positive photoresist stripper in a deep glass evaporation dish on a hotplate for 1 hour at 110 Celsius. Use an evaporation dish that

is deep enough to allow you to submerge the samples 2 inches below the ***PRS-3000*** level.

ii. Submerge sample in heated ***PRS-3000*** positive photoresist stripper at 110 Celsius for 2 hours.
iii. Remove evaporation dish from the hotplate and allow it to reach room temperature (~ 1 hour).
iv. Directly transfer the sample from the ***PRS-3000*** to the first deionized water Petri dish. **It is critical that the sample remains wet during the transfer process.** Allow it to soak for 20 minutes.
v. Directly transfer the sample from the first deionized water Petri dish to the second deionized water Petri dish. **It is critical that the sample remains wet during the transfer process.** Allow it to soak for 20 minutes.
vi. Directly transfer the sample from the second deionized water Petri dish to the first ***acetone*** Petri dish. **It is critical that the sample remains wet during the transfer process.** Allow it to soak for 20 minutes.
vii. Directly transfer the sample from the first ***acetone*** Petri dish to the second ***acetone*** Petri dish. **It is critical that the sample remains wet during the transfer process.** Allow it to soak for at least **8 hours. Preferably overnight.**
viii. Directly transfer the sample from the second ***acetone*** Petri dish to the first ***methanol*** Petri dish. **It is critical that the sample remains wet during the transfer process.** Allow it to soak for 20 minutes.
ix. Directly transfer the sample from the first ***methanol*** Petri dish to the second ***methanol*** Petri dish. **It is critical that the sample remains wet during the transfer process.** Allow it to soak for 20 minutes.
x. Directly transfer the sample from the second ***methanol*** Petri dish to the first ***isopropyl alcohol*** Petri dish. **It is critical that the sample remains wet during the transfer process.** Allow it to soak for 20 minutes
xi. Directly transfer the sample from the first ***isopropyl alcohol*** Petri dish to the second ***isopropyl alcohol*** Petri dish. **It is critical that the sample remains wet during the transfer process.** Allow it to soak for 20 minutes.

b. Critical Point Drying (**Tousimis Critical Point Dryer**)

i. Directly transfer the sample from the second ***isopropyl alcohol*** Petri dish to the CPD chamber. **It is critical that the sample remains wet during the transfer process.**
ii. Operate the CPD as per the instruction manual.

Figure 15 Final released structure.

Electrical Characterization

Table 1 Equipment needed for electrical characterization.

Equipment	Purpose
DC Probe Station	View devices at high magnification
Probe tip manipulators	Precise positioning of the probe tips
Tungsten probe tips	Apply the biasing voltage
Power supply	Provide test current through the switch
Discrete resistors	Used to ascertain switch contact resistance
Ammeter	Measure current through switch path
Oscilloscope	Measure switching time and lifetime
BNC Cables	To connect sources, meters and devices together
Function generator	Provide switching time and lifetime waveform
Linear Amplifier	To actuation voltage

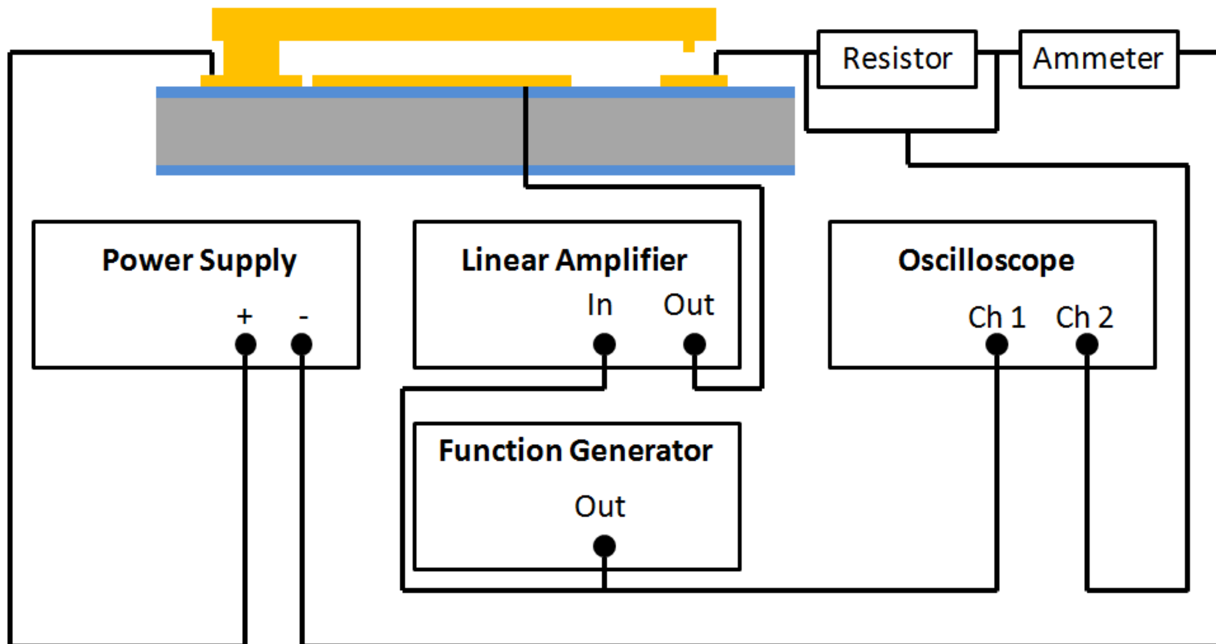


Figure 16 Schematic of electrical characterization setup.