Supplementary information for

Autoperforation of Two-Dimensional Materials to Generate Colloidal State Machines Capable of Locomotion

Albert Tianxiang Liu[1]†, Jing Fan Yang[1]†, Lexy N. LeMar[1], Ge Zhang[1], Ana Pervan[2], Todd D. Murphey[2], Michael S. Strano[1]*

† These authors contributed equally.

* Corresponding Author Email: strano@mit.edu

[1] Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139

[2] Department of Mechanical Engineering, Northwestern University, Evanston, IL 60208

1. Profilometer measurements for PMMA wells
2. Profilometer measurements for CMC on SiO_2
3. Tabulated data for PMMA well dimensions
4. Platinum deposition time series for various conditions

Experimental Details

We grew monolayer graphene on Cu substrates with the following protocol. Hydrogen, methane, and argon canisters feed into a quartz mixing tube inside a CVD furnace. CVD growth of graphene is carried out by heating copper foil to 1000° C with a constant 30 sccm flow of hydrogen. The temperature is held constant at 1000° C for 20 min. Methane is injected into the mixing tube at a constant flowrate of 0.5 sccm for 15 min. The sample is then bathed in hydrogen for 5 min before the furnace is turned off and allowed to cool to room temperature. The sample is then bathed in argon and allowed to return to standard pressure.

The as-prepared graphene/Cu substrate is used directly for the subsequent inversion-moulding step. A carboxymethyl cellulose ink was prepared by dissolving 285 mg sodium carboxymethyl cellulose (Sigma-Aldrich, average Mw ~90000) in 100 mL deionized water. A commercial Fujifilm Dimatix Materials Printer DMP-2850 was used to print a 6 × 20 array of CMC disks of

radius 20 µm with 100 µm spacing onto graphene. 2% PMMA (MicroChem) was spun onto the sample at a typical spin-rate of 4000 rpm for 1 min. The sample was then etched in water for approximately 18 h. 1 cm^2 of the sample was electroplated in a 3 mM $PtCl_4$ solution with a Pt counter electrode and a constant 0.1 A current. Graphene is conductive which allows for the Pt to deposit only on the array of exposed graphene wells.

For the subsequent autoperforation process, a layer of 7% PMMA was spin-coated onto the sample at a spin-rate of 500 rpm for 10 min then 4000 rpm for 2 min. The sample was floated on APS-100 Cu etchant for approximately 2 h or until the Cu was completely etched away. The sample was then flipped onto a SiO_2 wafer resulting in a PMMA-Pt-graphene vertical stack. The sample was annealed for 10 min at 125° C. A dyed PS-EG ink was prepared by mixing 2 mL polystyrene and 2 mL ethylene glycol (both from Sigma-Aldrich), and dissolving approximately 2 mg Rhodamine B in the mixture. DMP-285 printer was used to print a 6 × 20 array of PS-EG aligned to the prefabricated array of Pt patches. The printed sample was annealed for 10 min at 125° C. A separate sample of graphene was transferred by spin-coating 4% PMMA onto the graphene-copper for 1 min at 4000 rpm. The sample was then placed in APS-100 for approximately 2 h or until the copper was completely etched away. The PMMA-Pt-graphene-PS-EG vertical stack was capped with this second layer of graphene-PMMA and annealed for 10 min at 125° C. The complete vertical stack is PMMA-graphene-PS-EG-graphene-Pt-PMMA. The sample was lifted-off in 10 mL of 80% ethanol heated from room temperature using a hot plate set to 120° C with magnetic stirring. After 10 min, the lifted-off cells were centrifuged and rinsed with 12-13 mL of deionized water three times.

1. *Profilometer measurements for PMMA wells*

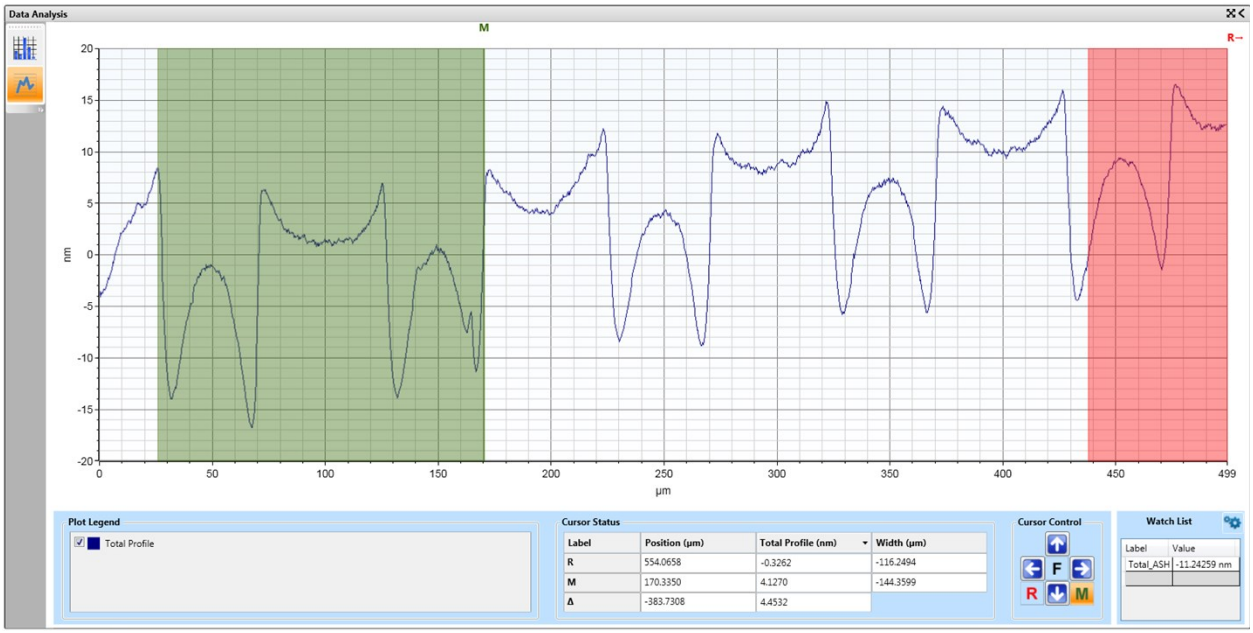

Figure S1: Linear profile 1 for PMMA wells fabricated from 2 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

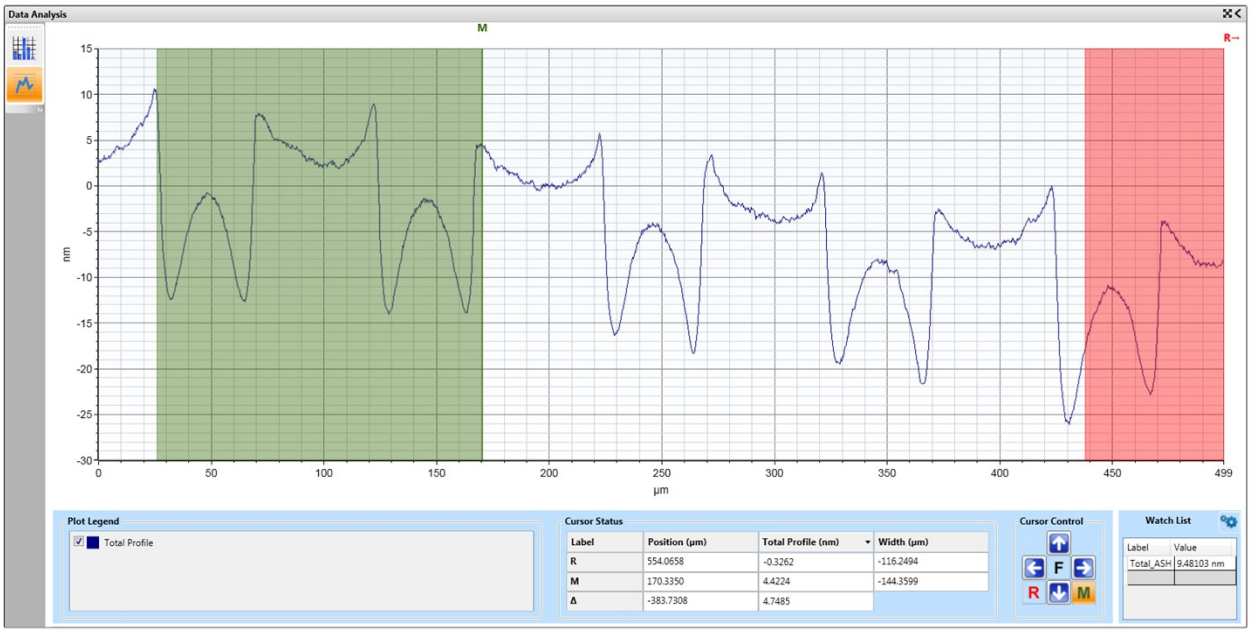

Figure S2: Linear profile 2 for PMMA wells fabricated from 2 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

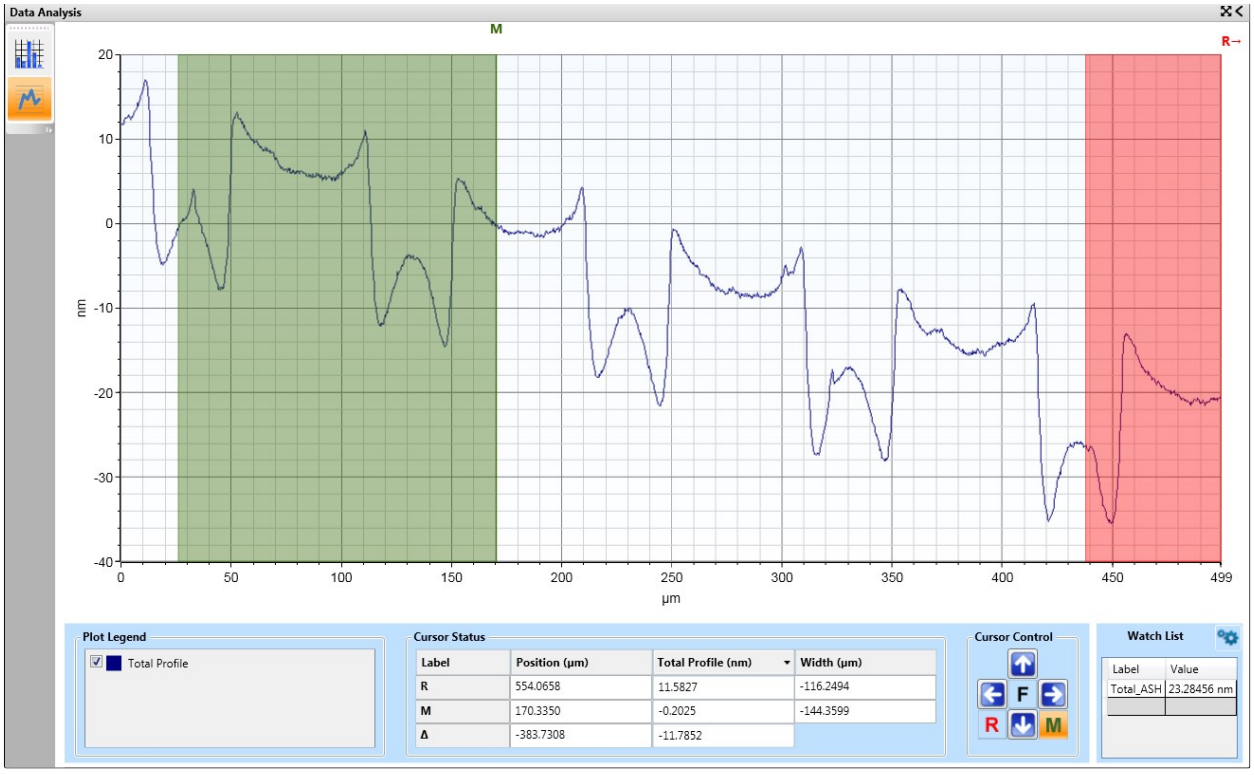

Figure S3: Linear profile 3 for PMMA wells fabricated from 2 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

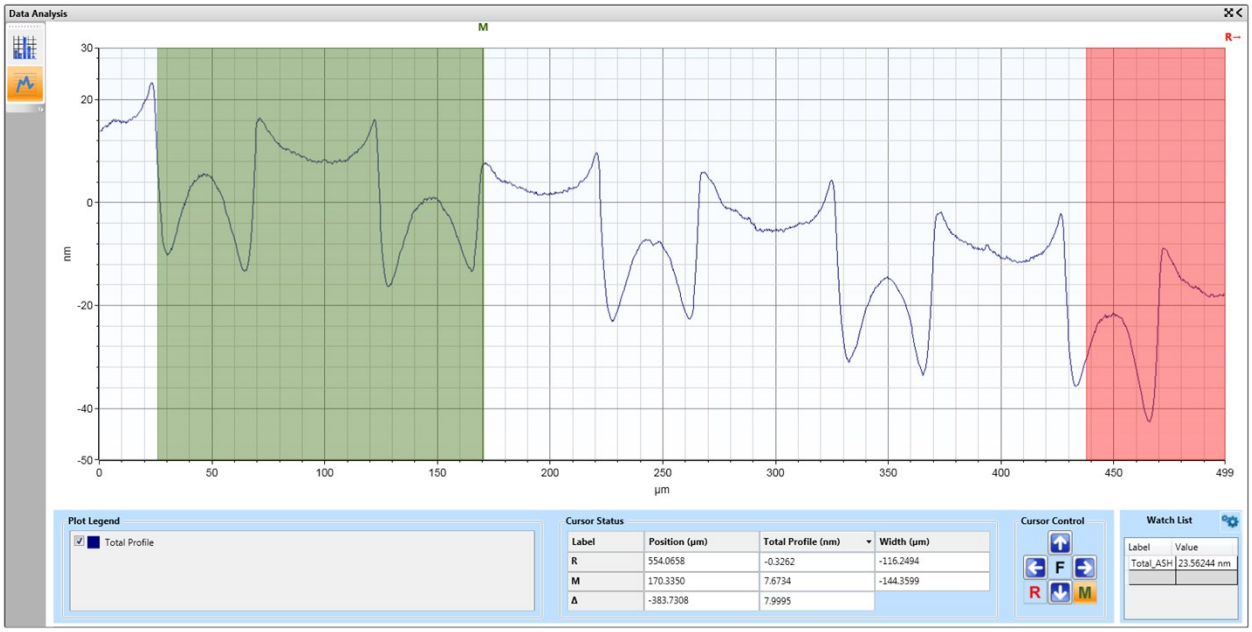

Figure S4: Linear profile 1 for PMMA wells fabricated from 3 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

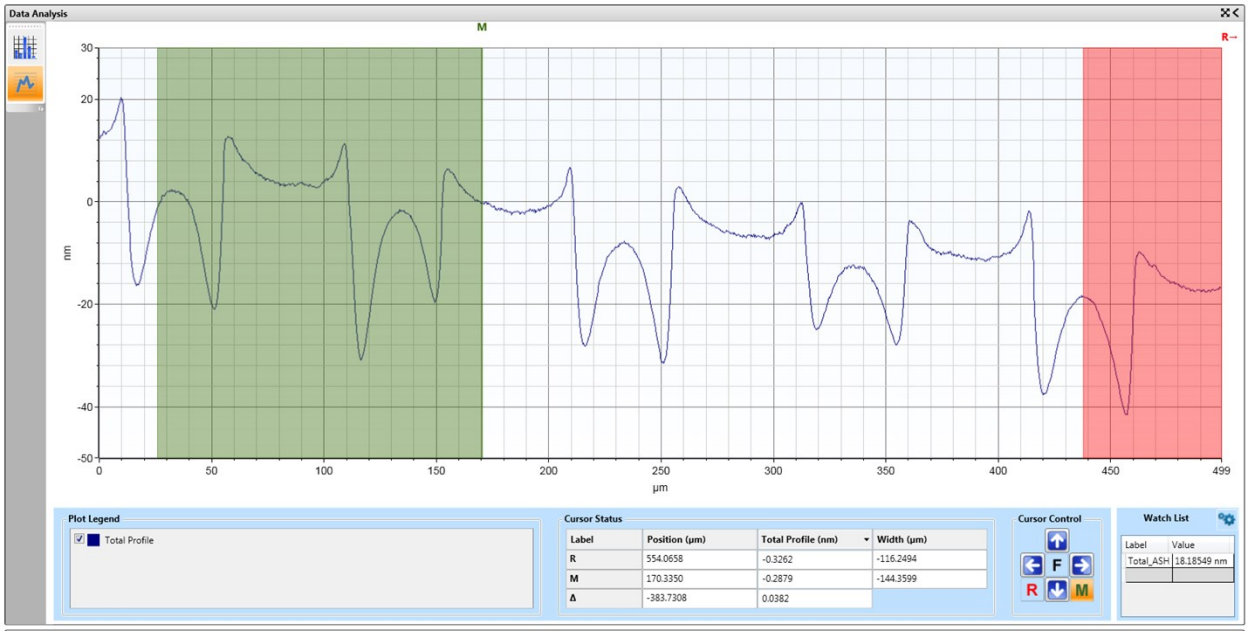

Figure S5: Linear profile 2 for PMMA wells fabricated from 3 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

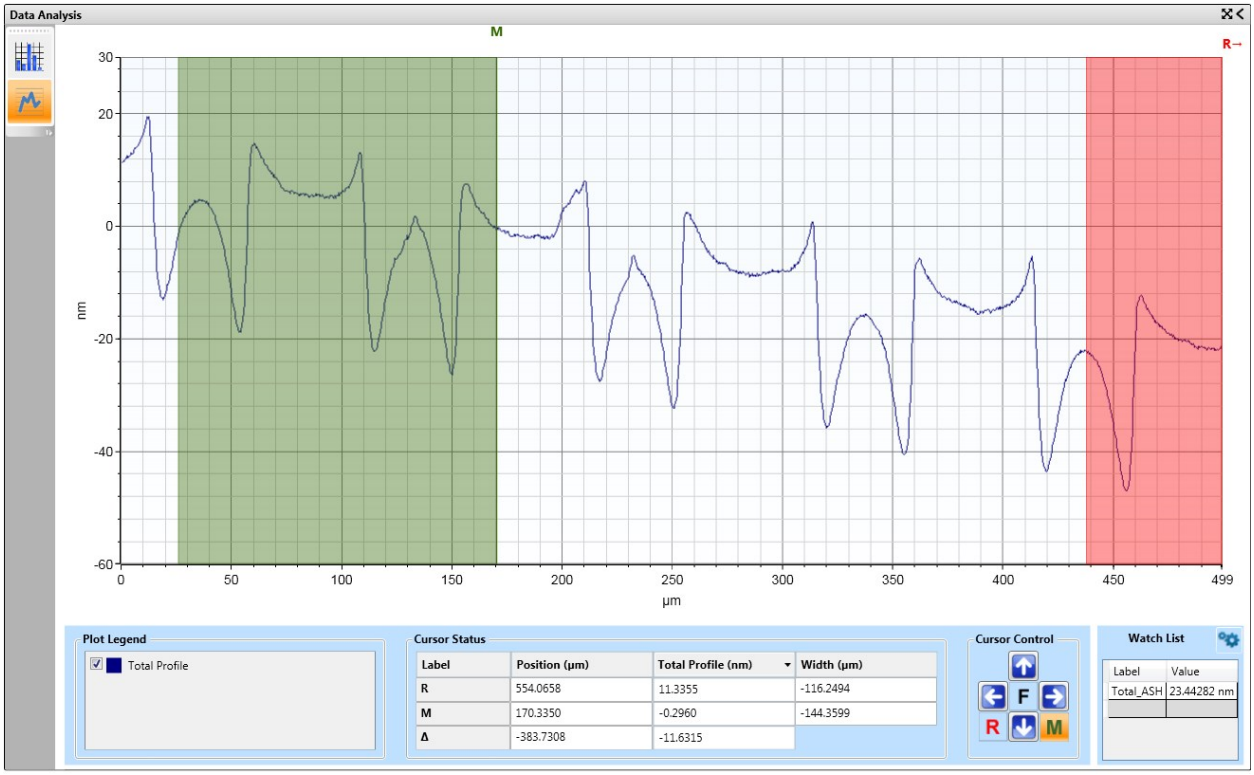

Figure S6: Linear profile 3 for PMMA wells fabricated from 3 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

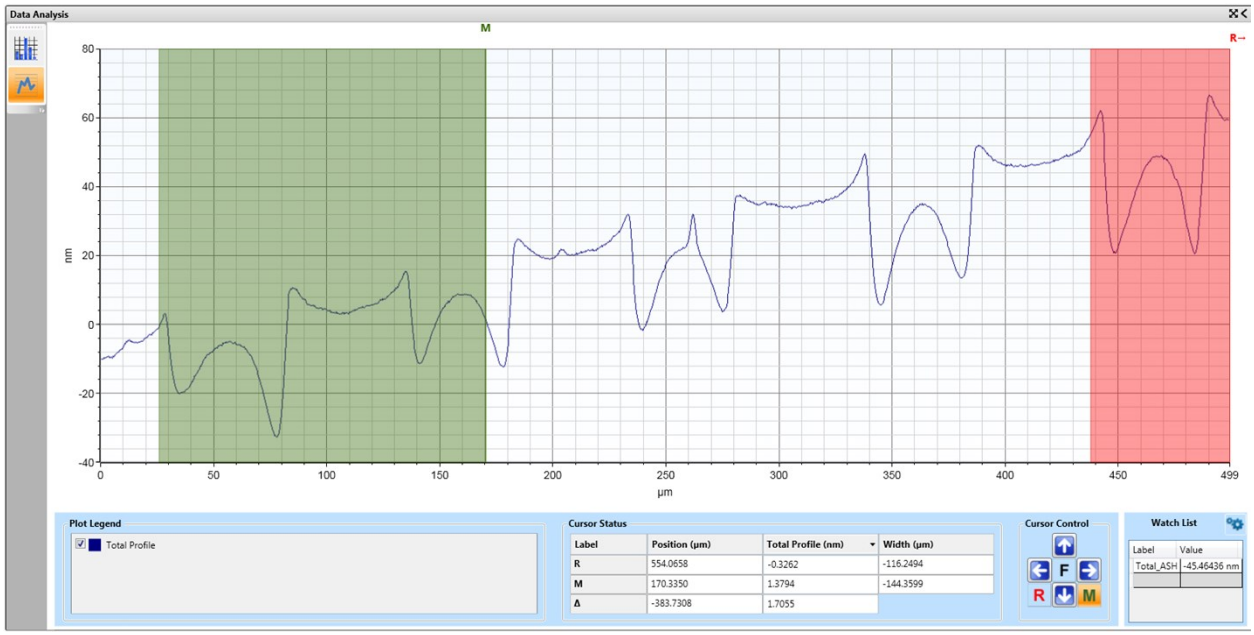

Figure S7: Linear profile 1 for PMMA wells fabricated from 4 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

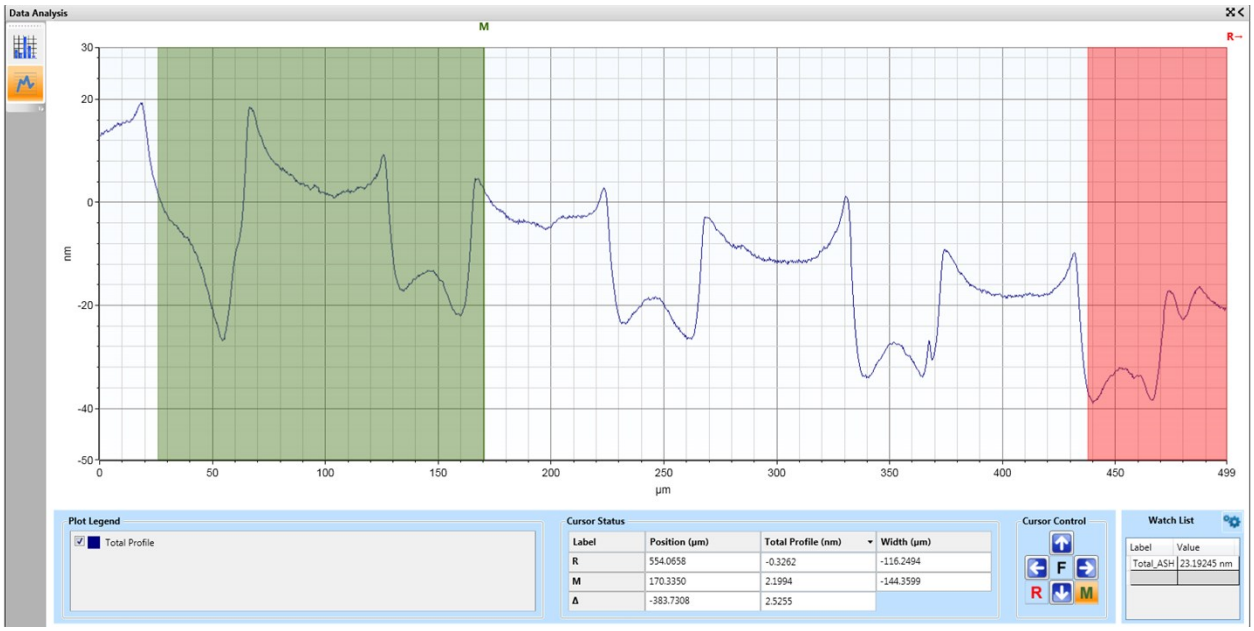

Figure S8: Linear profile 2 for PMMA wells fabricated from 4 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

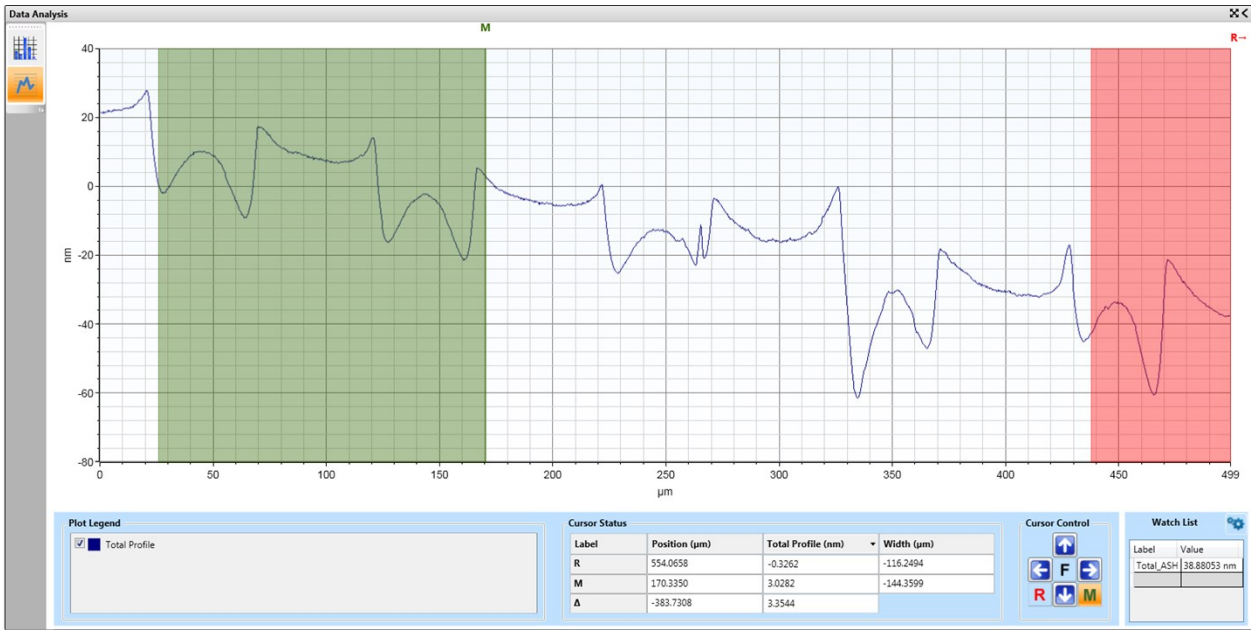

Figure S9: Linear profile 3 for PMMA wells fabricated from 4 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

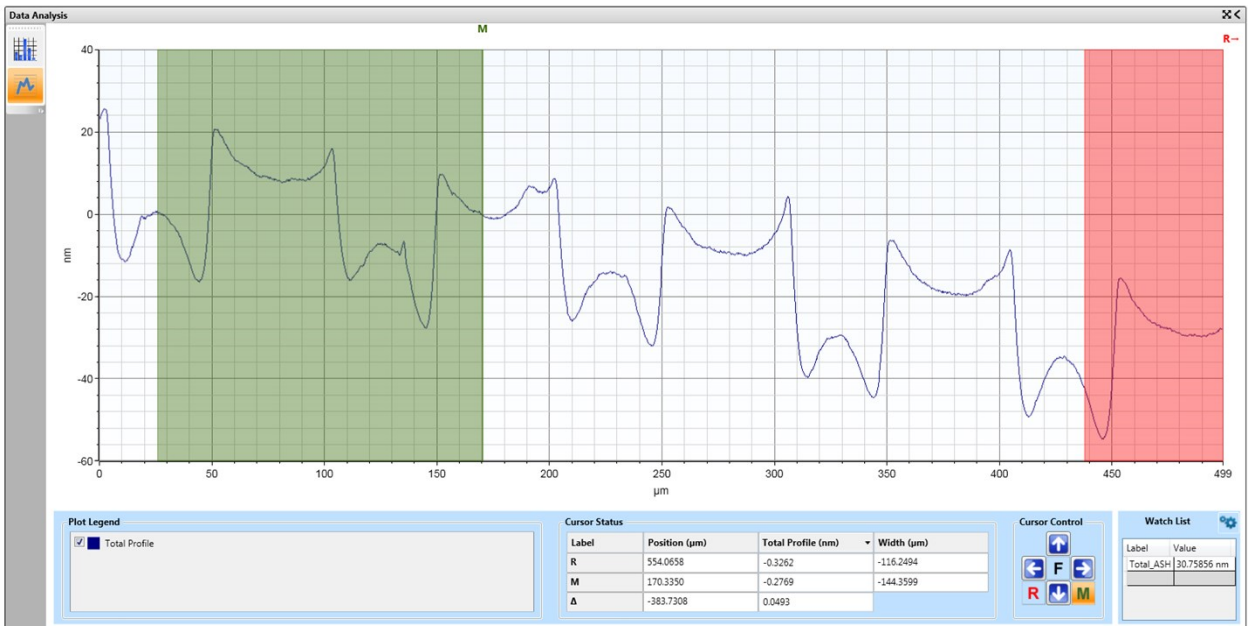

Figure S10: Linear profile 1 for PMMA wells fabricated from 5 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

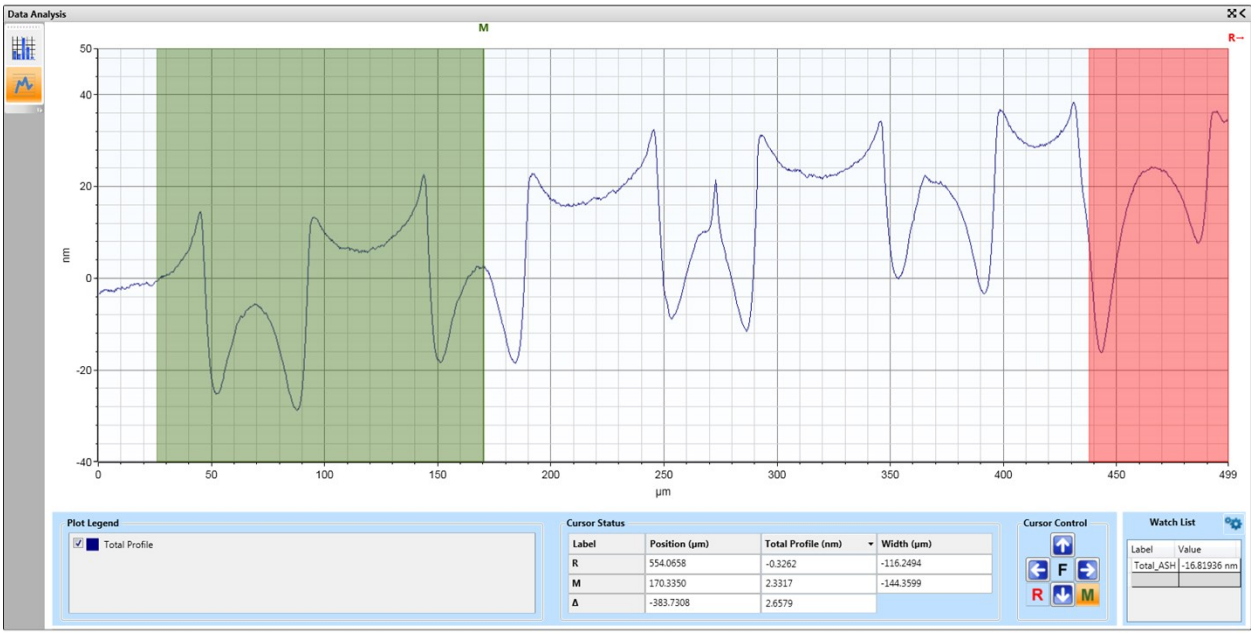

Figure S11: Linear profile 2 for PMMA wells fabricated from 5 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

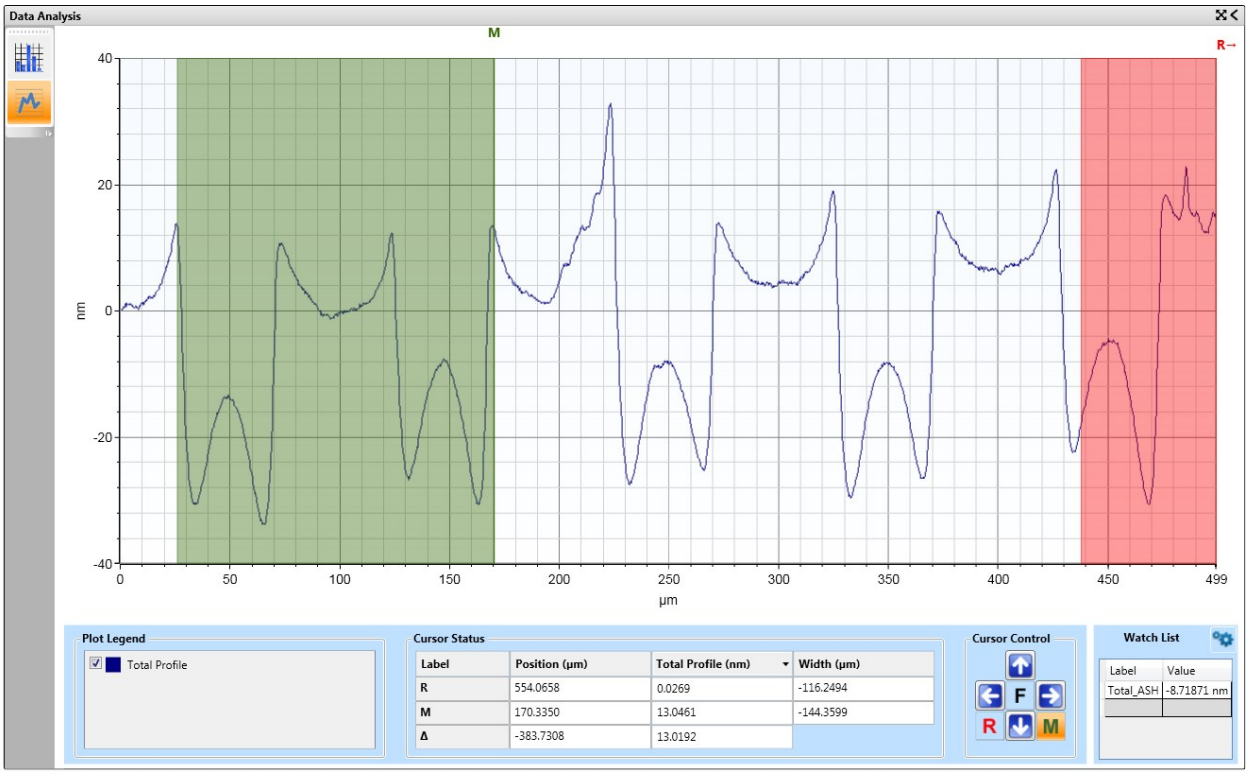

Figure S12: Linear profile 3 for PMMA wells fabricated from 5 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

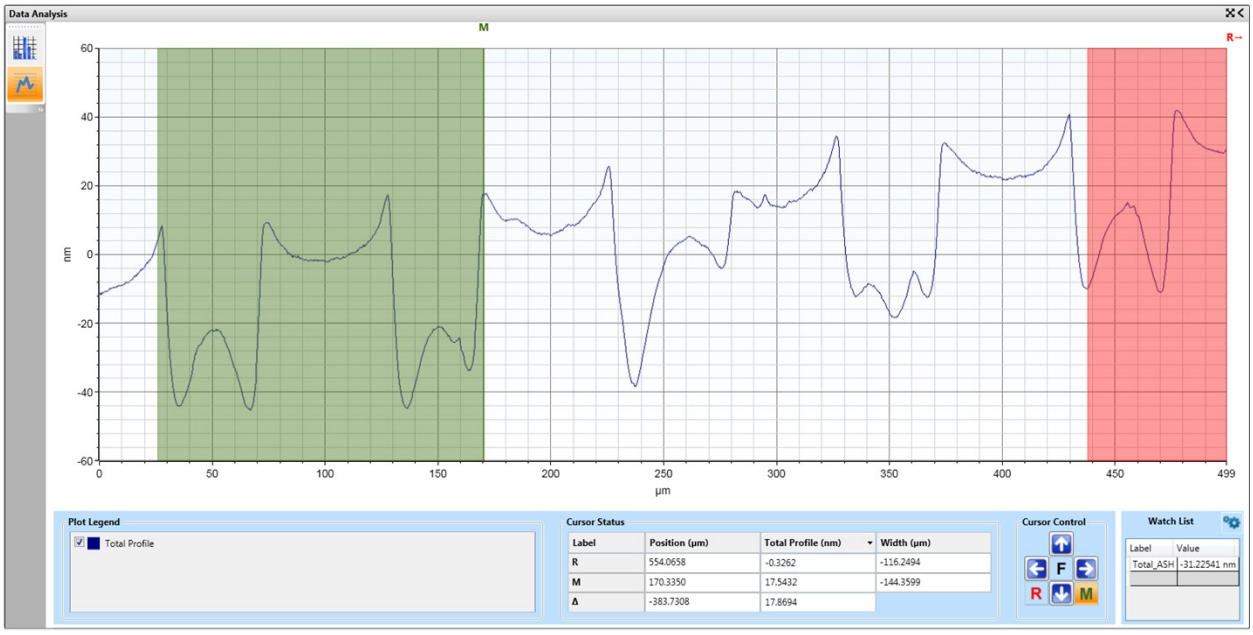

Figure S13: Linear profile 1 for PMMA wells fabricated from 6 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

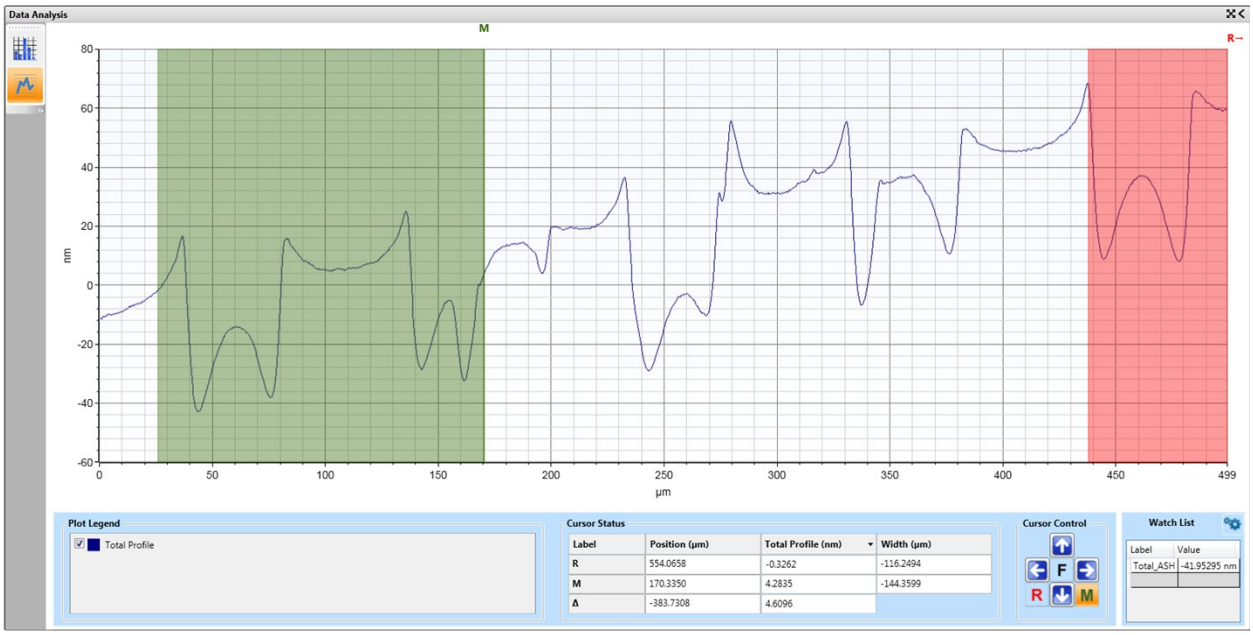

Figure S14: Linear profile 2 for PMMA wells fabricated from 6 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

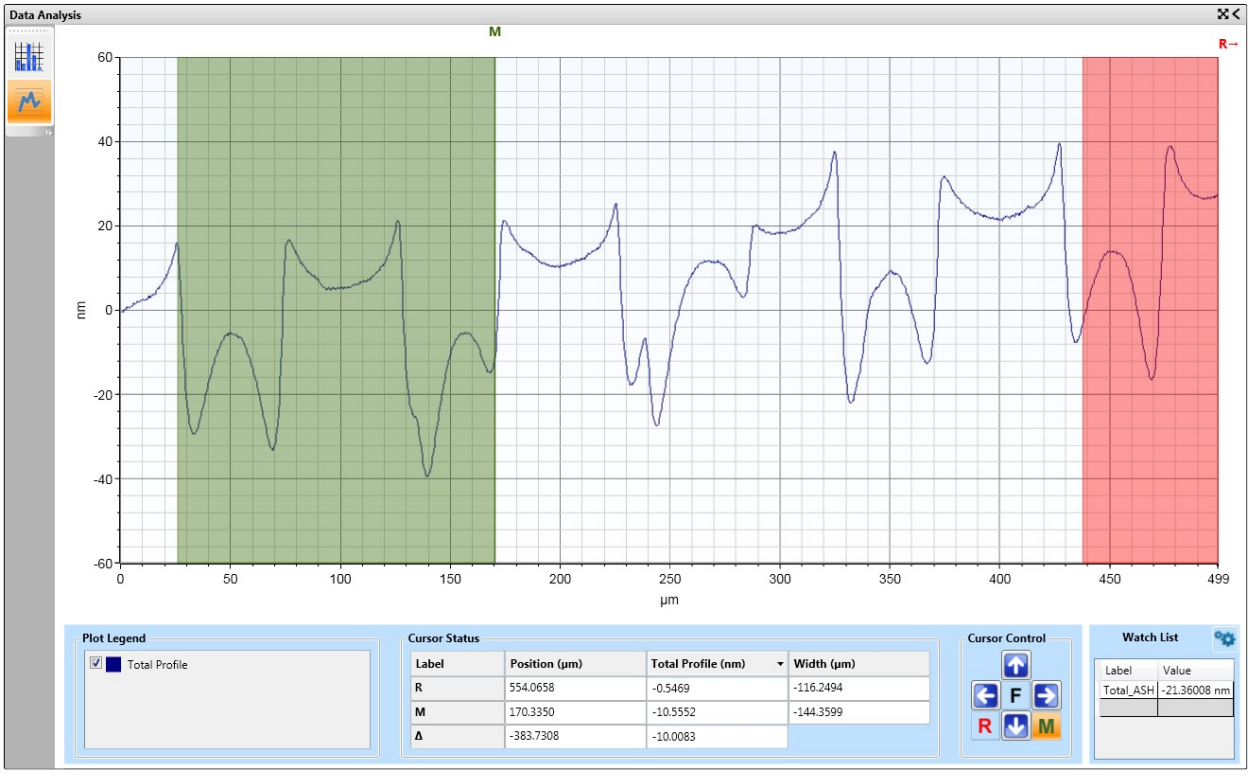

Figure S15: Linear profile 3 for PMMA wells fabricated from 6 layers of CMC and 2% PMMA spin-coated for 1 min at 1000 rpm.

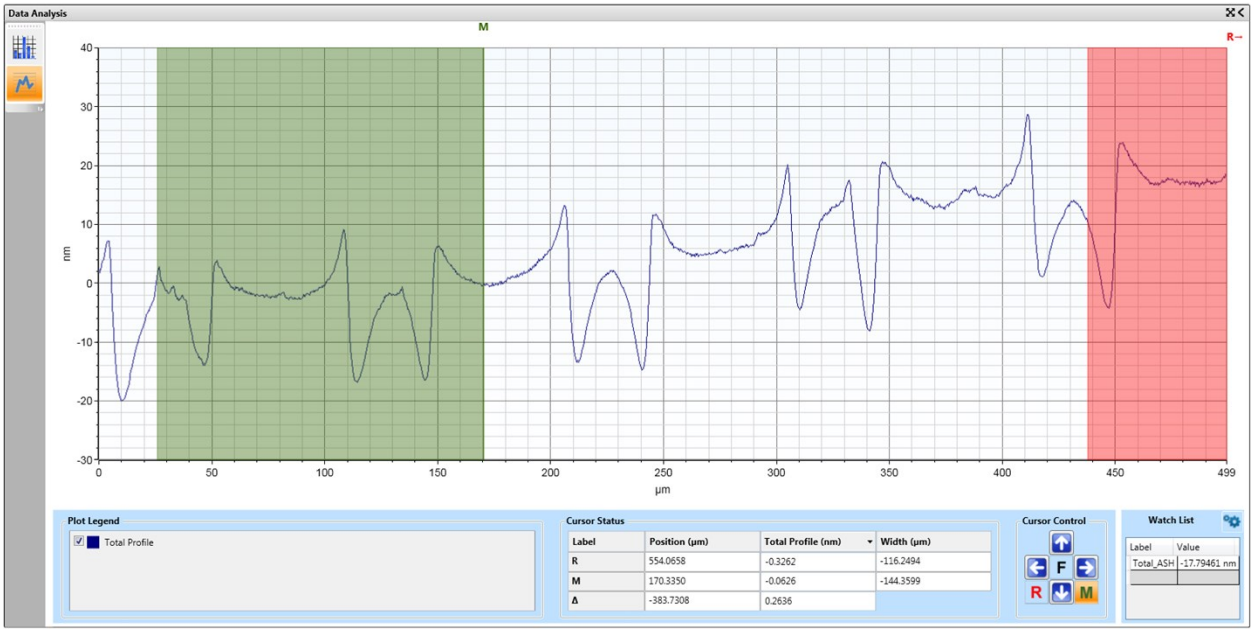

Figure S16: Linear profile 1 for PMMA wells fabricated from 2 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

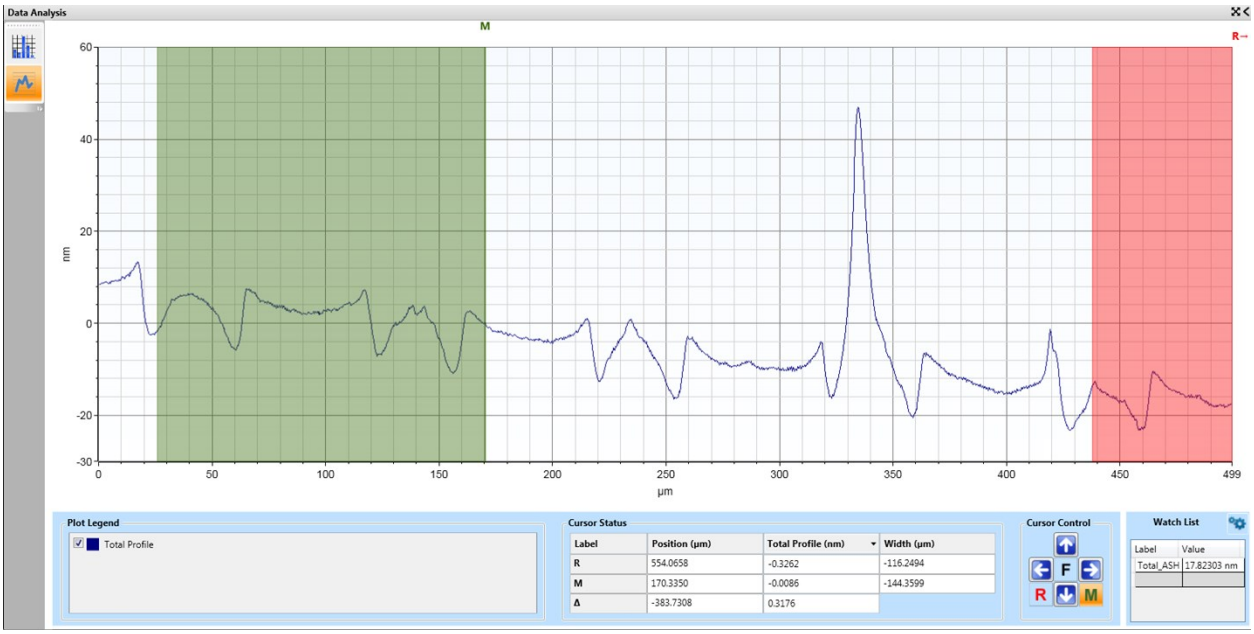

Figure S17: Linear profile 2 for PMMA wells fabricated from 2 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

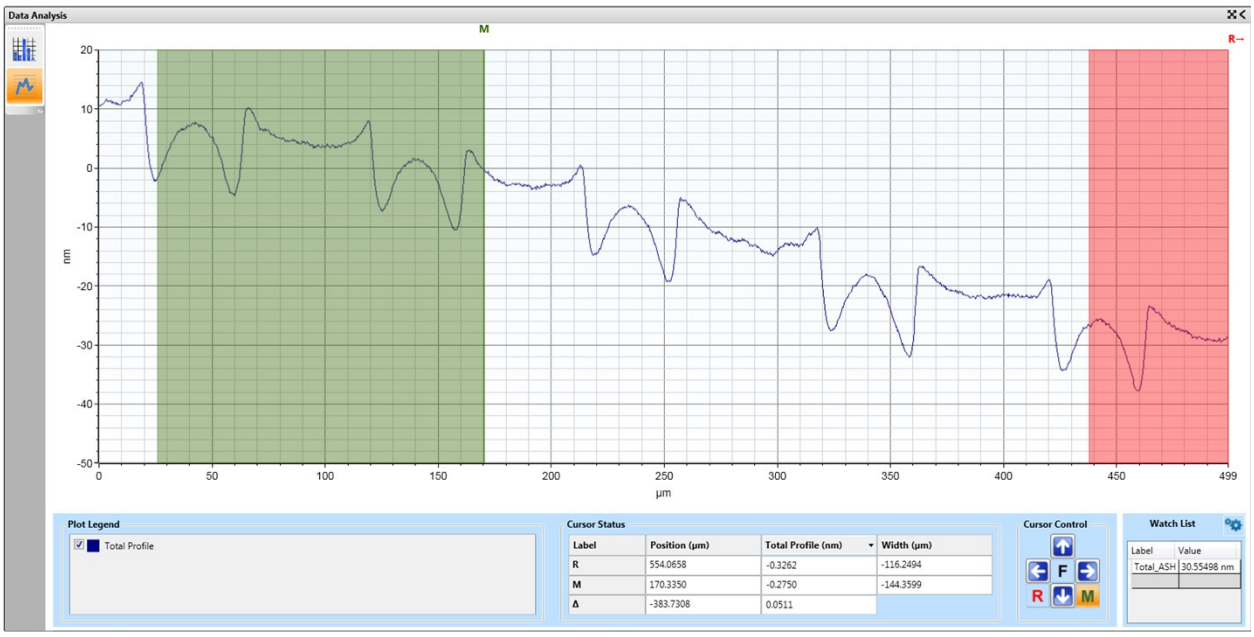

Figure S18: Linear profile 3 for PMMA wells fabricated from 2 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

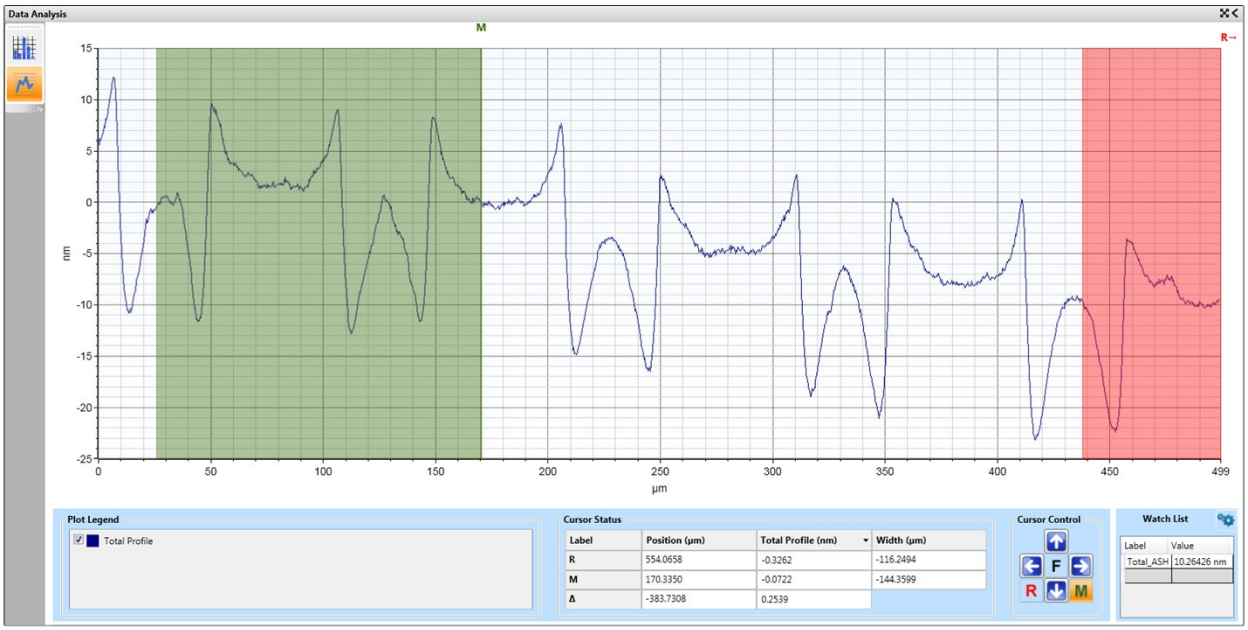

Figure S19: Linear profile 1 for PMMA wells fabricated from 3 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

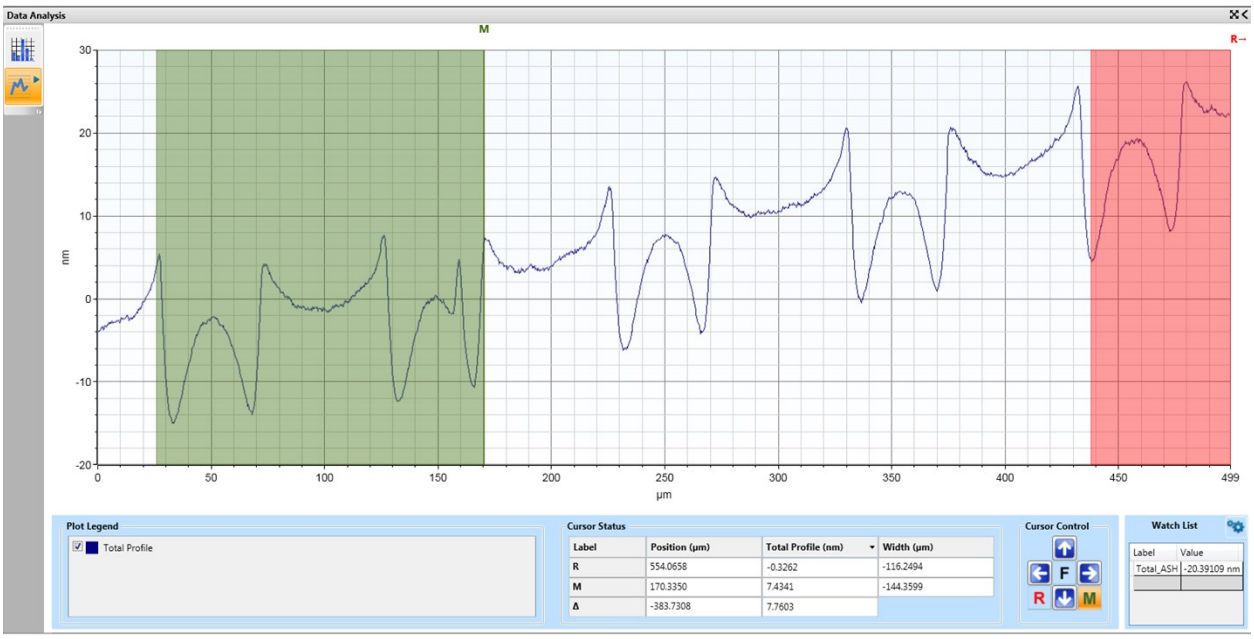

Figure S20: Linear profile 2 for PMMA wells fabricated from 3 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

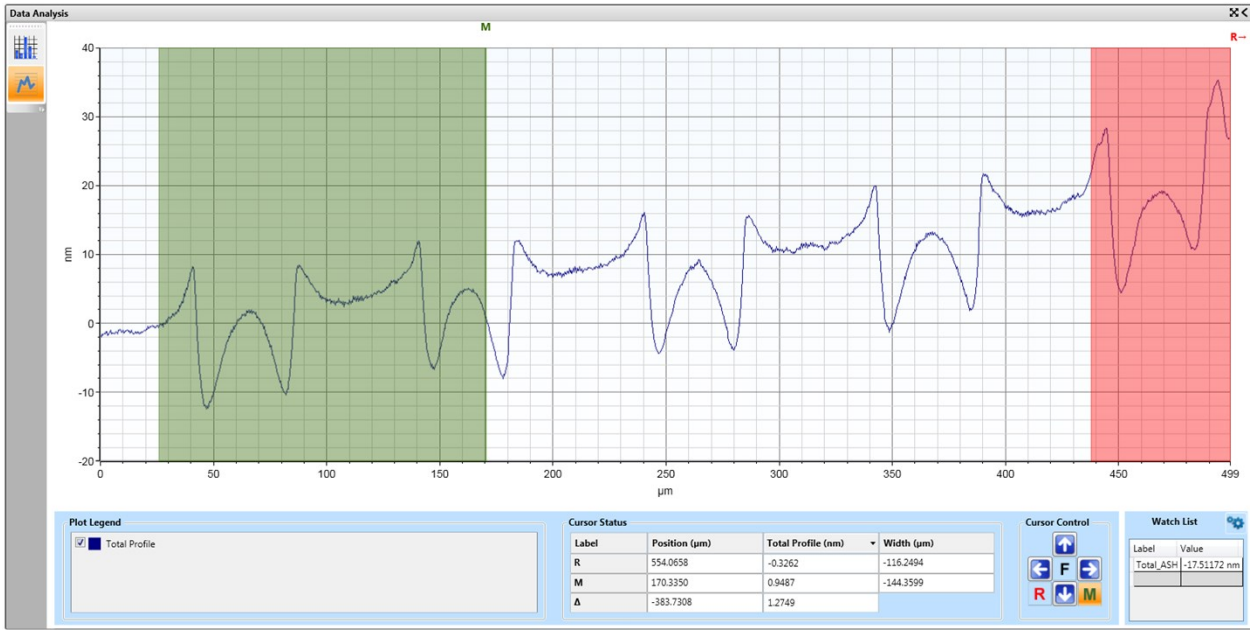

Figure S21: Linear profile 3 for PMMA wells fabricated from 3 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

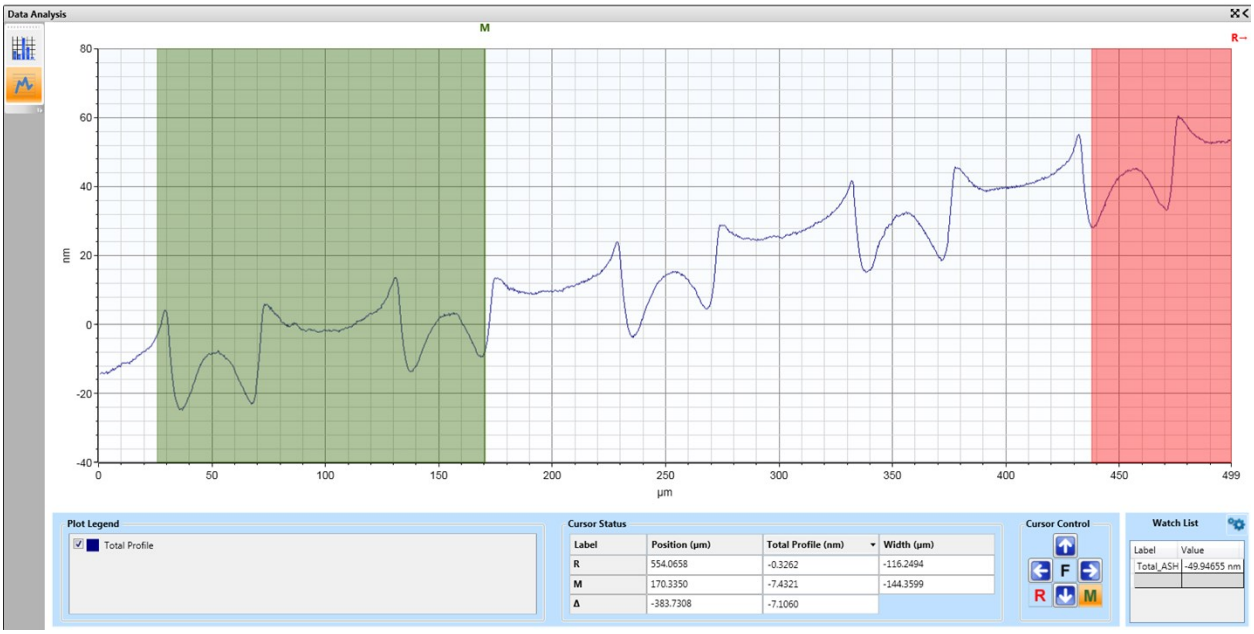

Figure S22: Linear profile 1 for PMMA wells fabricated from 4 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

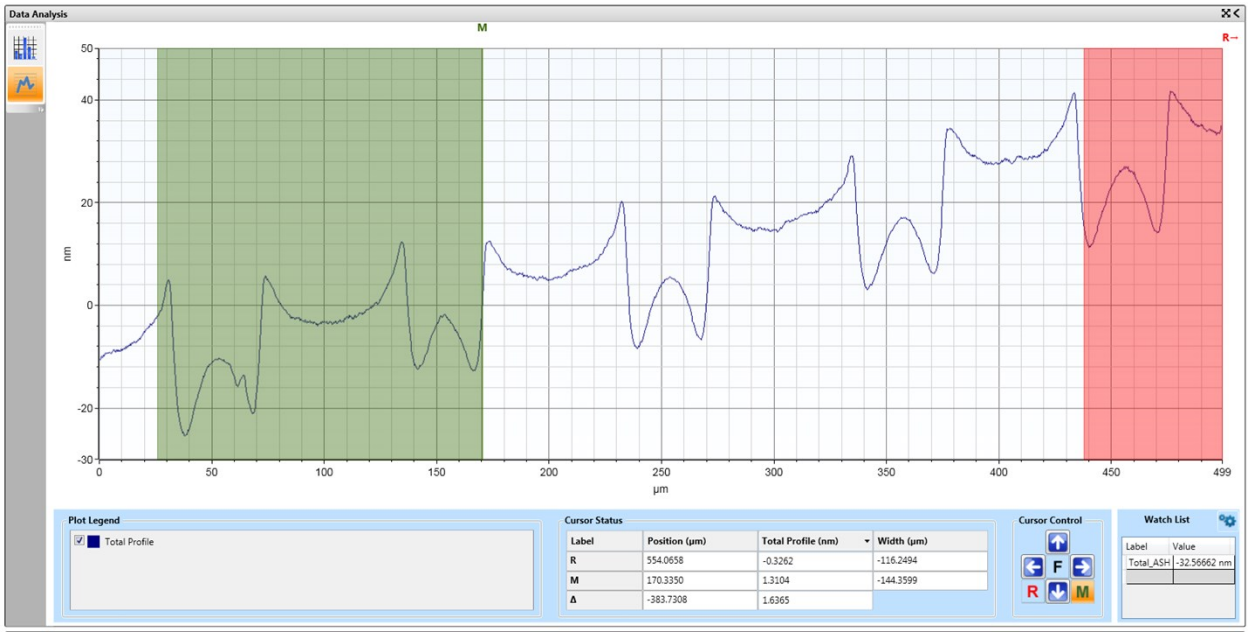

Figure S23: Linear profile 2 for PMMA wells fabricated from 4 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

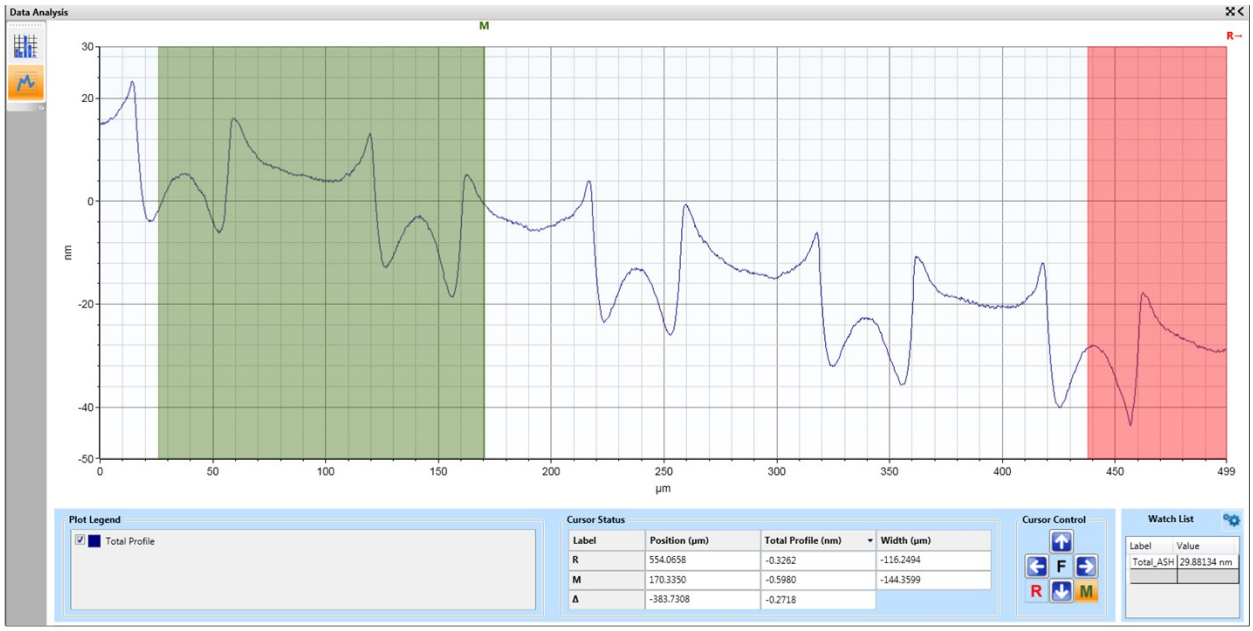

Figure S24: Linear profile 3 for PMMA wells fabricated from 4 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

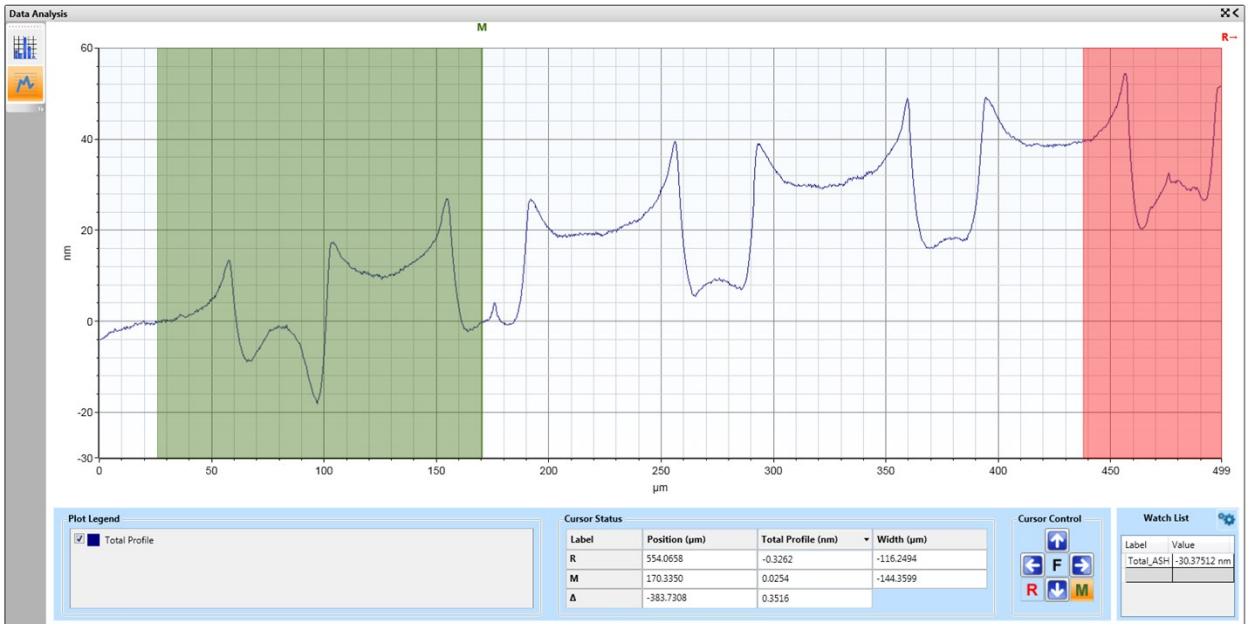

Figure S25: Linear profile 1 for PMMA wells fabricated from 5 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

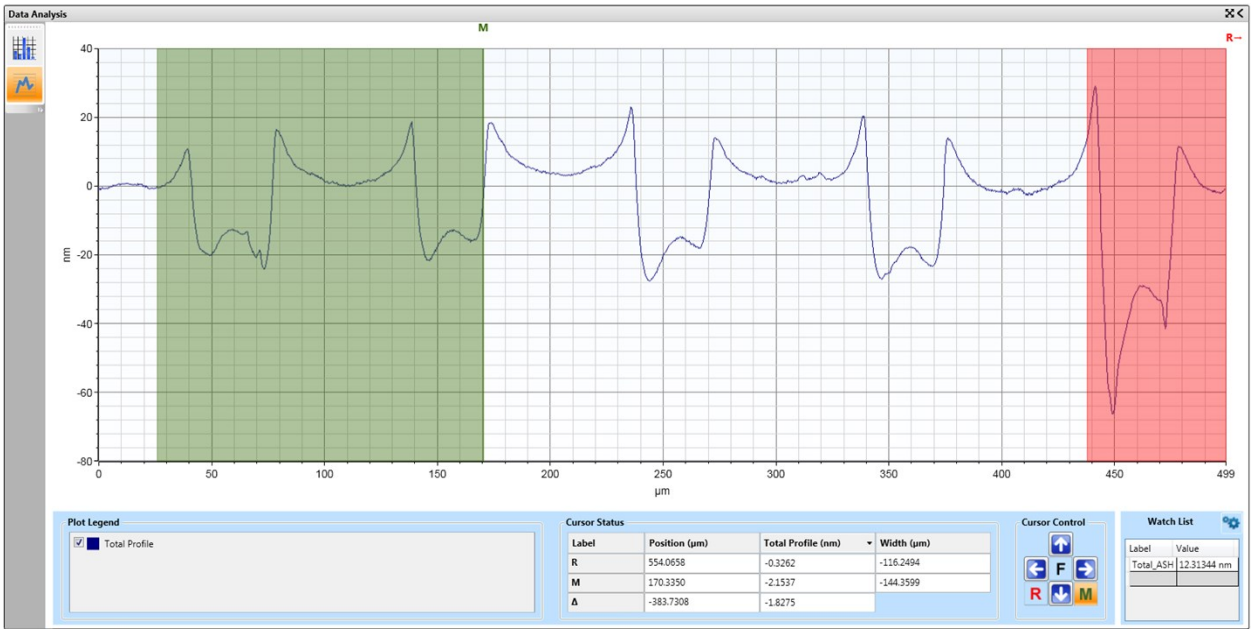

Figure S26: Linear profile 2 for PMMA wells fabricated from 5 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

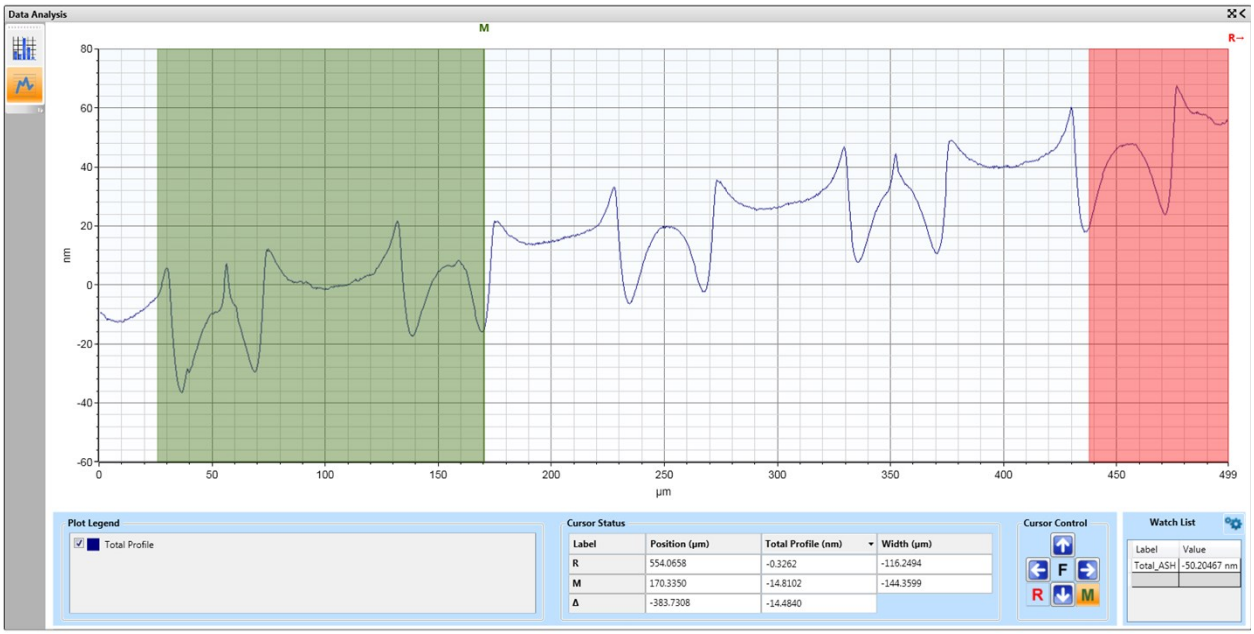

Figure S27: Linear profile 3 for PMMA wells fabricated from 5 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

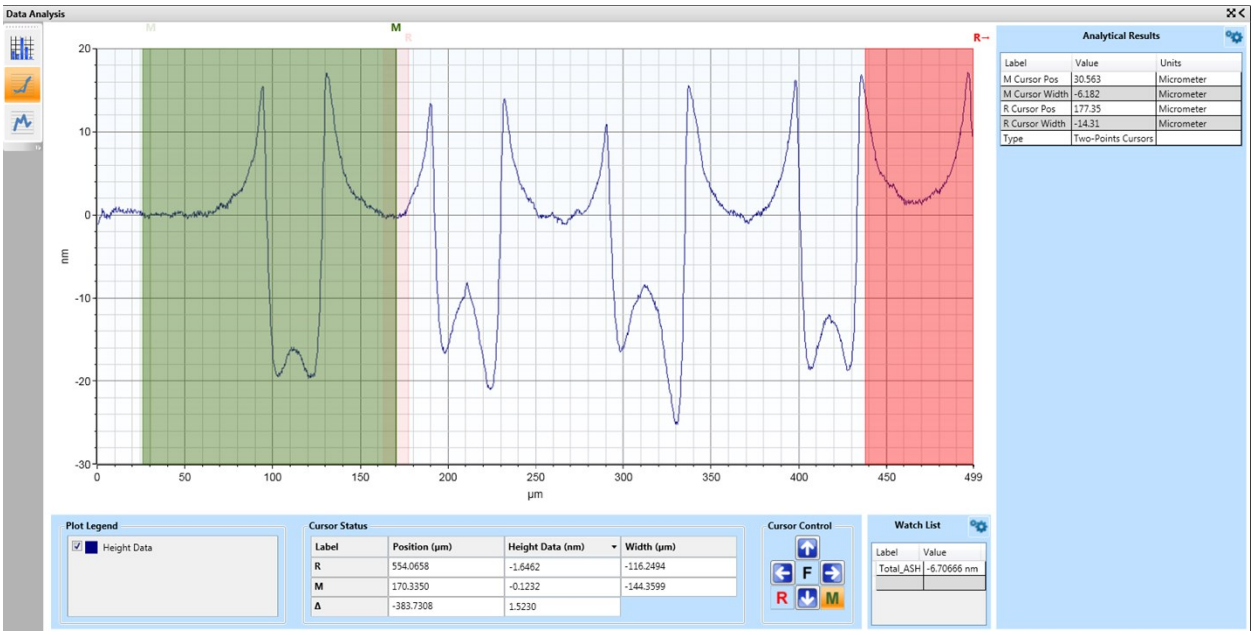

Figure S28: Linear profile 1 for PMMA wells fabricated from 6 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

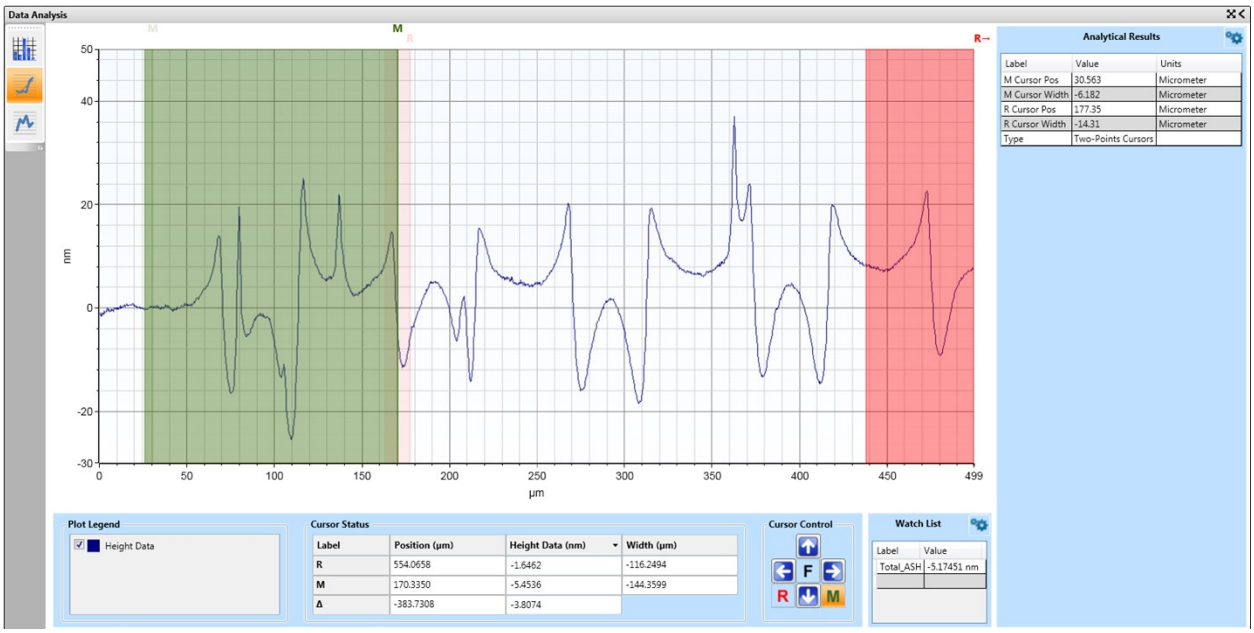

Figure S29: Linear profile 2 for PMMA wells fabricated from 6 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

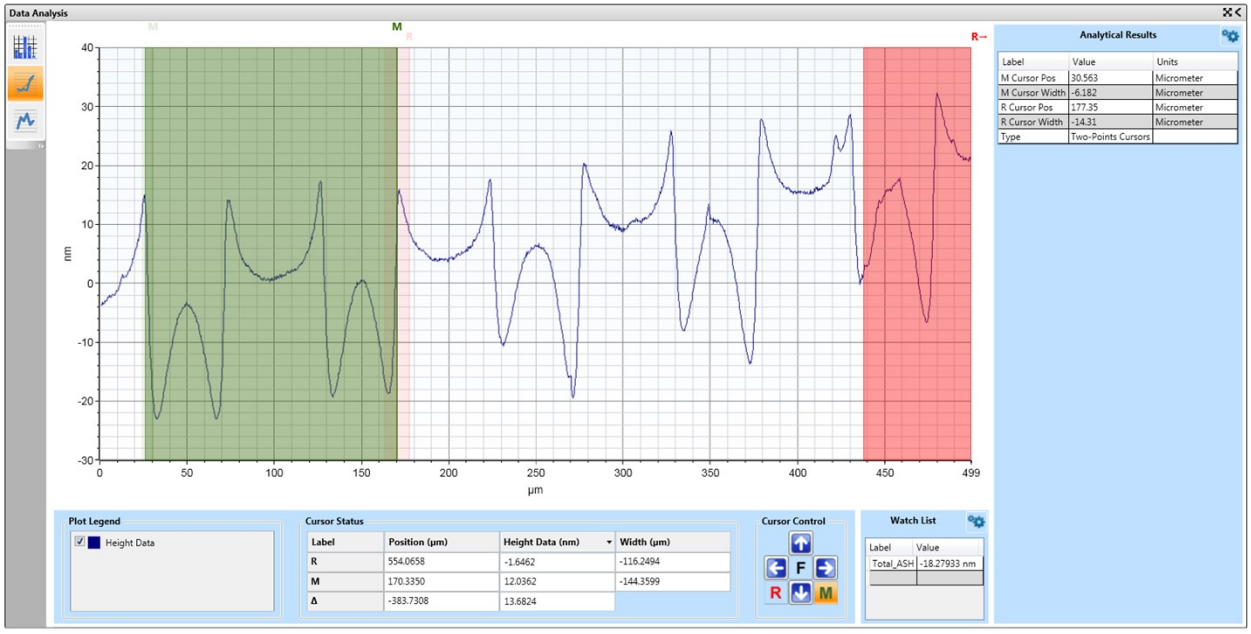

Figure S30: Linear profile 3 for PMMA wells fabricated from 6 layers of CMC and 2% PMMA spin-coated for 1 min at 2500 rpm.

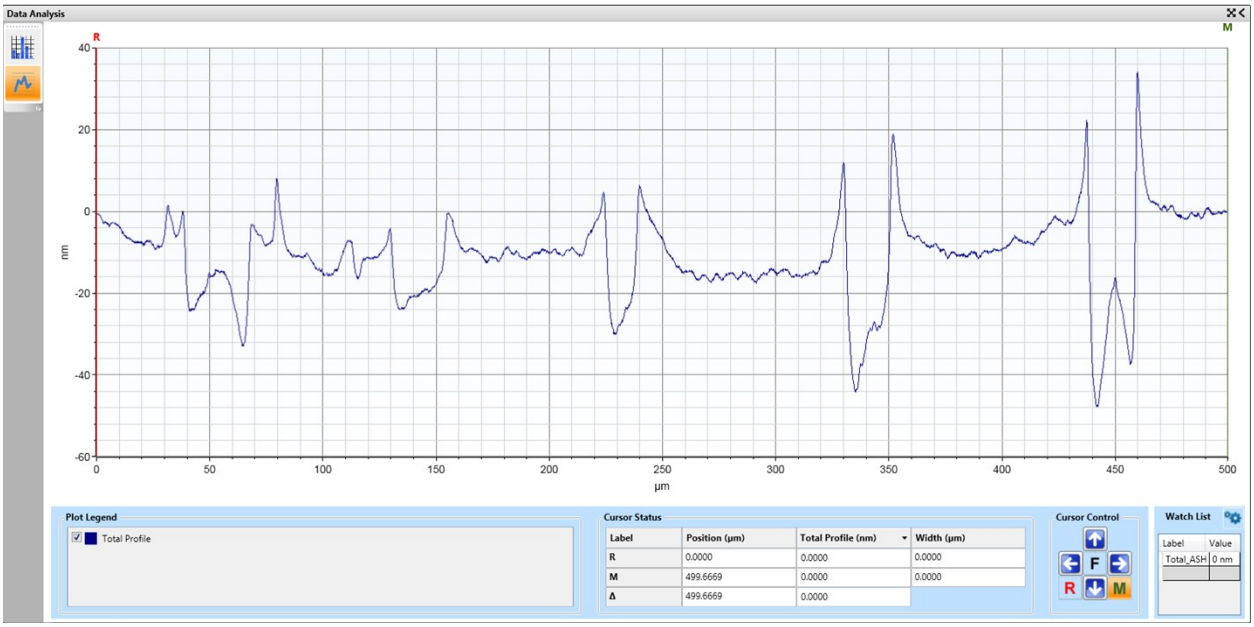

Figure S31: Linear profile 1 for PMMA wells fabricated from 2 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

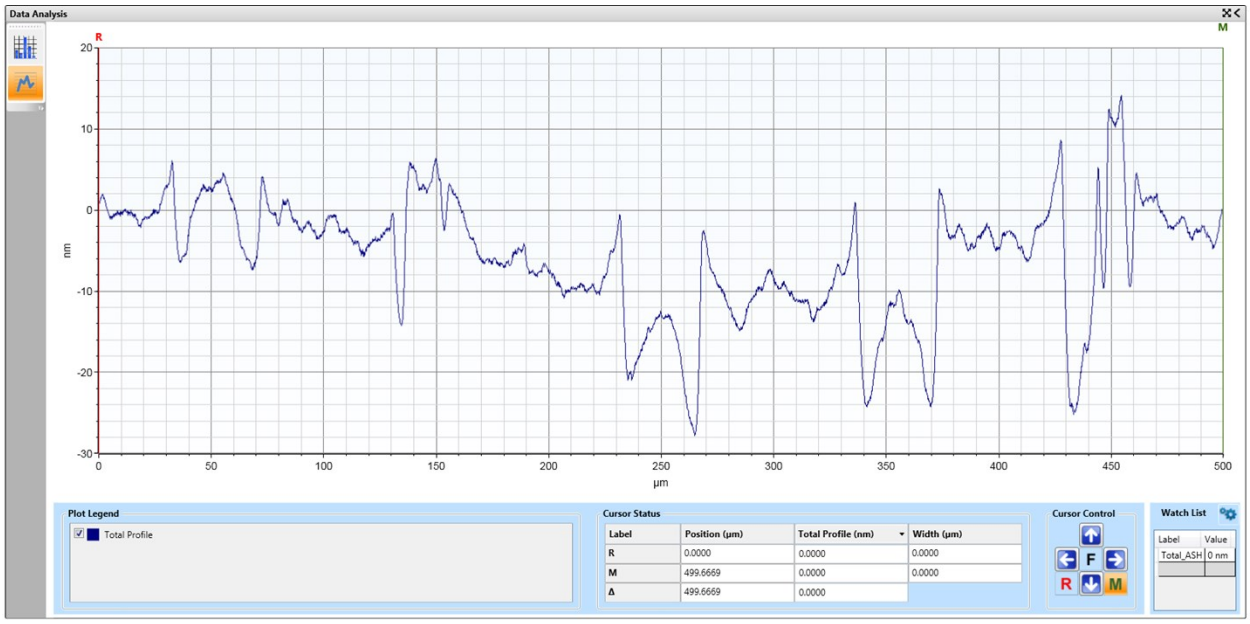

Figure S32: Linear profile 2 for PMMA wells fabricated from 2 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

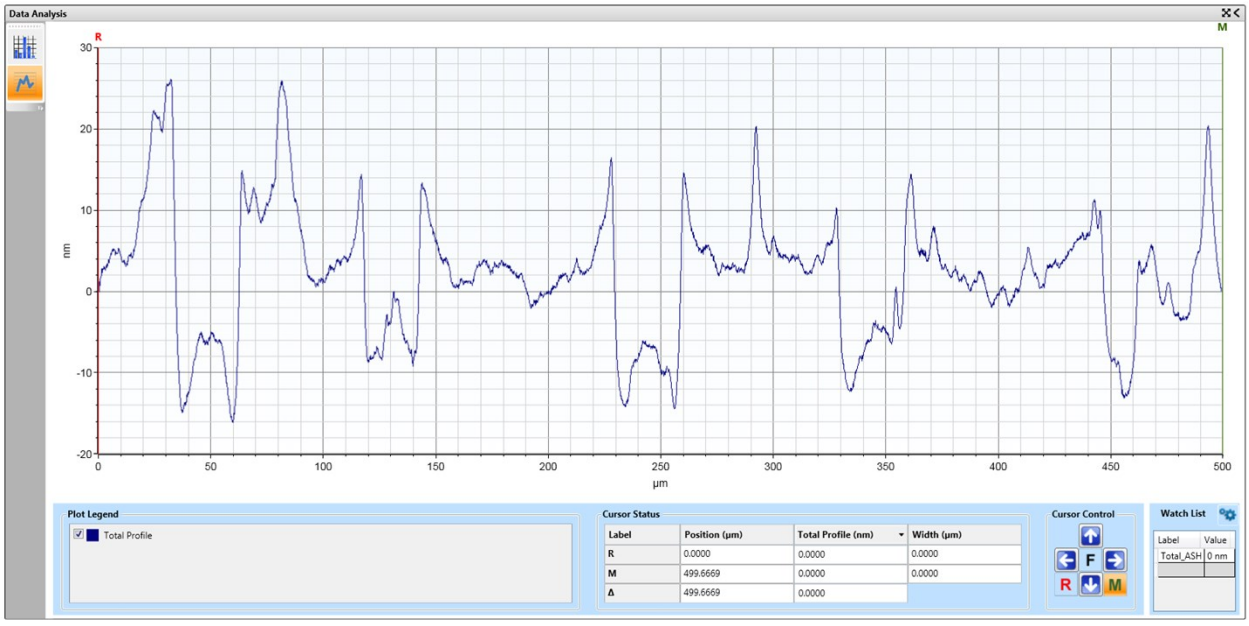

Figure S33: Linear profile 3 for PMMA wells fabricated from 2 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

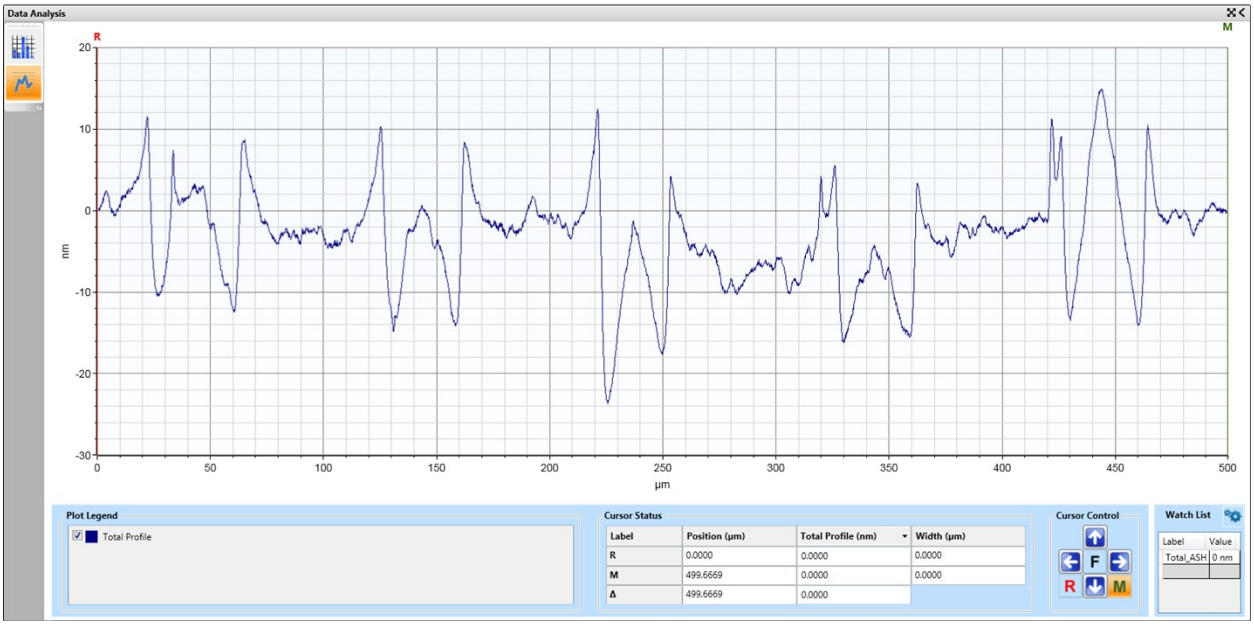

Figure S34: Linear profile 1 for PMMA wells fabricated from 3 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

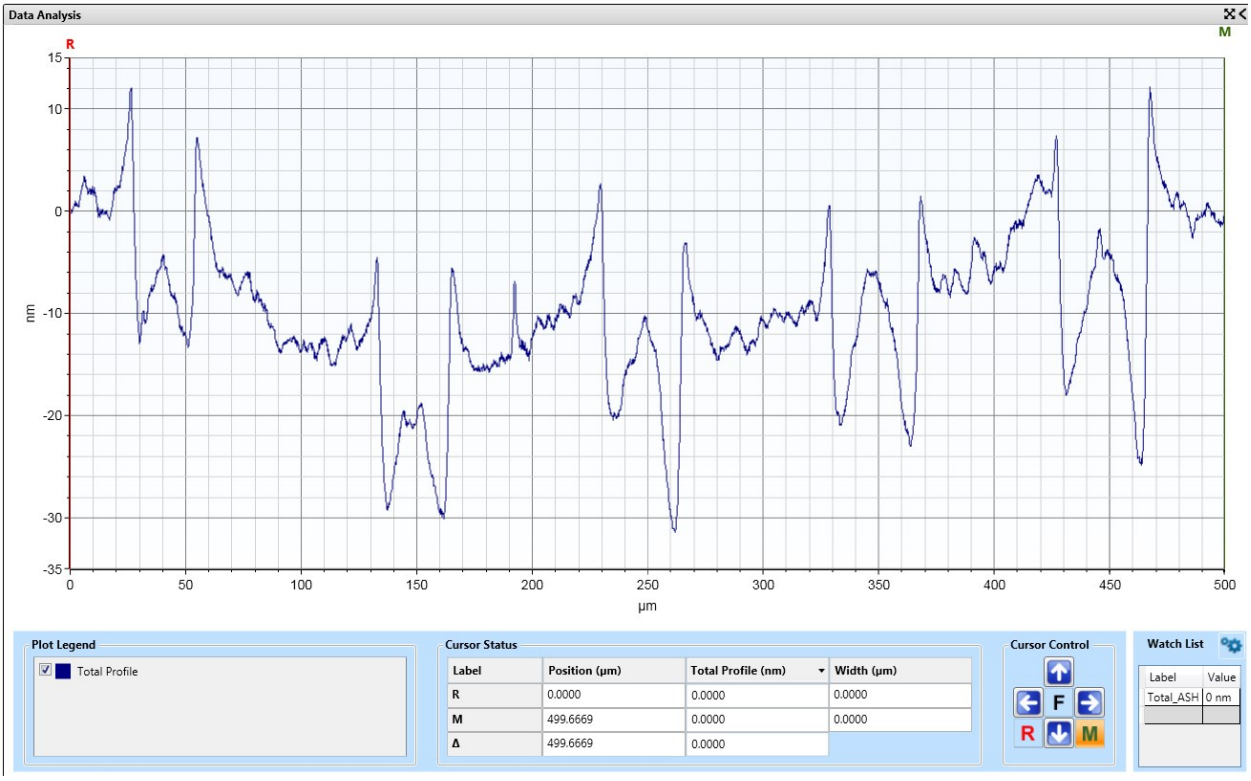

Figure S35: Linear profile 2 for PMMA wells fabricated from 3 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

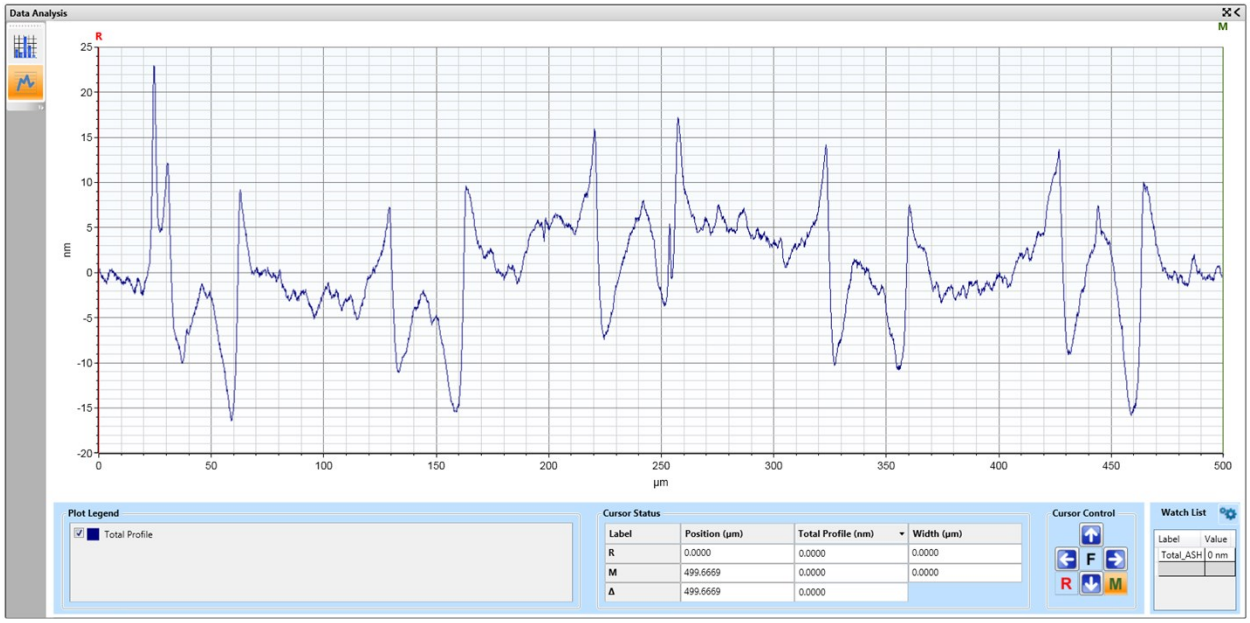

Figure S36: Linear profile 3 for PMMA wells fabricated from 3 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

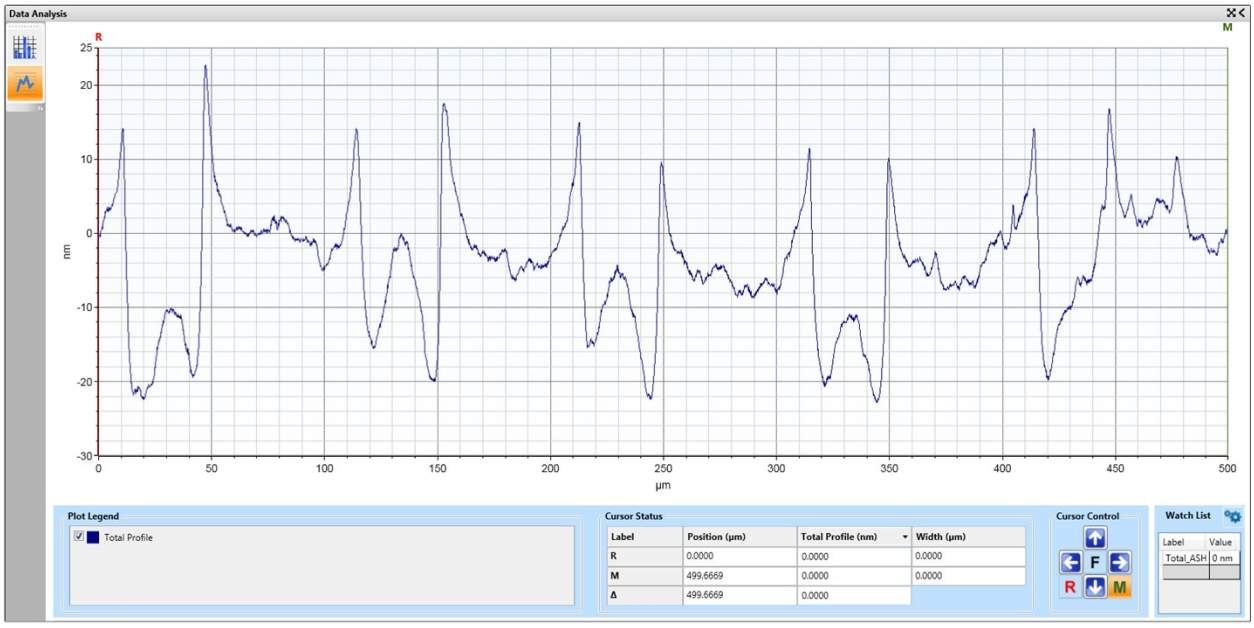

Figure S37: Linear profile 1 for PMMA wells fabricated from 4 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

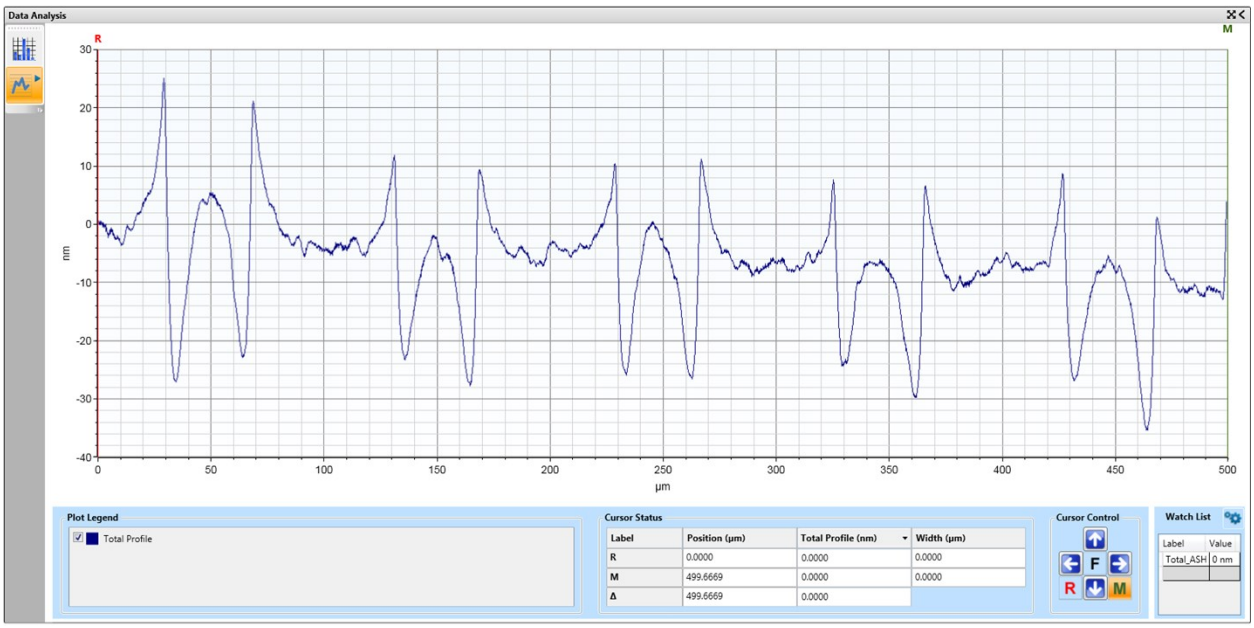

Figure S38: Linear profile 2 for PMMA wells fabricated from 4 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

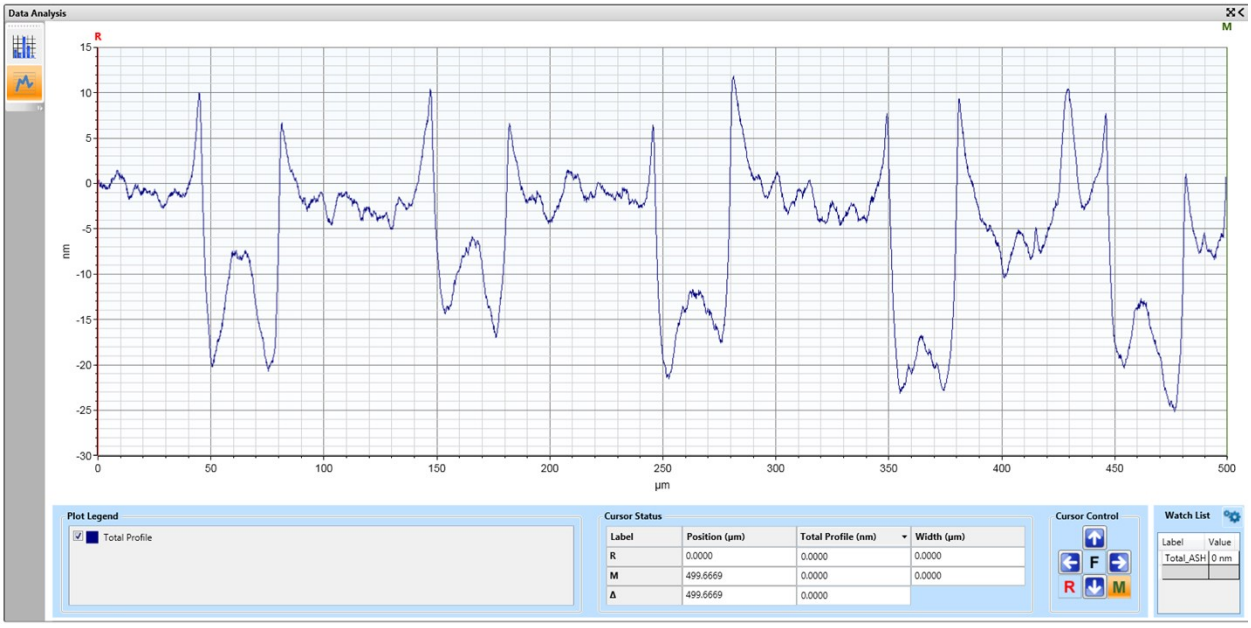

Figure S39: Linear profile 3 for PMMA wells fabricated from 4 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

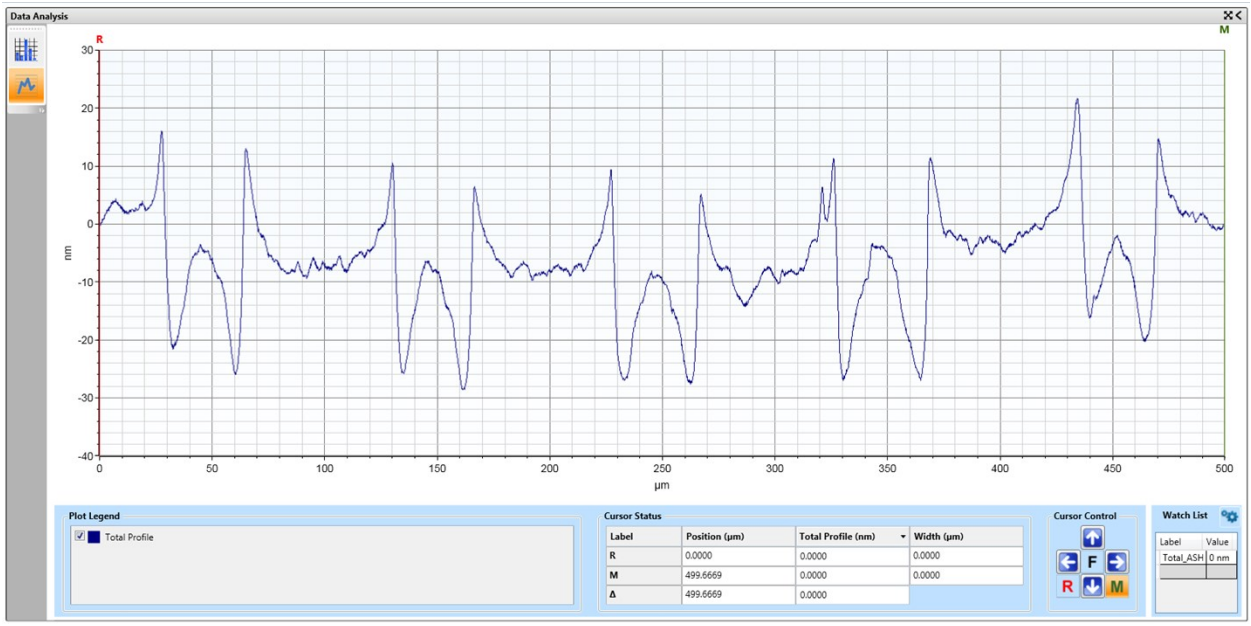

Figure S40: Linear profile 1 for PMMA wells fabricated from 5 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

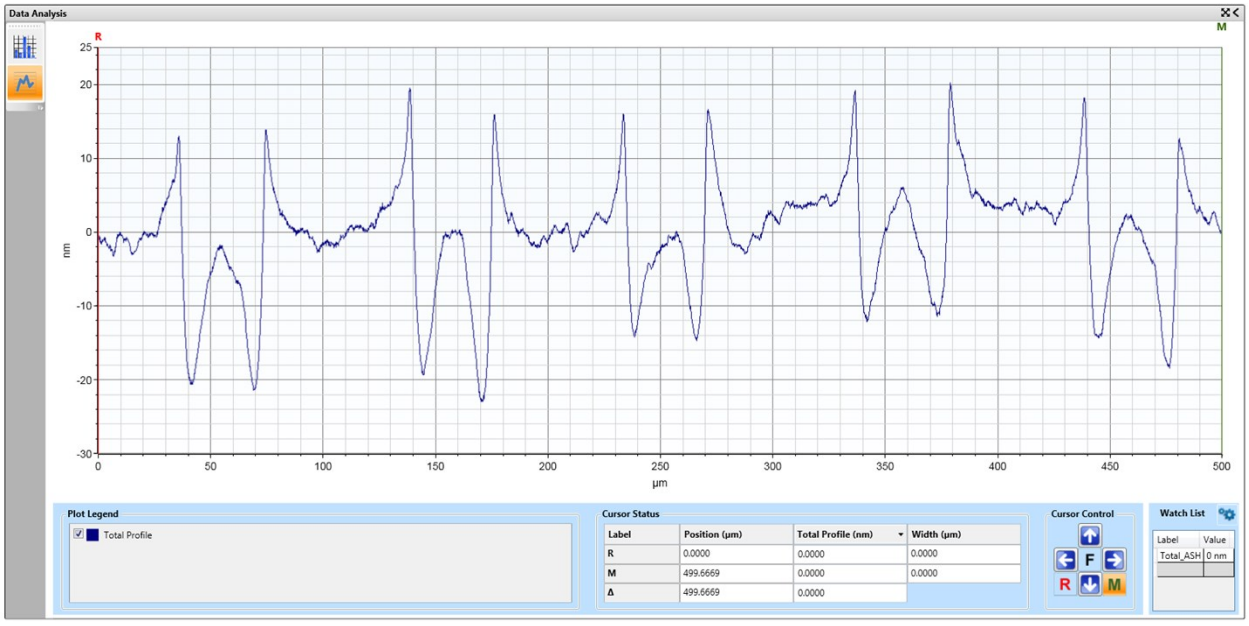

Figure S41: Linear profile 2 for PMMA wells fabricated from 5 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

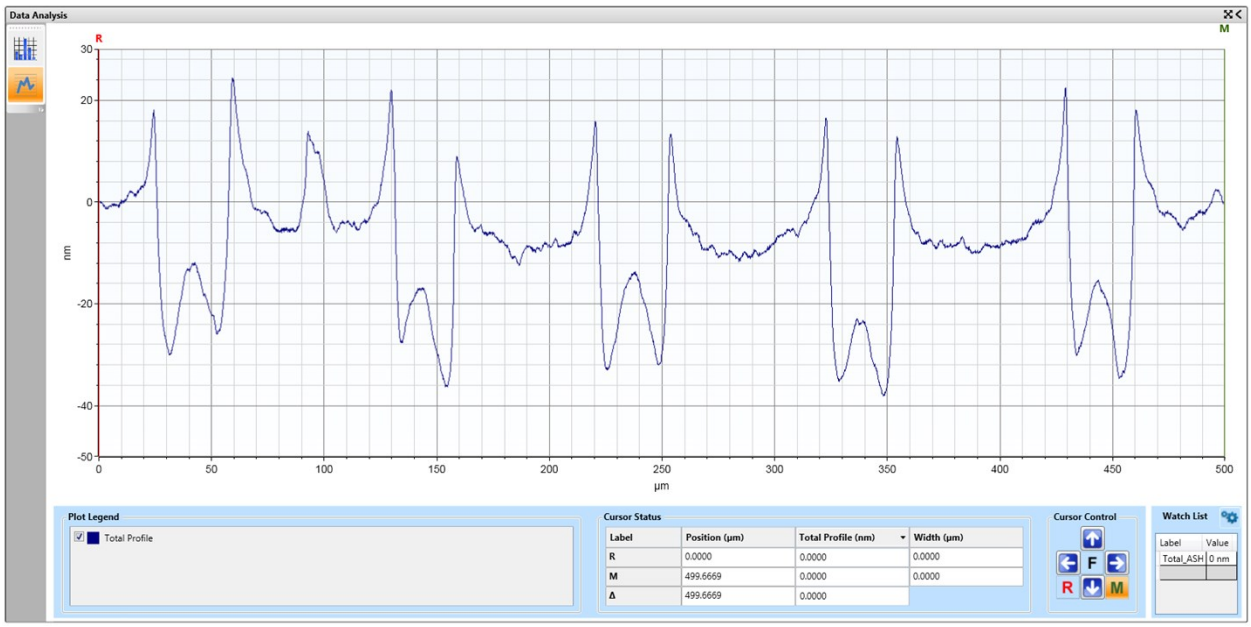

Figure S42: Linear profile 3 for PMMA wells fabricated from 5 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

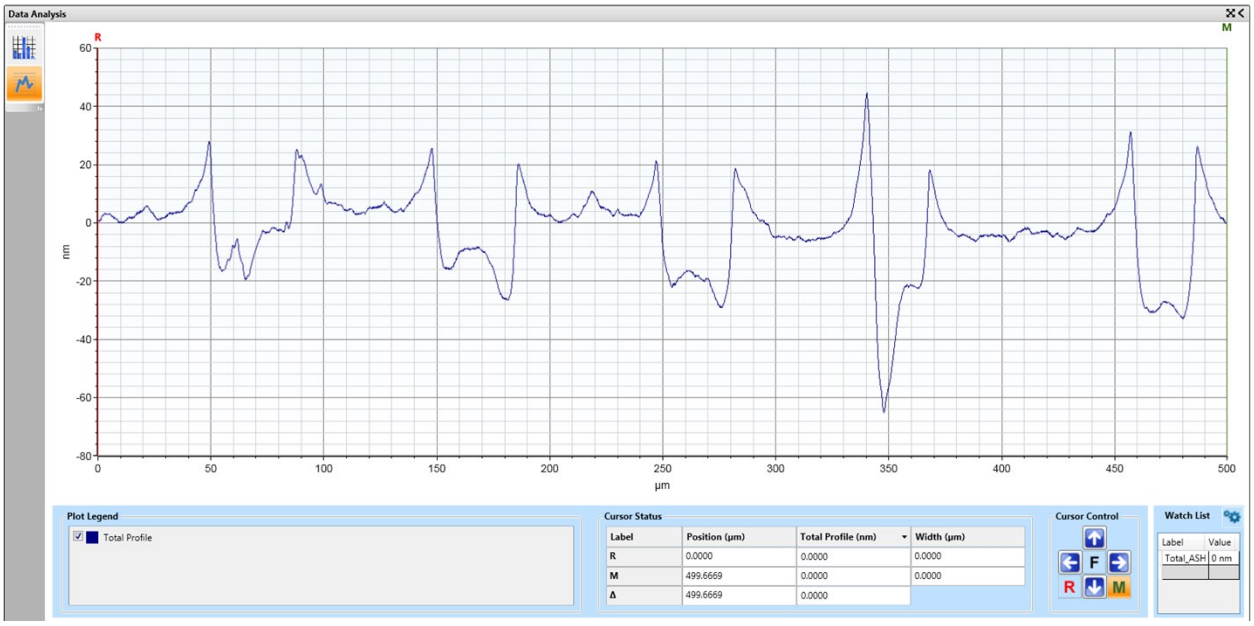

Figure S43: Linear profile 1 for PMMA wells fabricated from 6 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

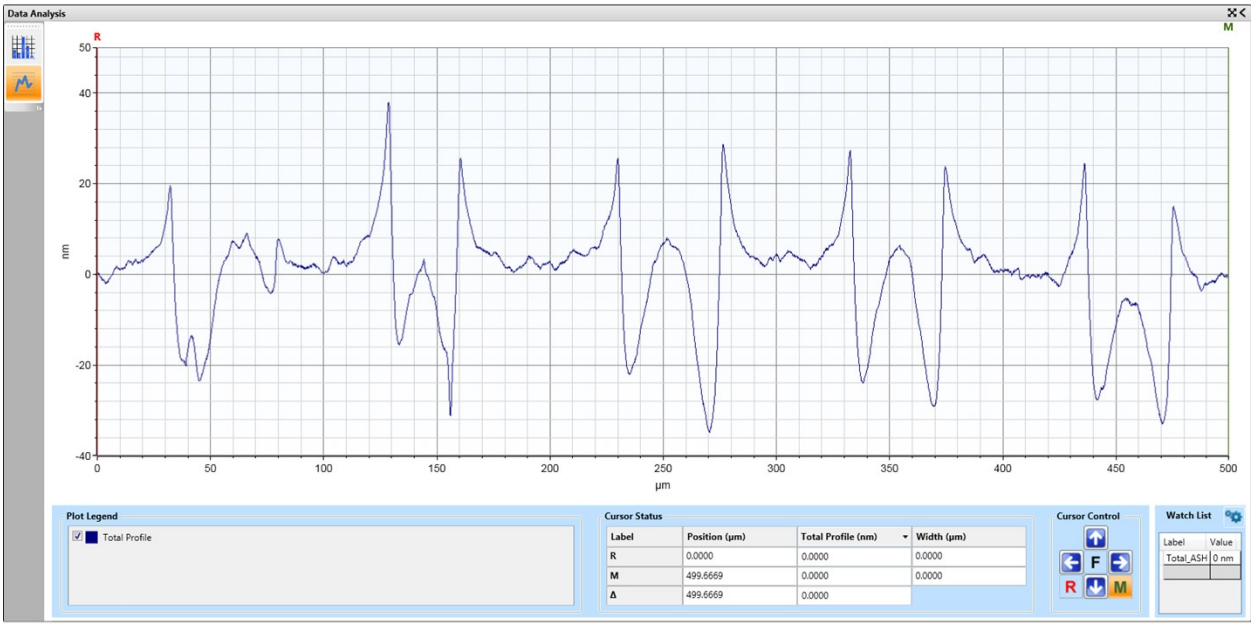

Figure S44: Linear profile 2 for PMMA wells fabricated from 6 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

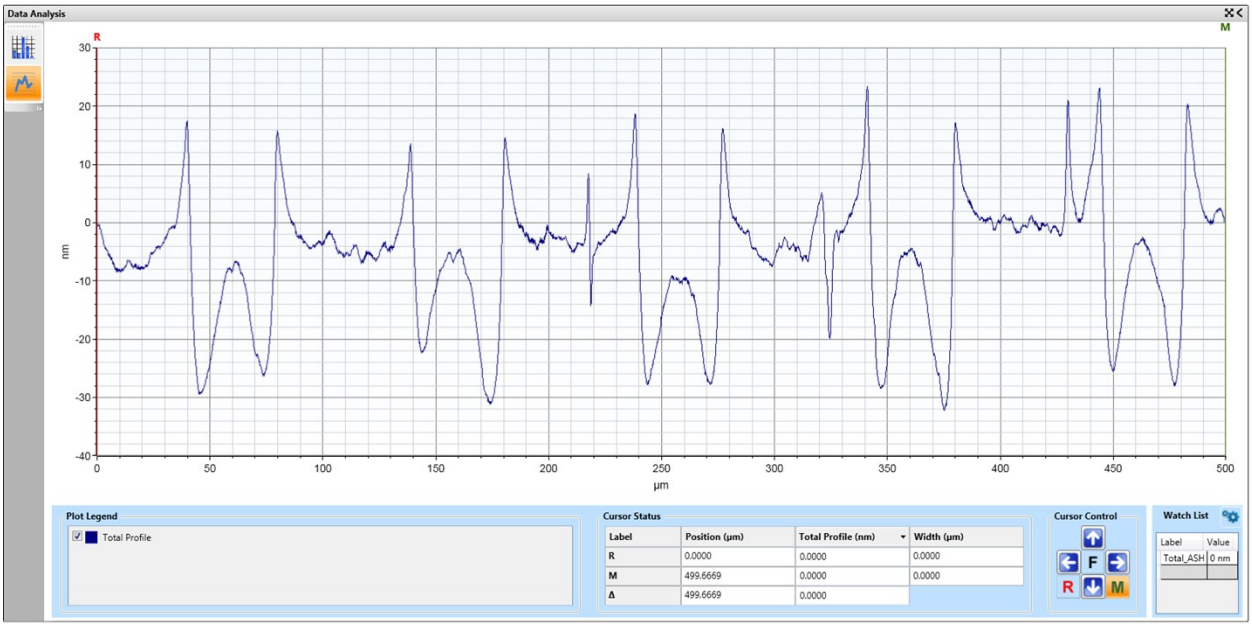

Figure S45: Linear profile 3 for PMMA wells fabricated from 6 layers of CMC and 2% PMMA spin-coated for 1 min at 4000 rpm.

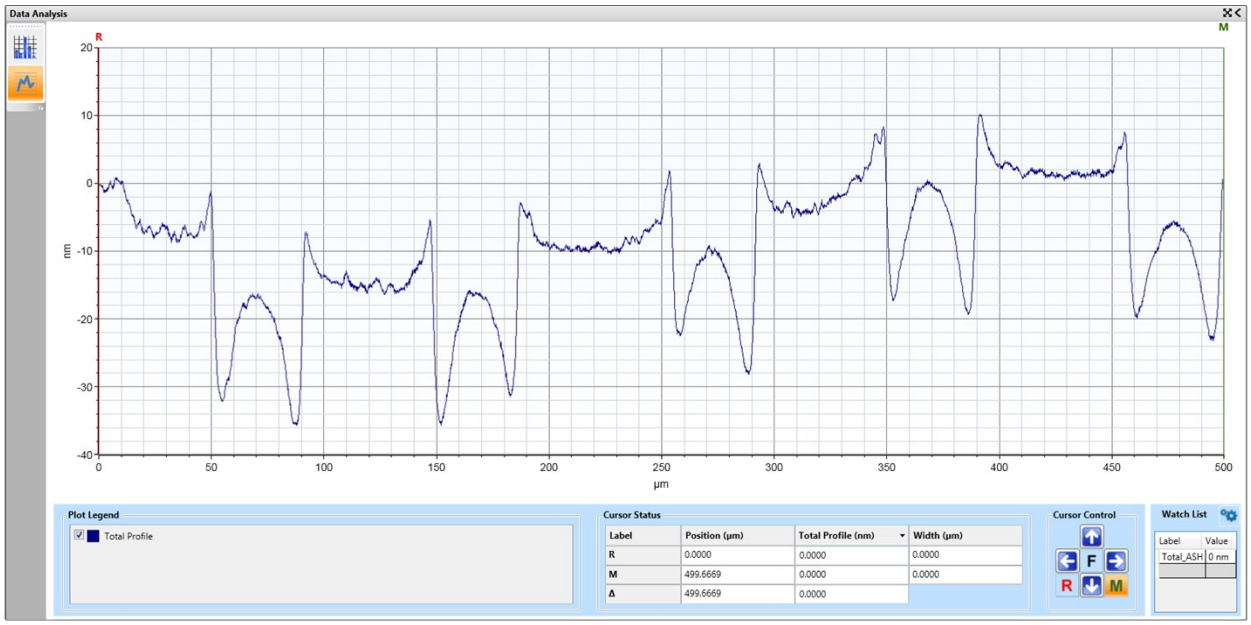

Figure S46: Linear profile 1 for PMMA wells fabricated from 2 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

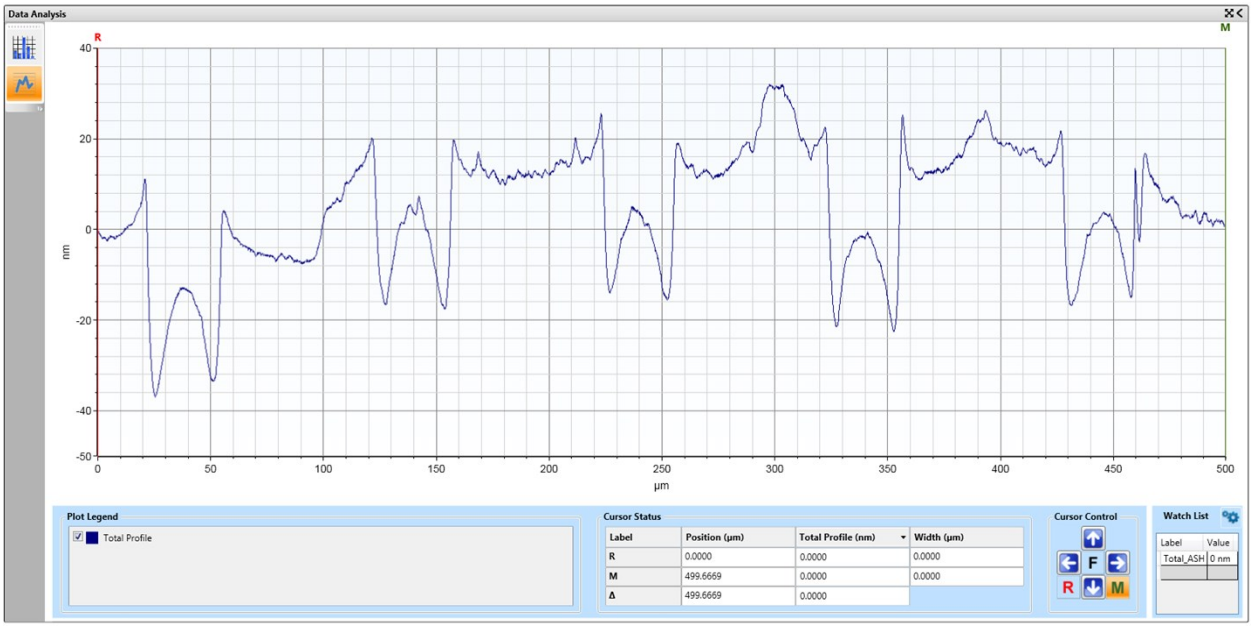

Figure S47: Linear profile 2 for PMMA wells fabricated from 2 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

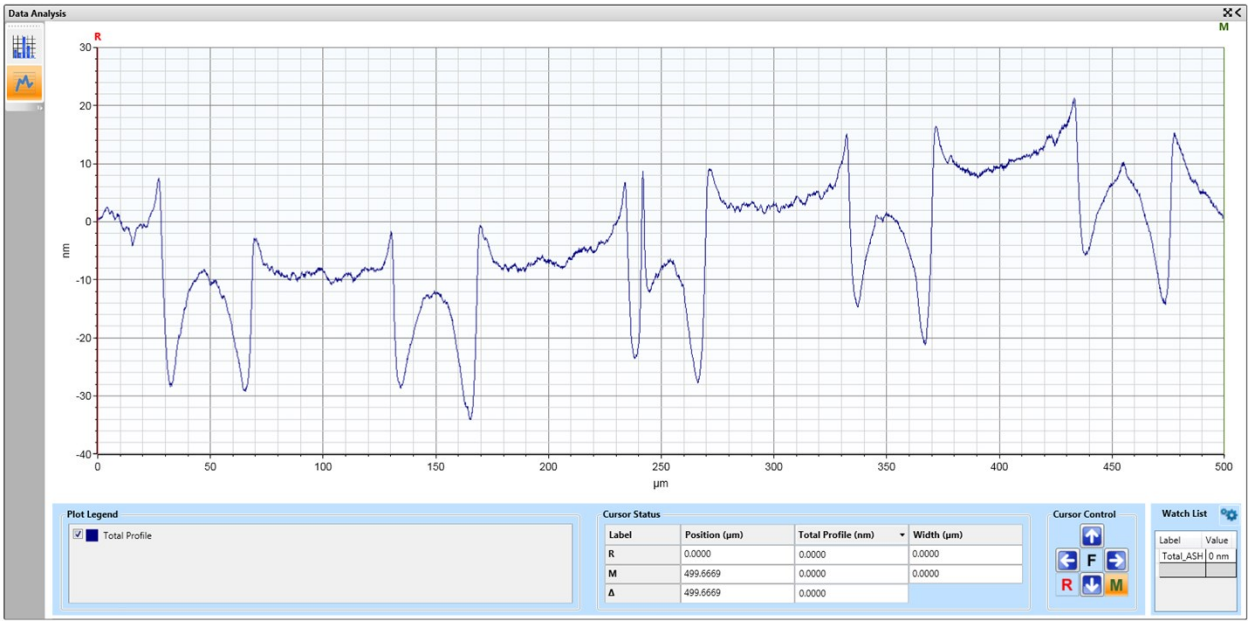

Figure S48: Linear profile 3 for PMMA wells fabricated from 2 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

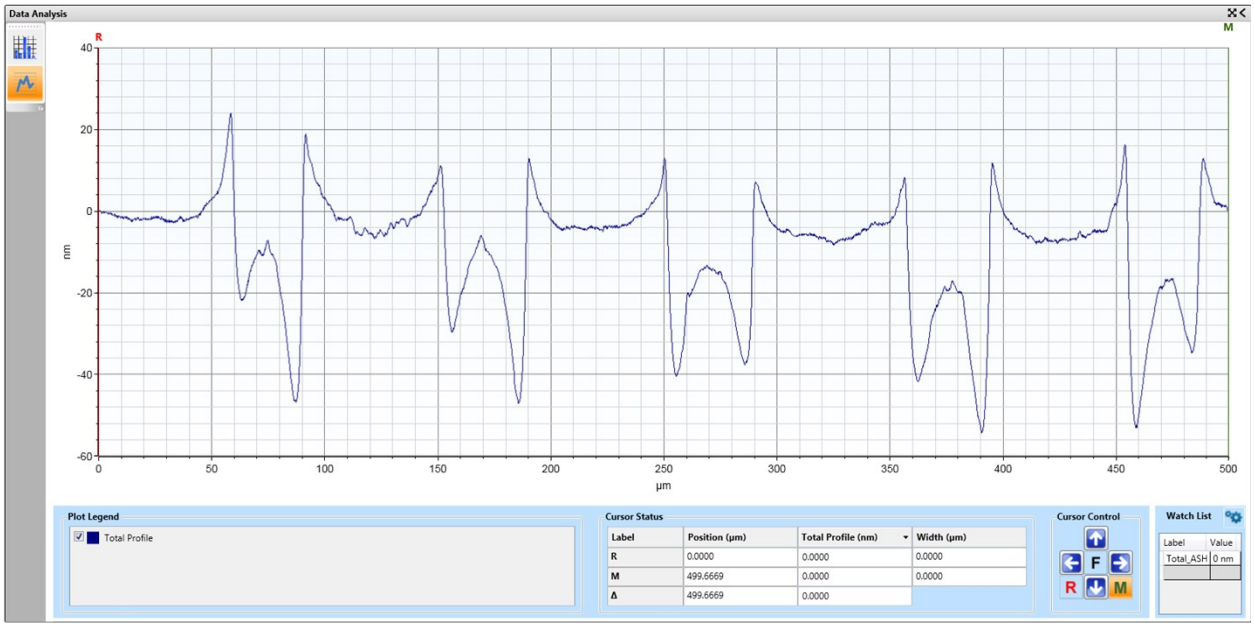

Figure S49: Linear profile 1 for PMMA wells fabricated from 3 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

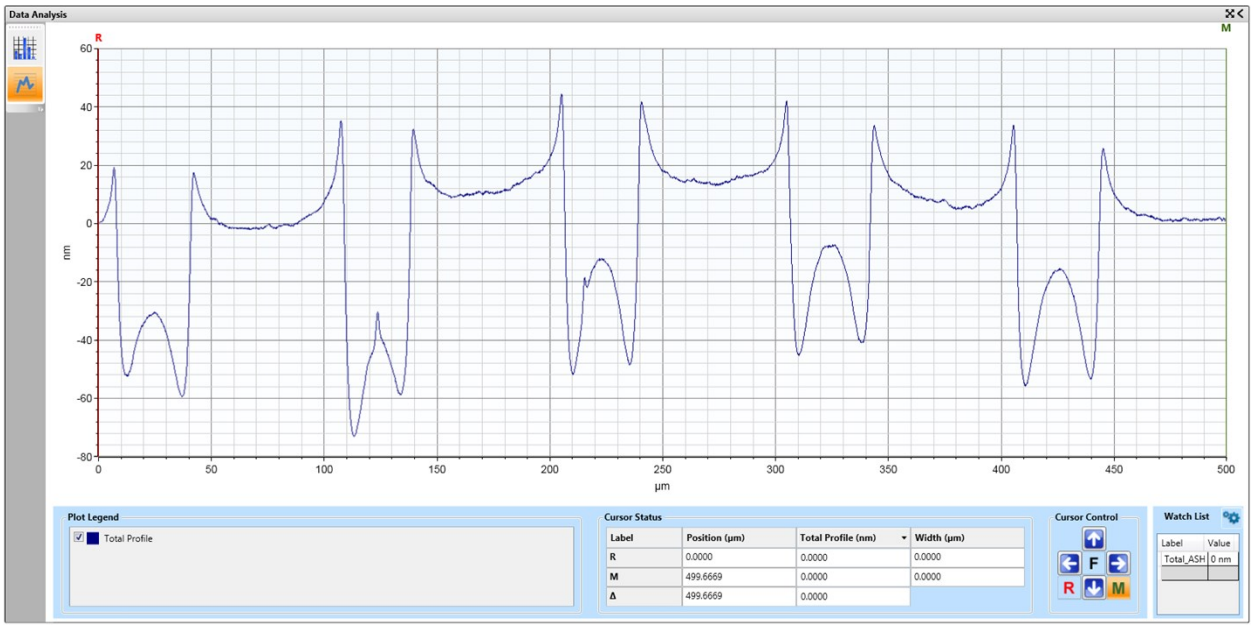

Figure S50: Linear profile 2 for PMMA wells fabricated from 3 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

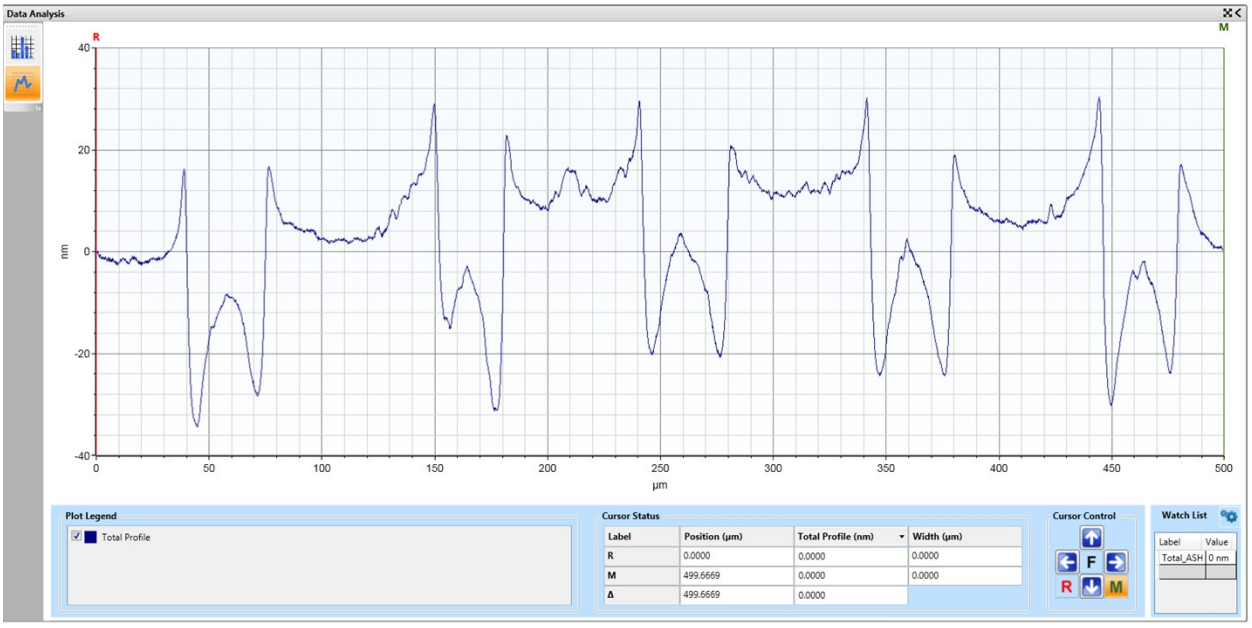

Figure S51: Linear profile 3 for PMMA wells fabricated from 3 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

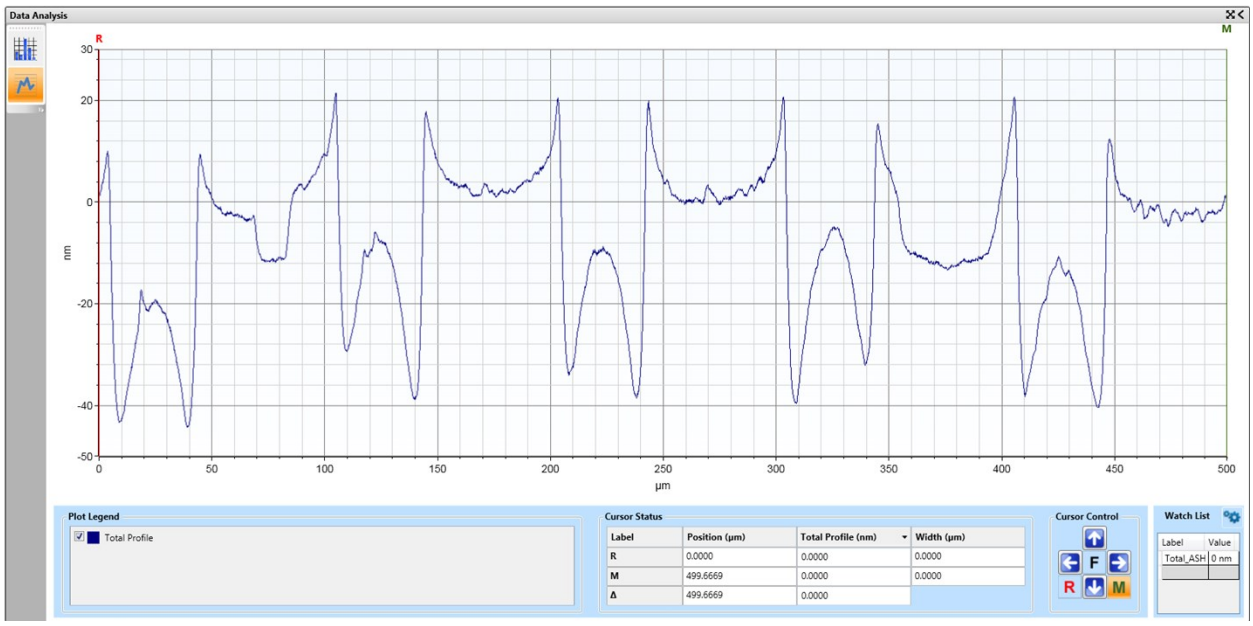

Figure S52: Linear profile 1 for PMMA wells fabricated from 4 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

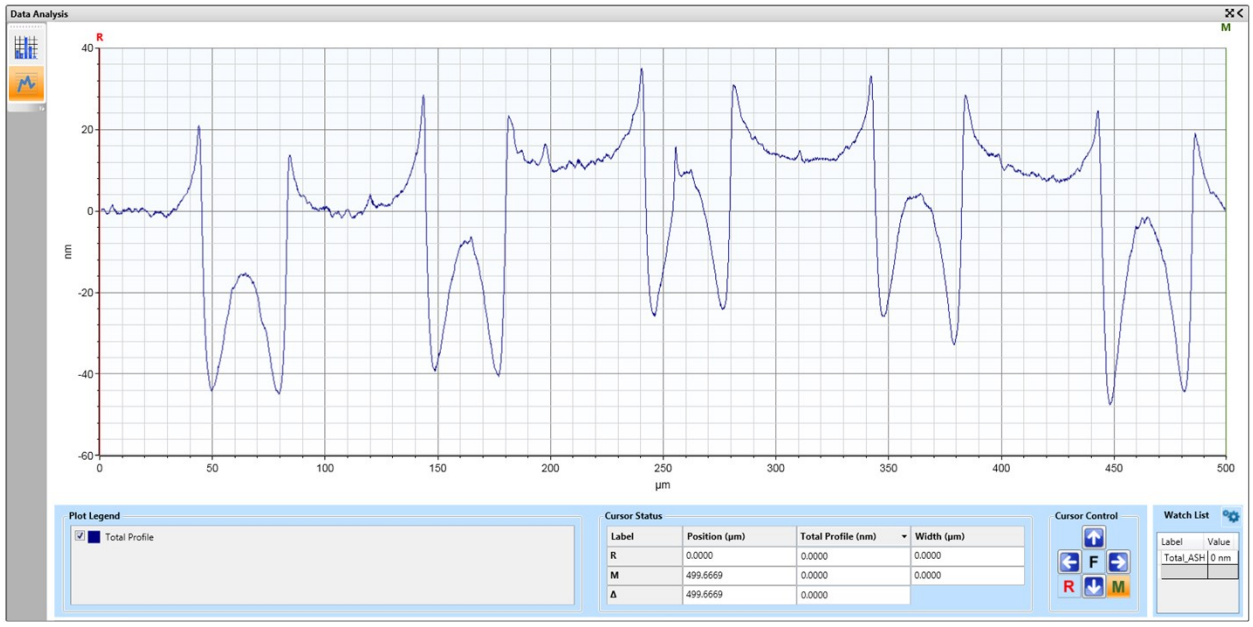

Figure S53: Linear profile 2 for PMMA wells fabricated from 4 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

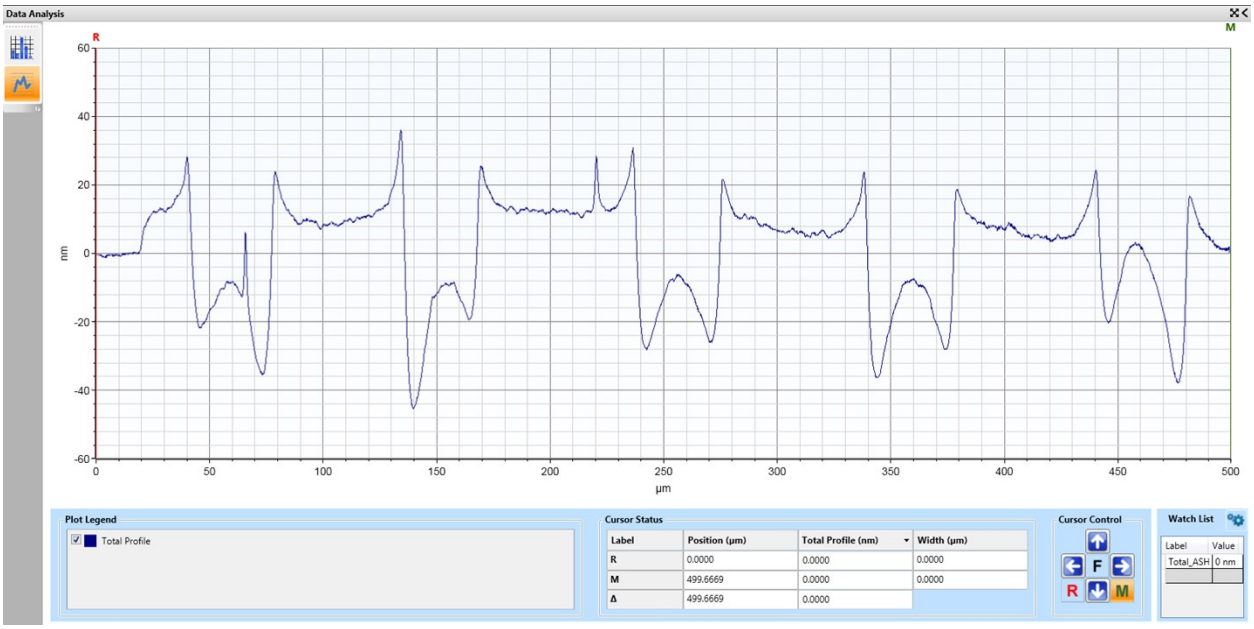

Figure S54: Linear profile 3 for PMMA wells fabricated from 4 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

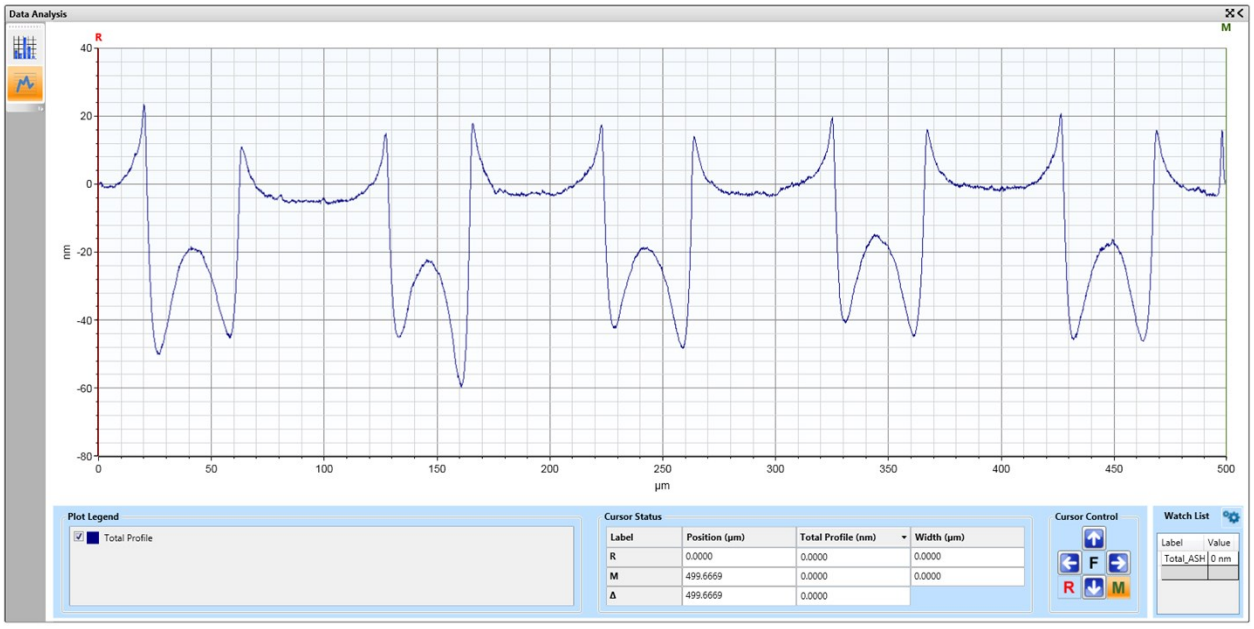

Figure S55: Linear profile 1 for PMMA wells fabricated from 5 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

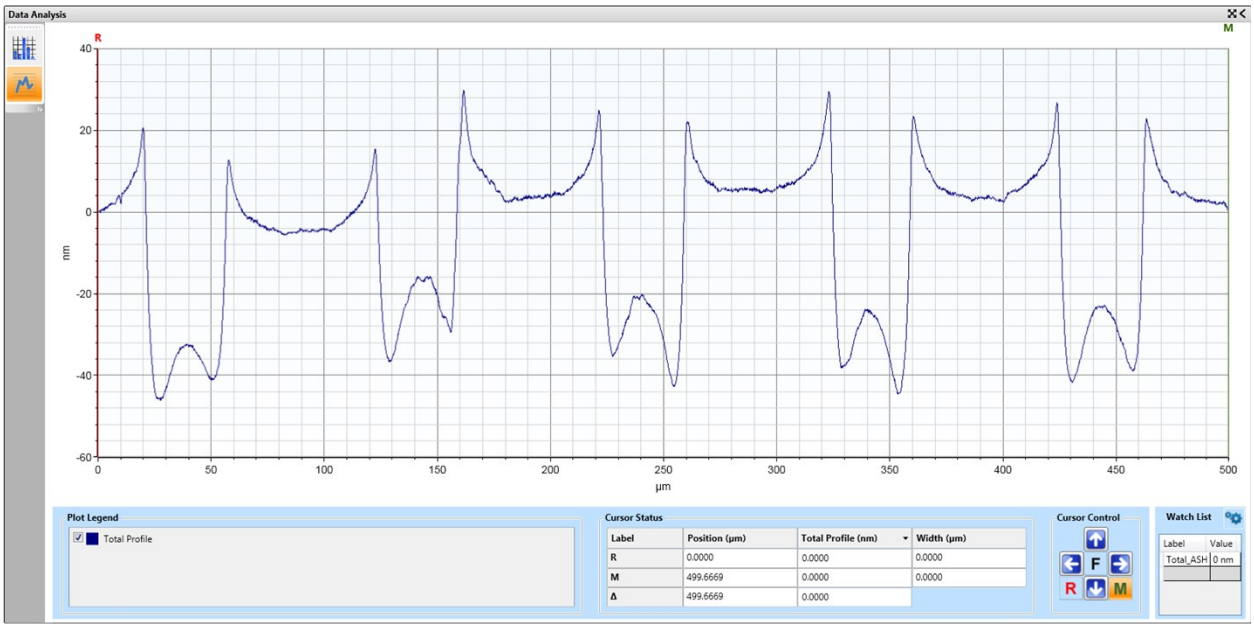

Figure S56: Linear profile 2 for PMMA wells fabricated from 5 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

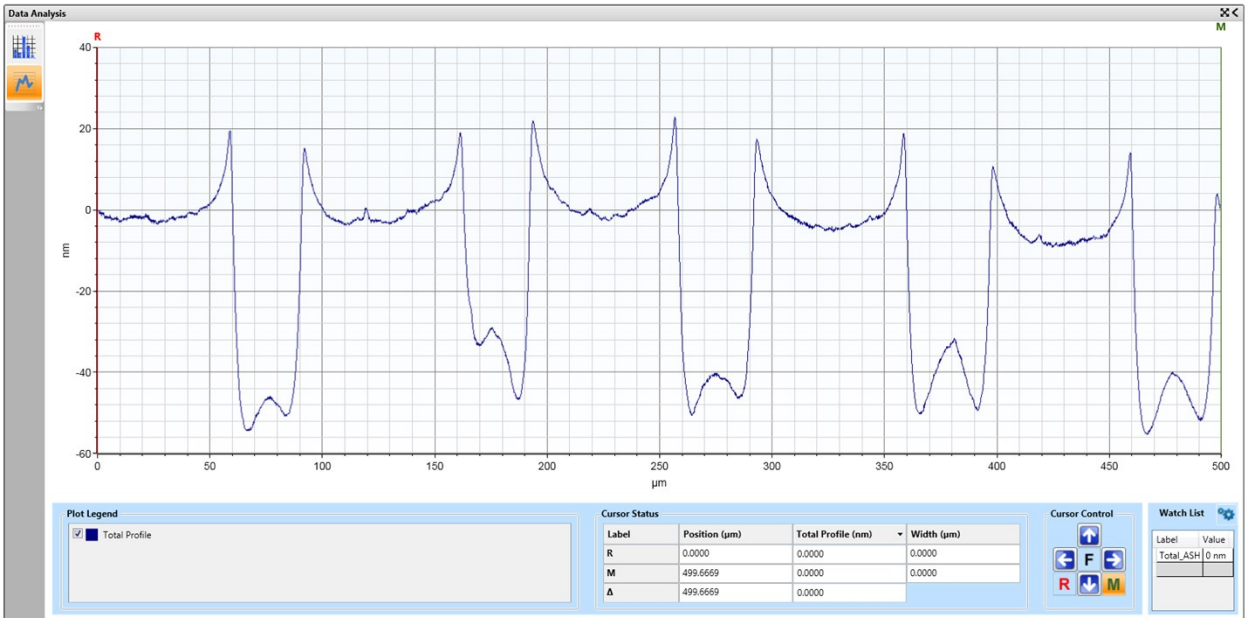

Figure S57: Linear profile 3 for PMMA wells fabricated from 5 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

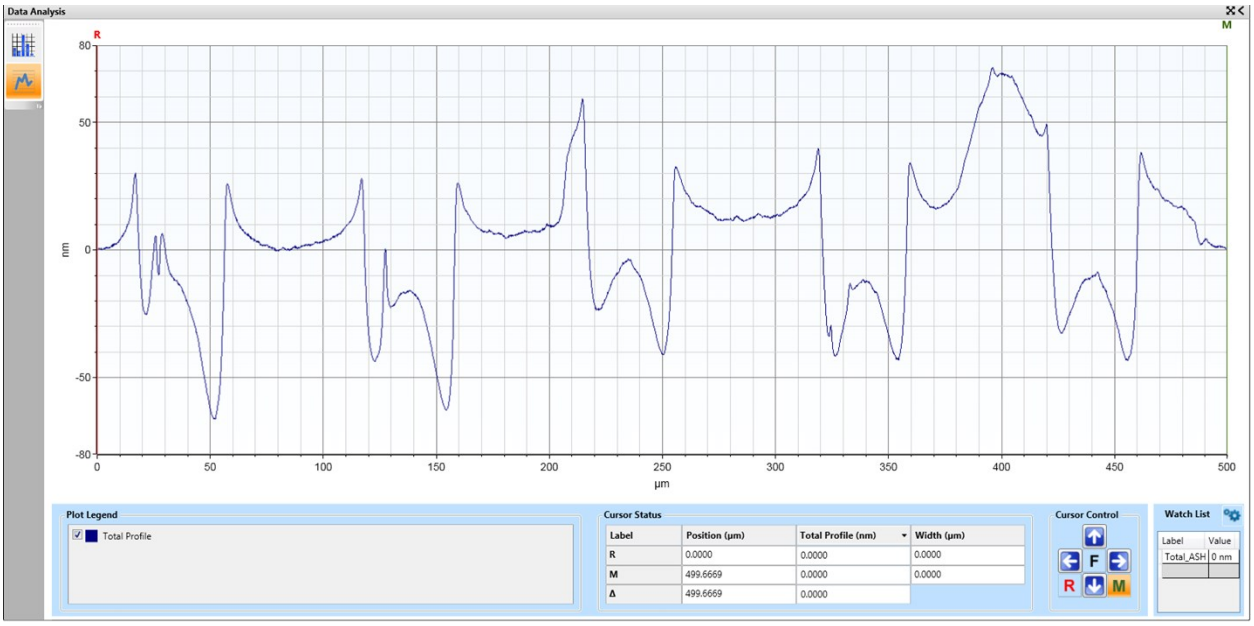

Figure S58: Linear profile 1 for PMMA wells fabricated from 6 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

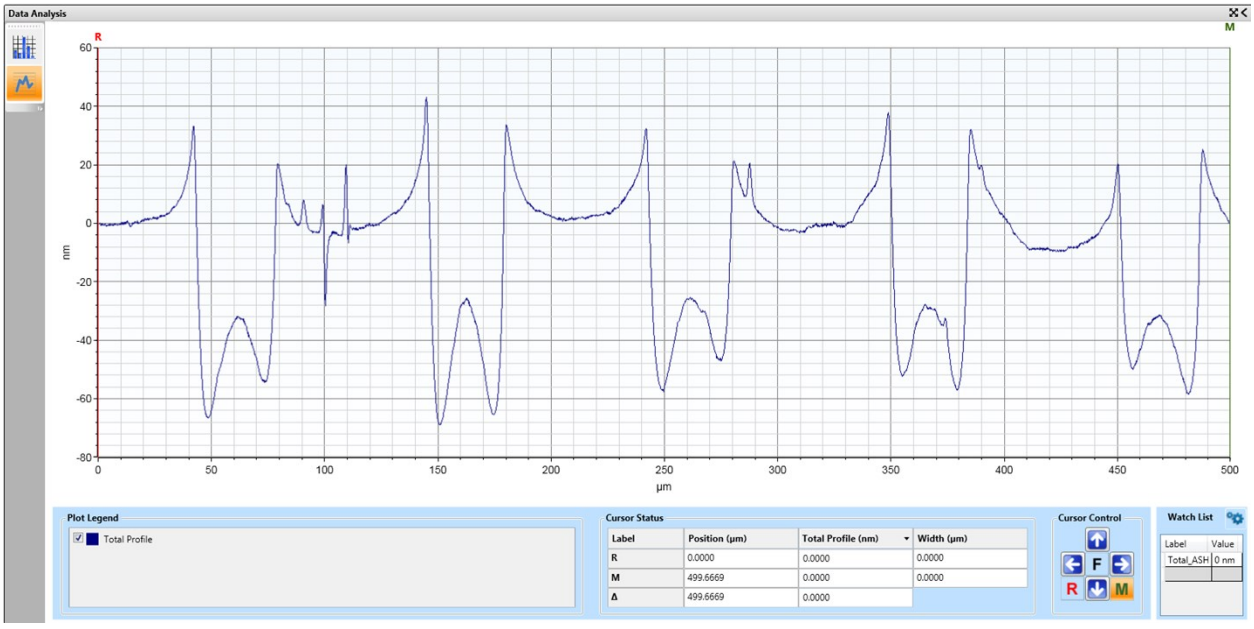

Figure S59: Linear profile 2 for PMMA wells fabricated from 6 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

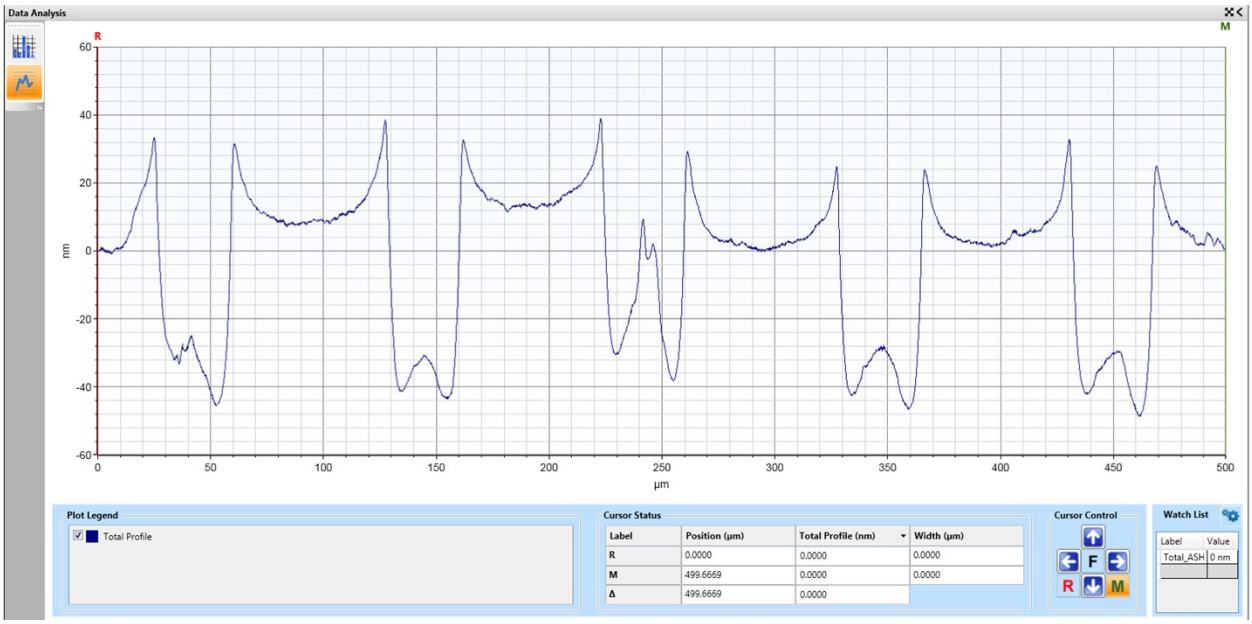

Figure S60: Linear profile 3 for PMMA wells fabricated from 6 layers of CMC and 4% PMMA spin-coated for 1 min at 4000 rpm.

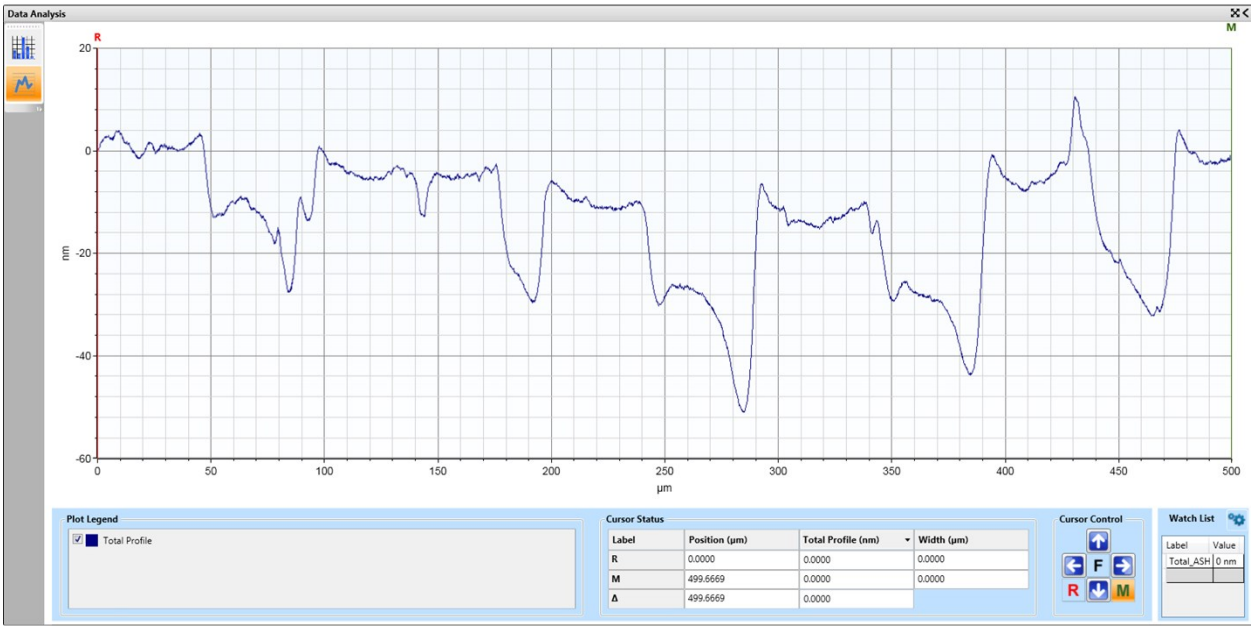

Figure S61: Linear profile 1 for PMMA wells fabricated from 2 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

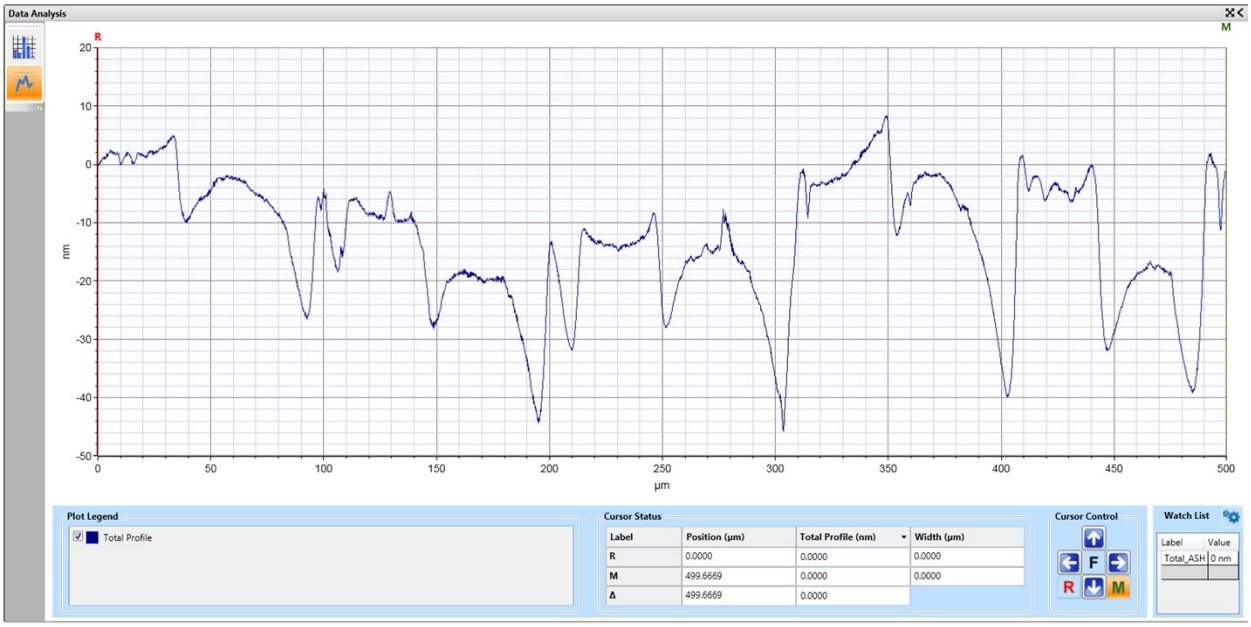

Figure S62: Linear profile 2 for PMMA wells fabricated from 2 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

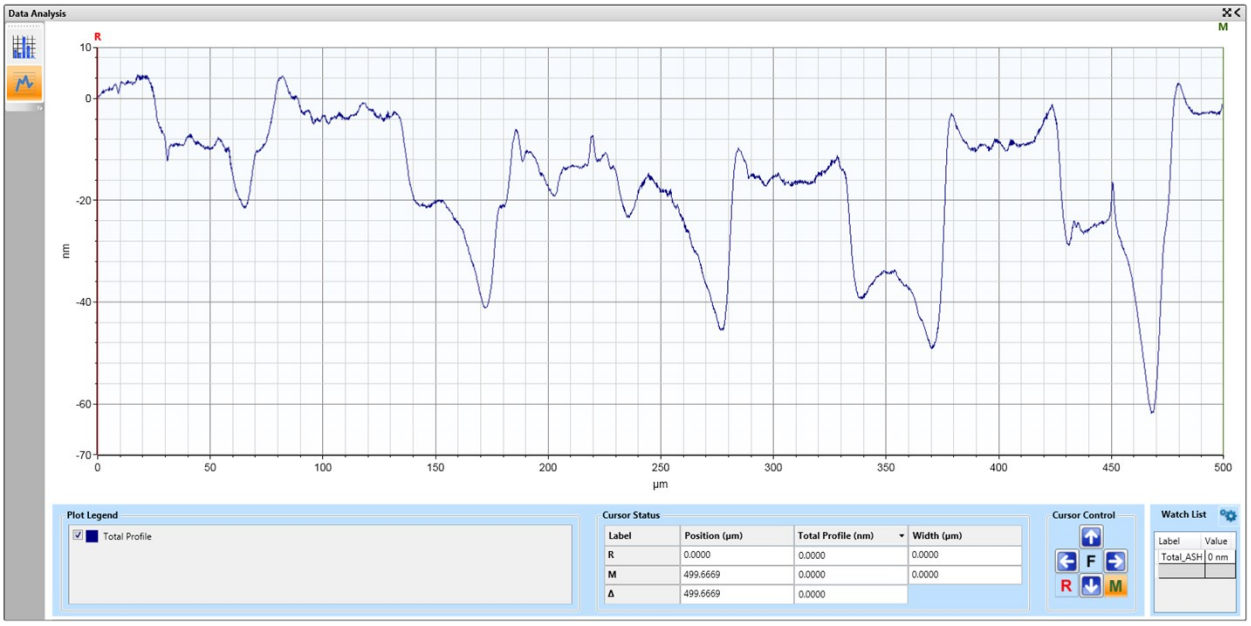

Figure S63: Linear profile 3 for PMMA wells fabricated from 2 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

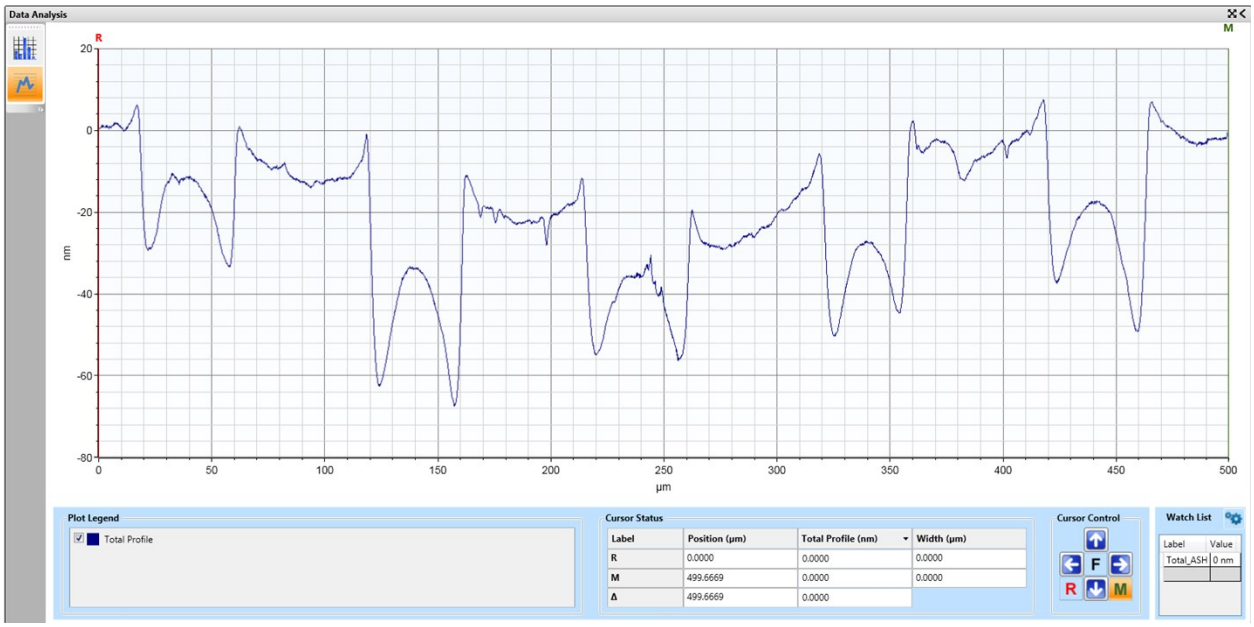

Figure S64: Linear profile 1 for PMMA wells fabricated from 3 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

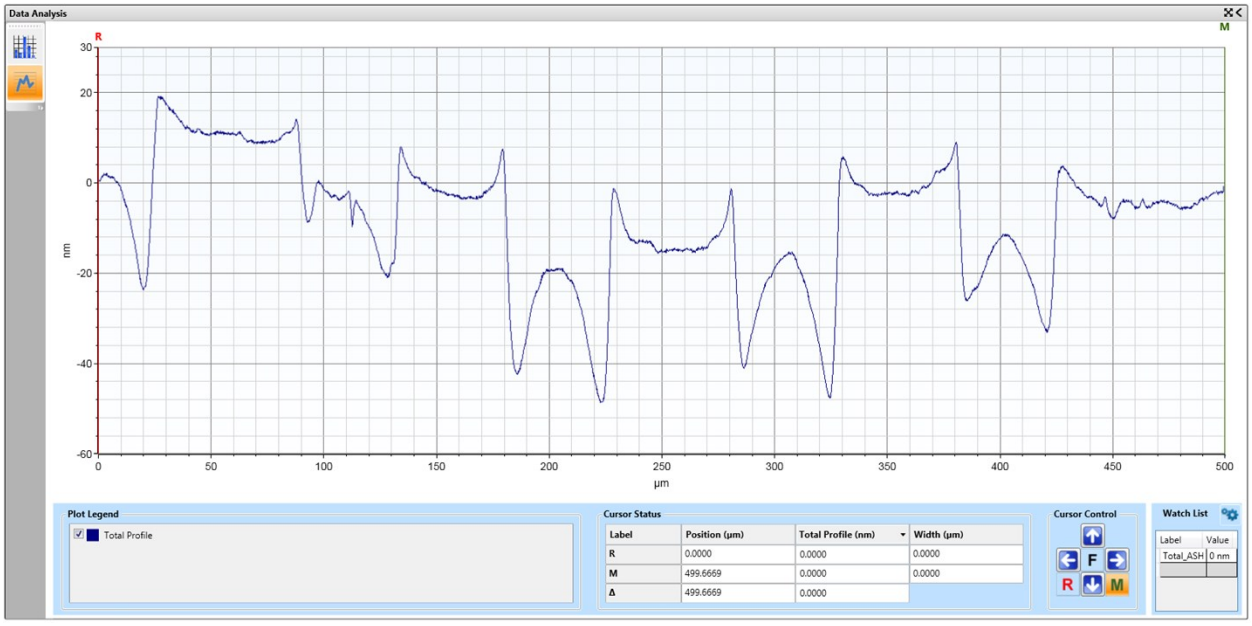

Figure S65: Linear profile 2 for PMMA wells fabricated from 3 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

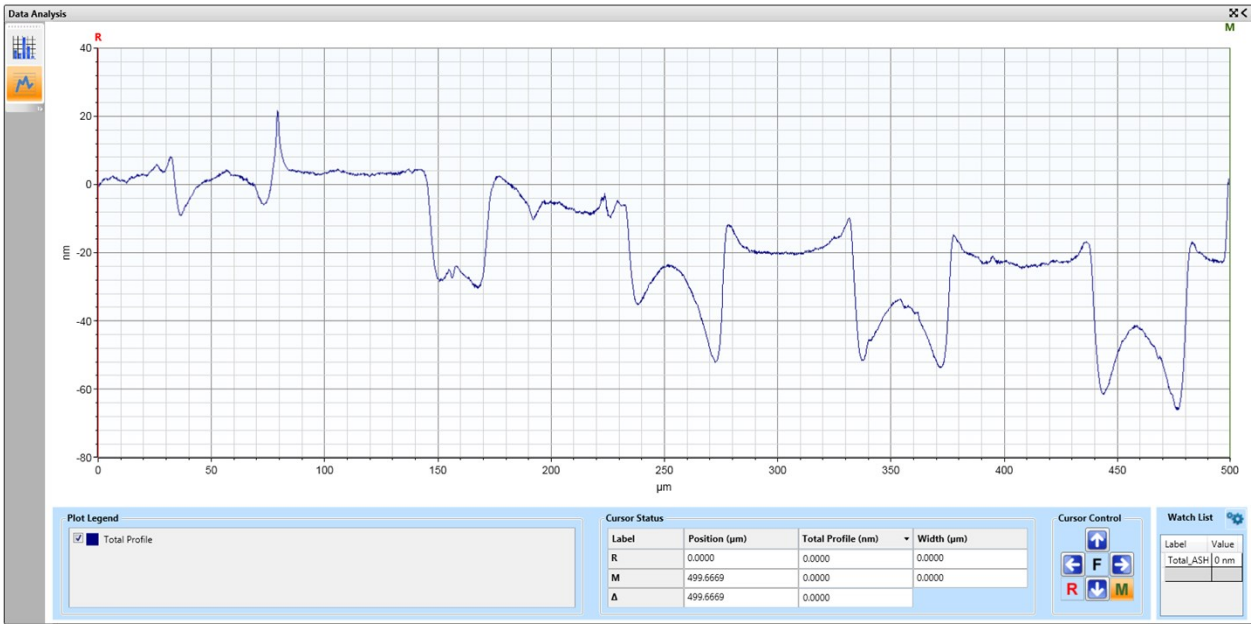

Figure S66: Linear profile 3 for PMMA wells fabricated from 3 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

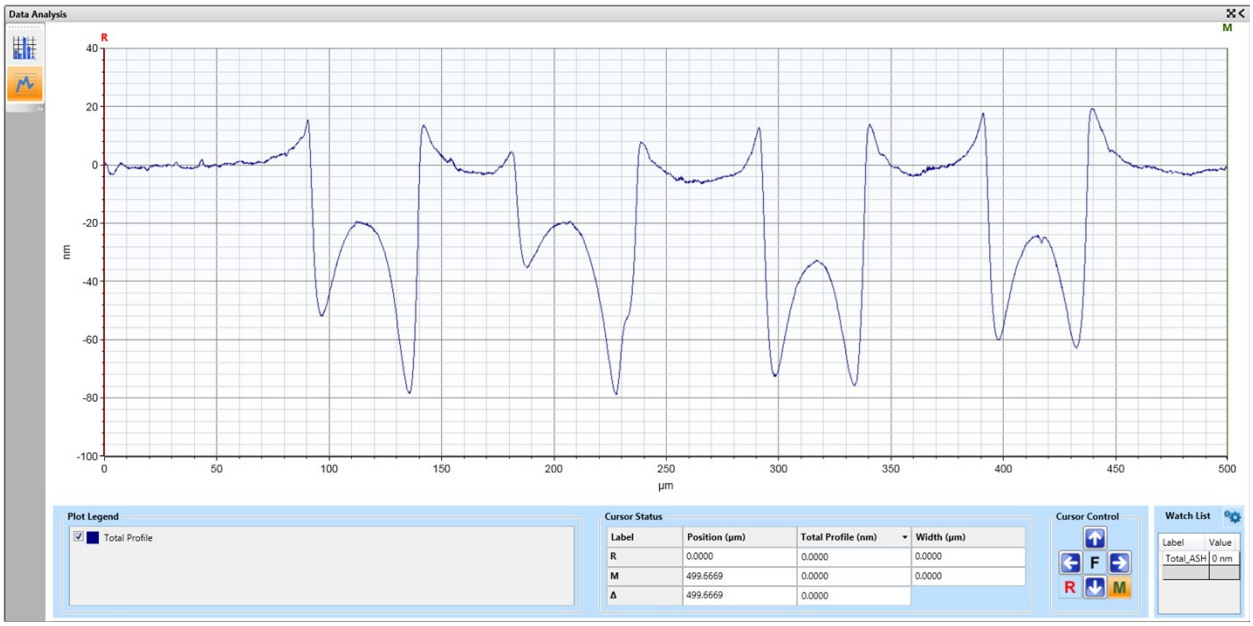

Figure S67: Linear profile 1 for PMMA wells fabricated from 4 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

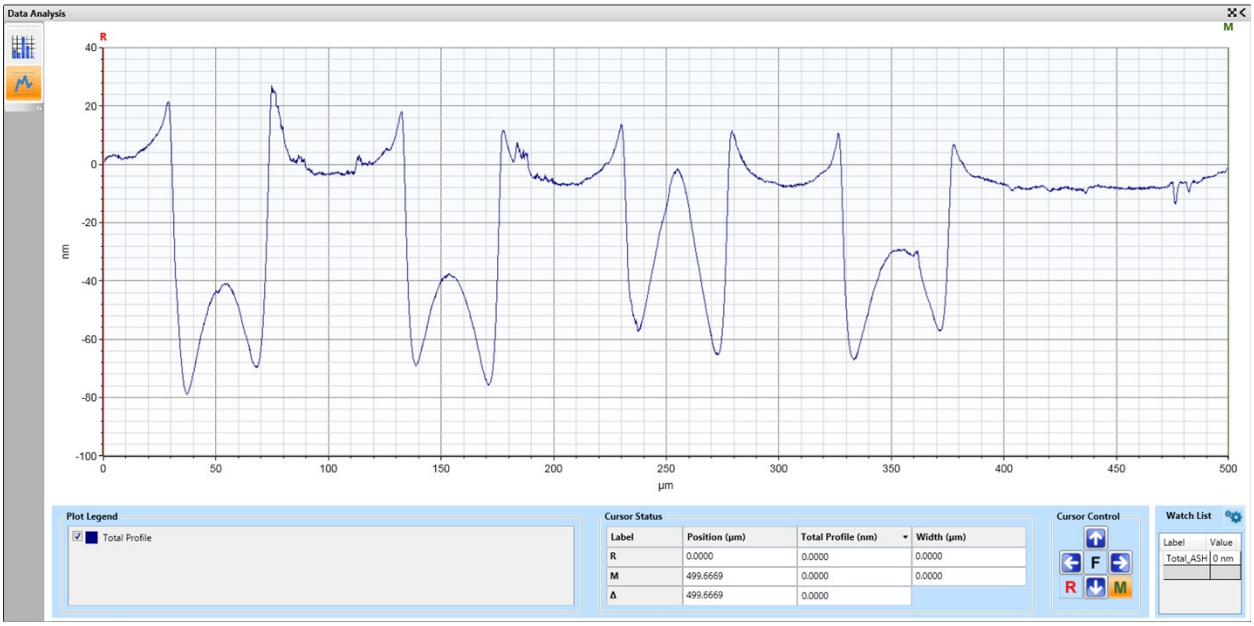

Figure S68: Linear profile 2 for PMMA wells fabricated from 4 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

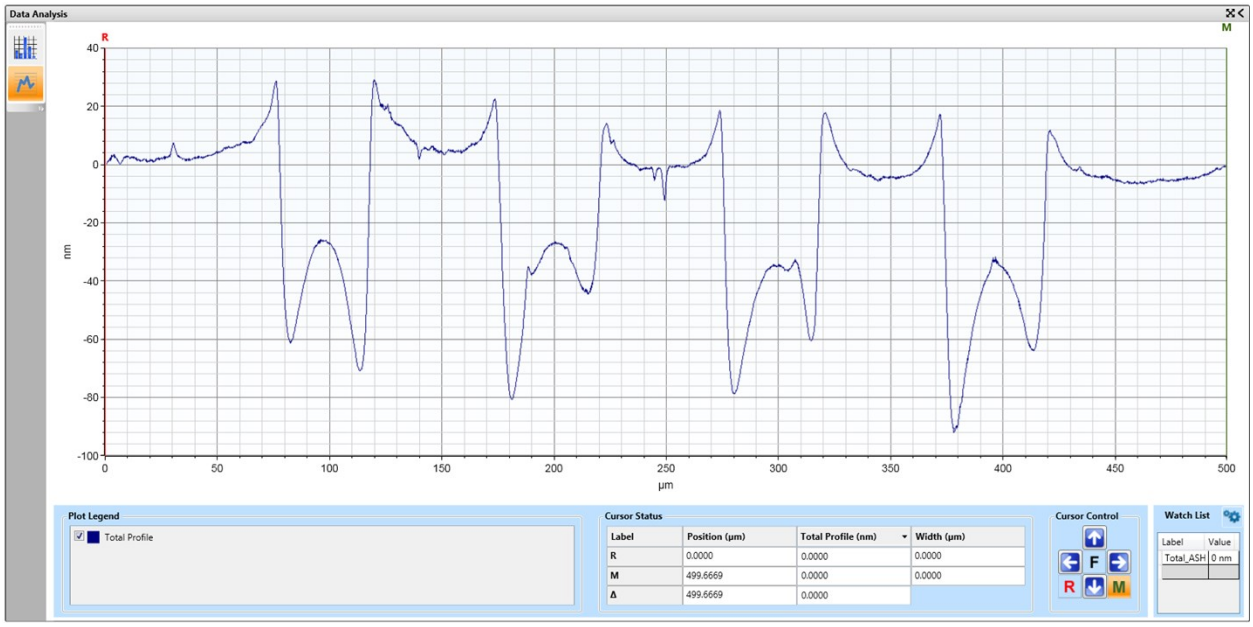

Figure S69: Linear profile 3 for PMMA wells fabricated from 4 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

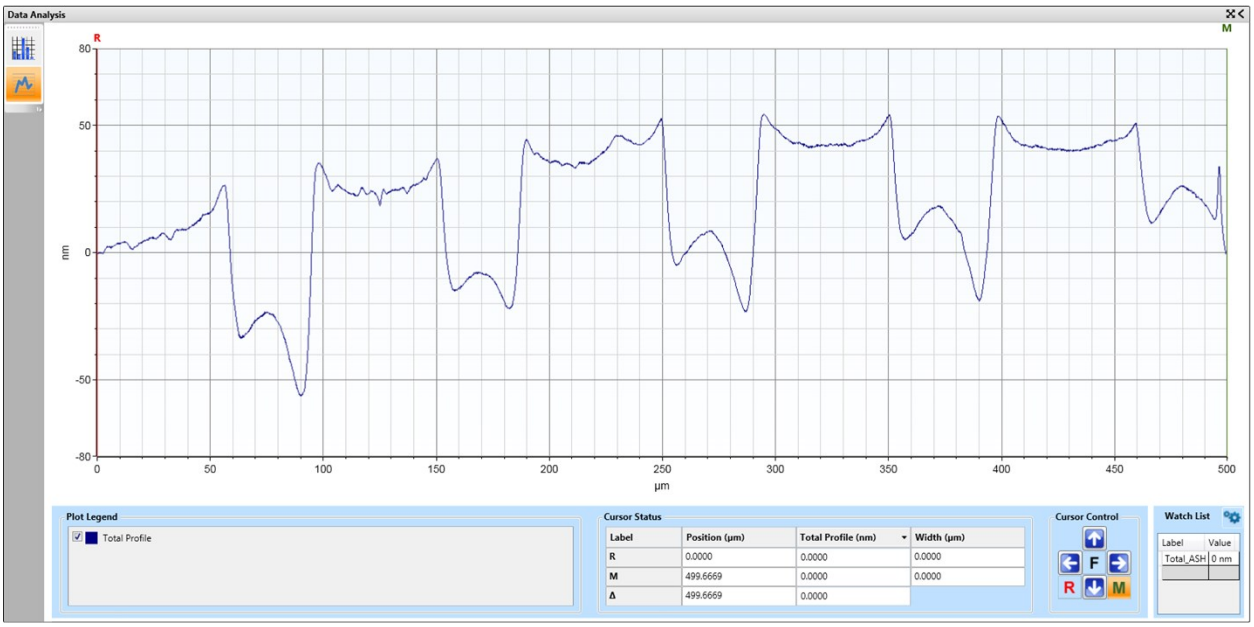

Figure S70: Linear profile 1 for PMMA wells fabricated from 5 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

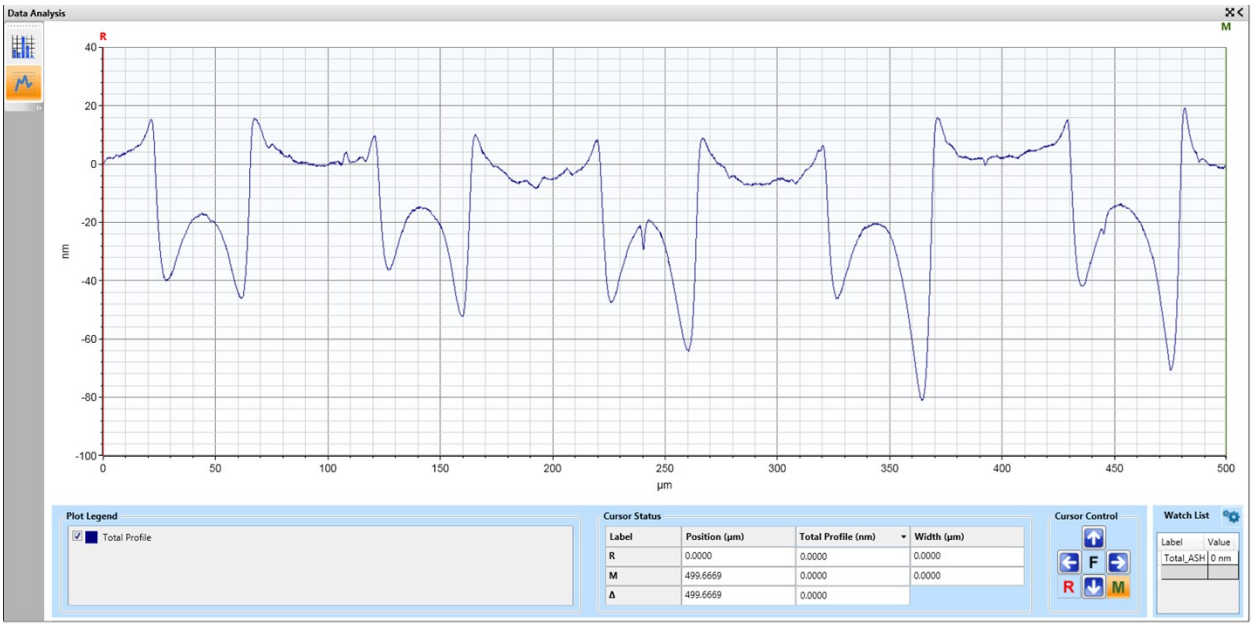

Figure S71: Linear profile 2 for PMMA wells fabricated from 5 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

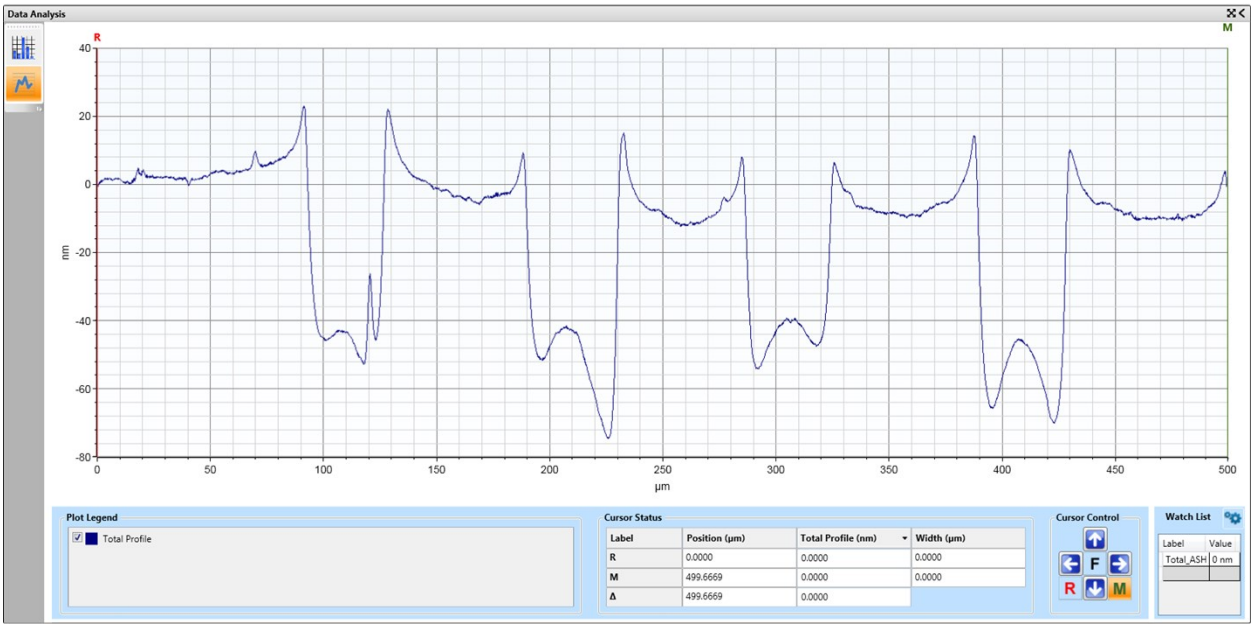

Figure S72: Linear profile 3 for PMMA wells fabricated from 5 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

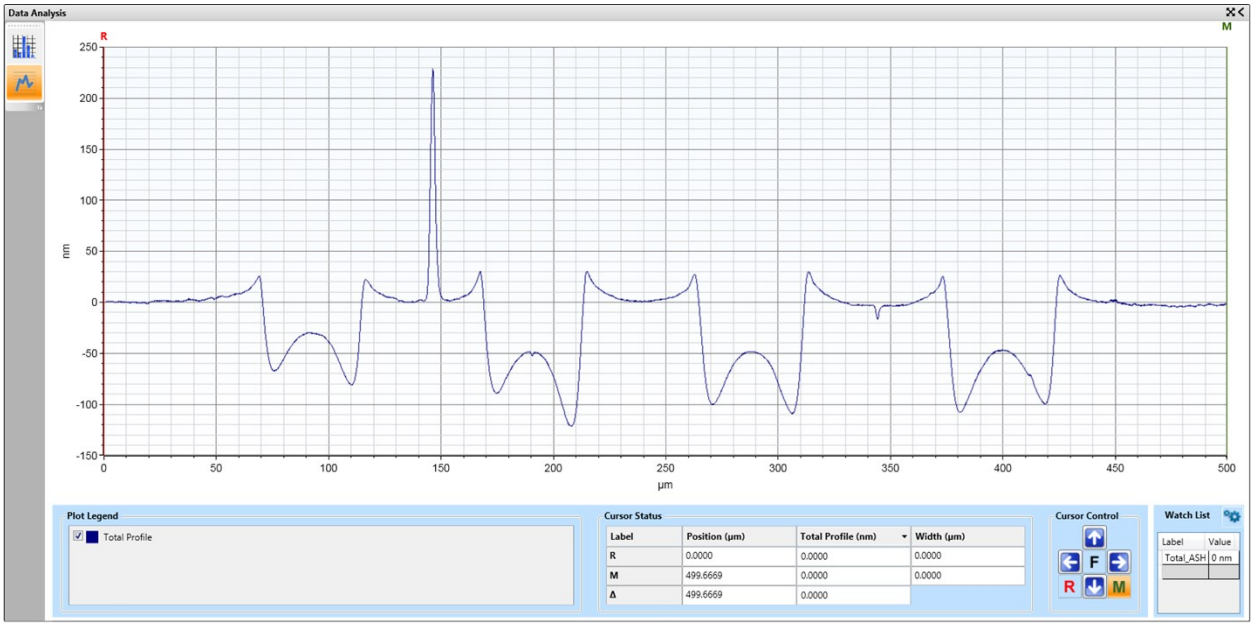

Figure S73: Linear profile 1 for PMMA wells fabricated from 6 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

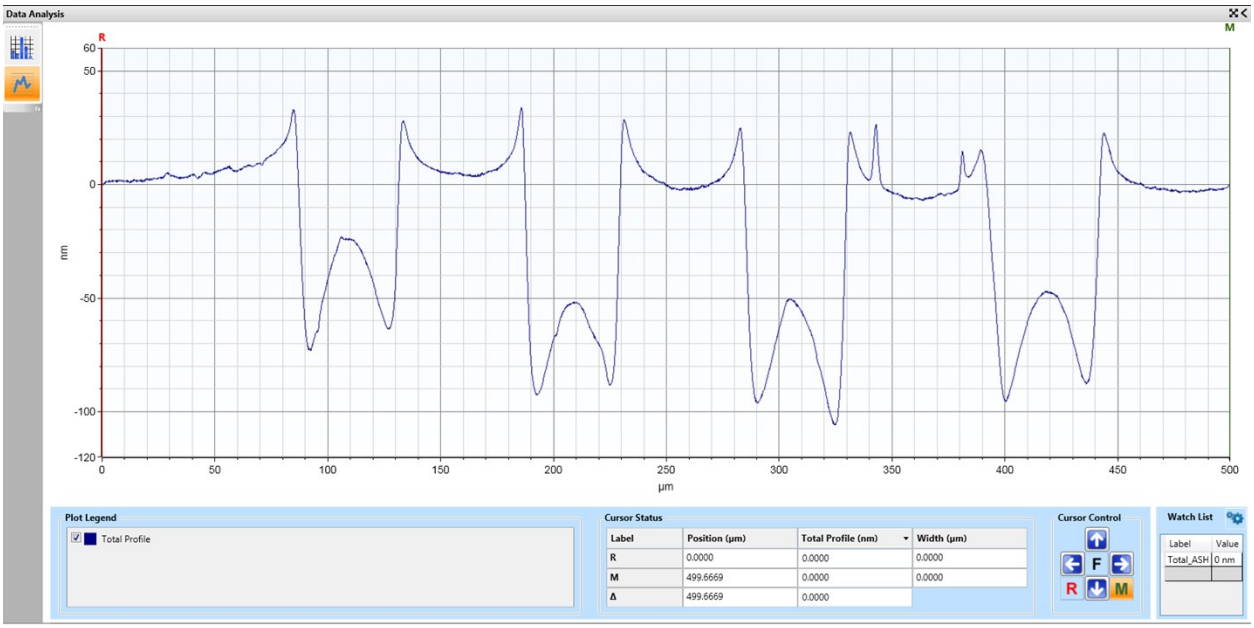

Figure S74: Linear profile 2 for PMMA wells fabricated from 6 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

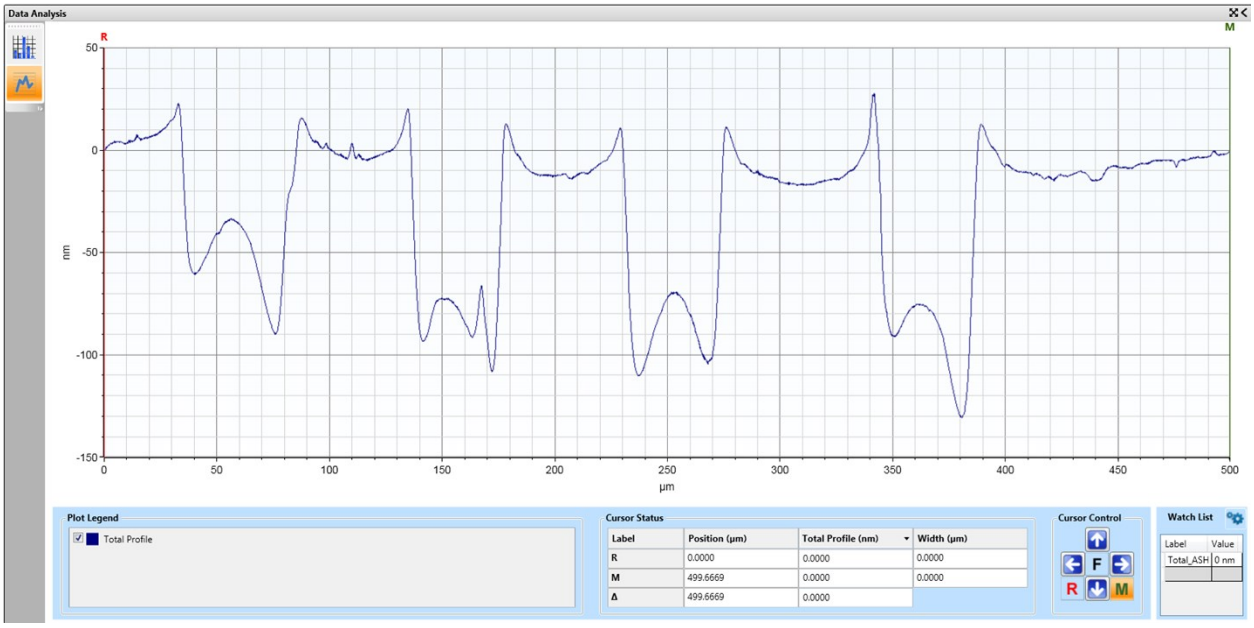

Figure S75: Linear profile 3 for PMMA wells fabricated from 6 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

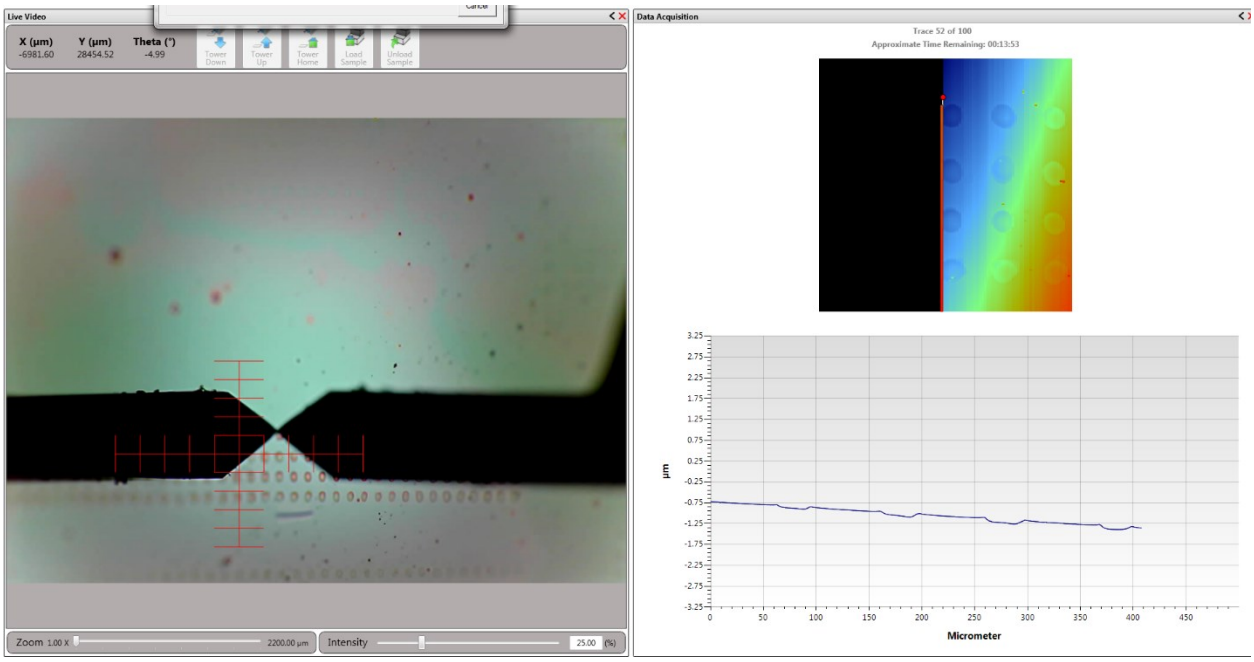

Figure S76: Set-up for profilometer instrument during a map scan. The instrument needle on the sample is shown on the left. The map scan in progress is shown on the right. The sample shown is PMMA wells fabricated from 6 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

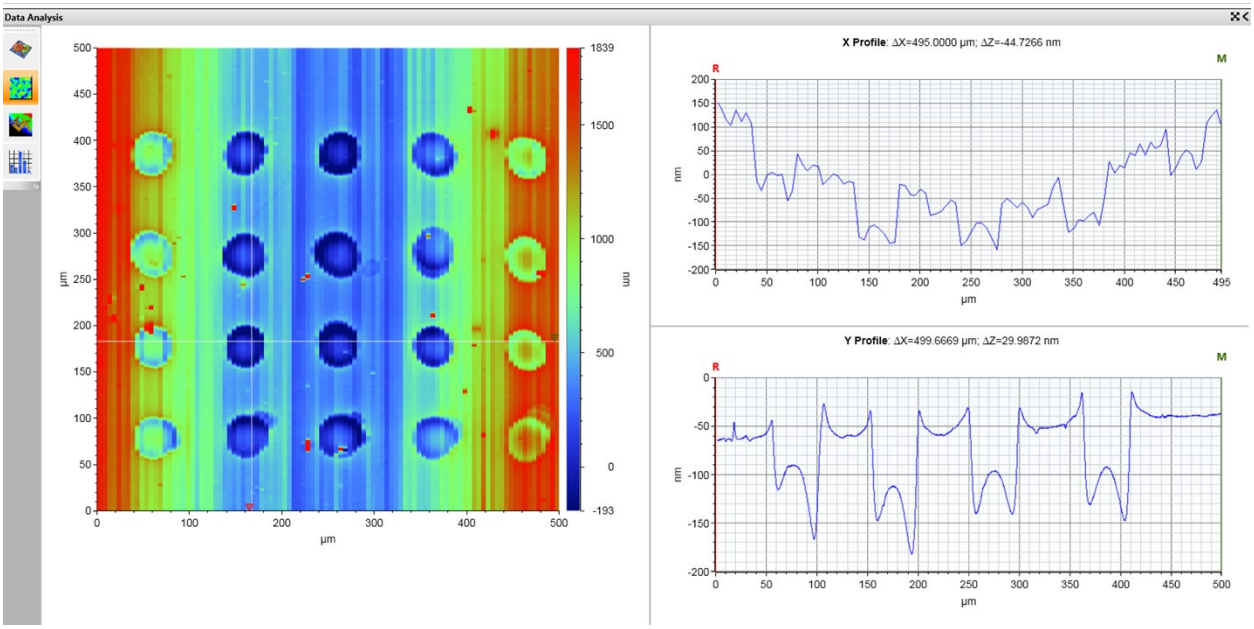

Figure S77: Map scan 1 for PMMA wells fabricated from 6 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

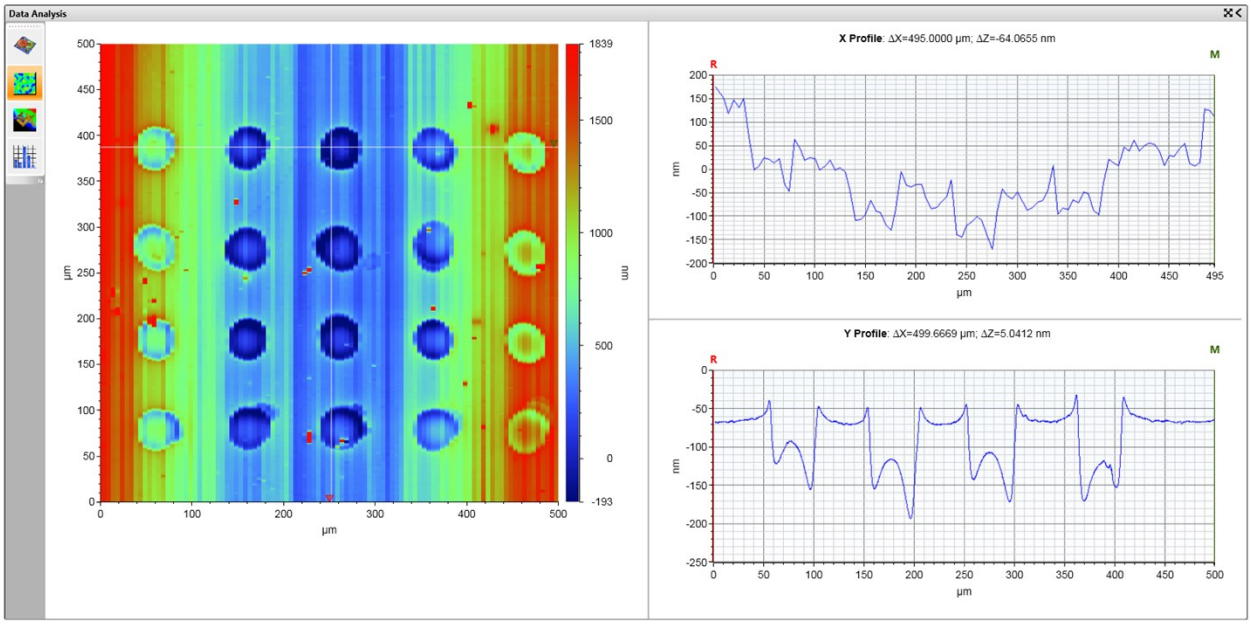

Figure S78: Map scan 2 for PMMA wells fabricated from 6 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

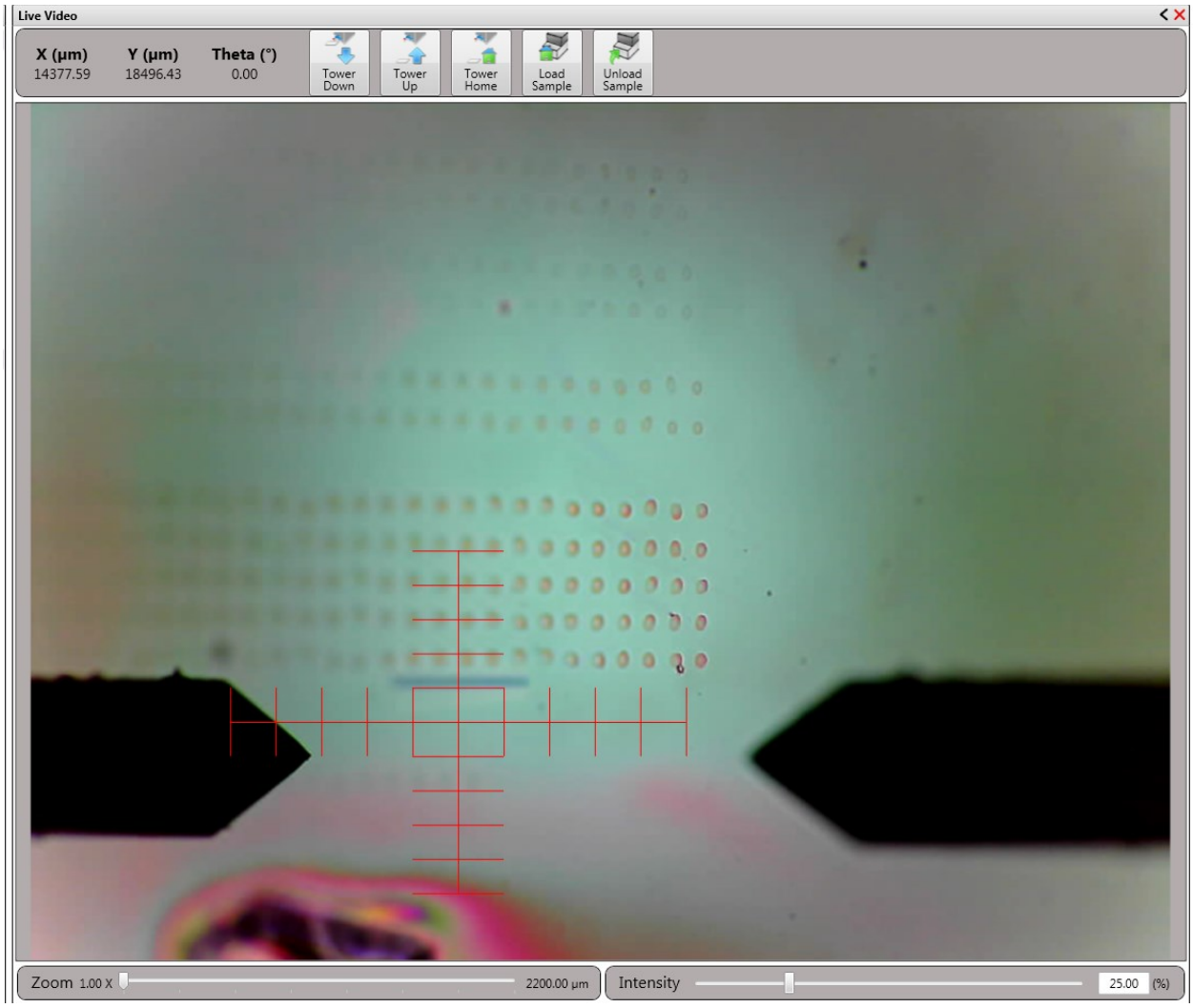

Figure S79: Set-up for profilometer instrument before a map scan. The instrument needle is shown hovering above the sample. The sample shown is PMMA wells fabricated from 5 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

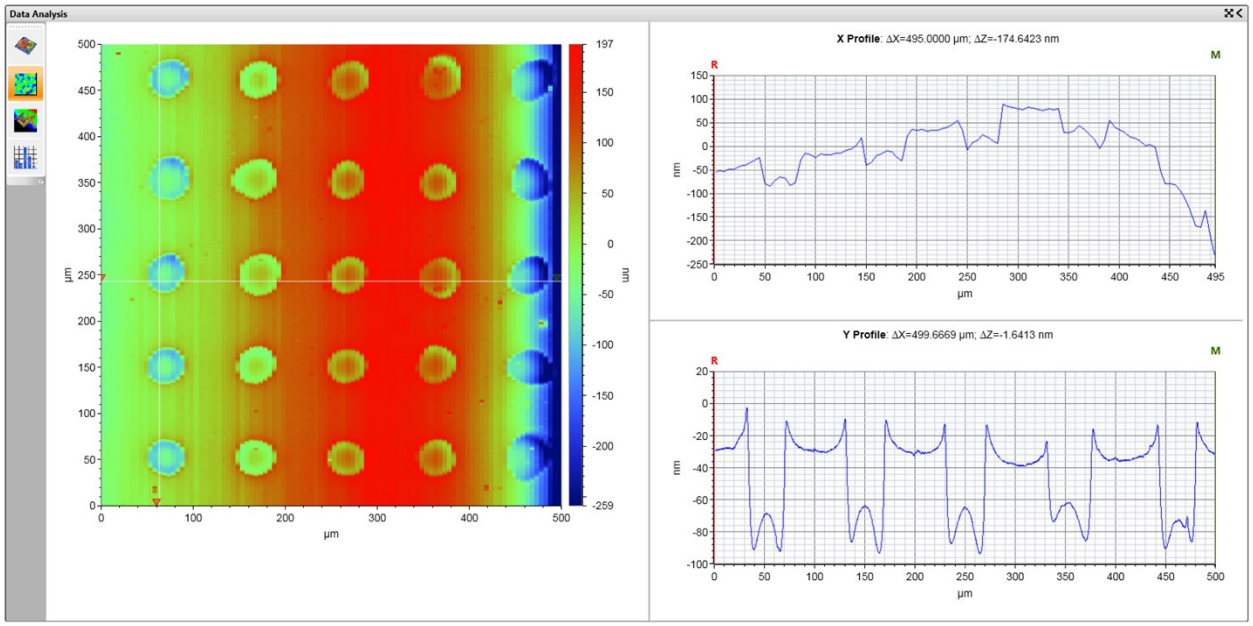

Figure S80: Map scan 1 for PMMA wells fabricated from 5 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

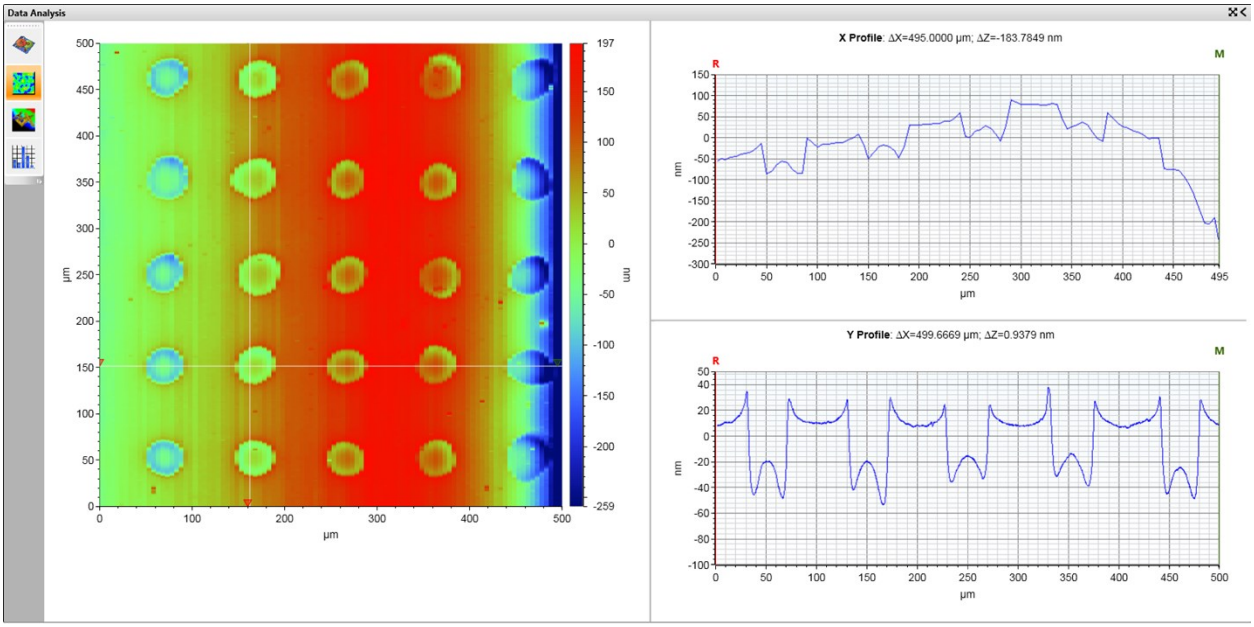

Figure S81: Map scan 2 for PMMA wells fabricated from 5 layers of CMC and 7% PMMA spin-coated for 1 min at 4000 rpm.

2. *Profilometer measurements for CMC on SiO_2*

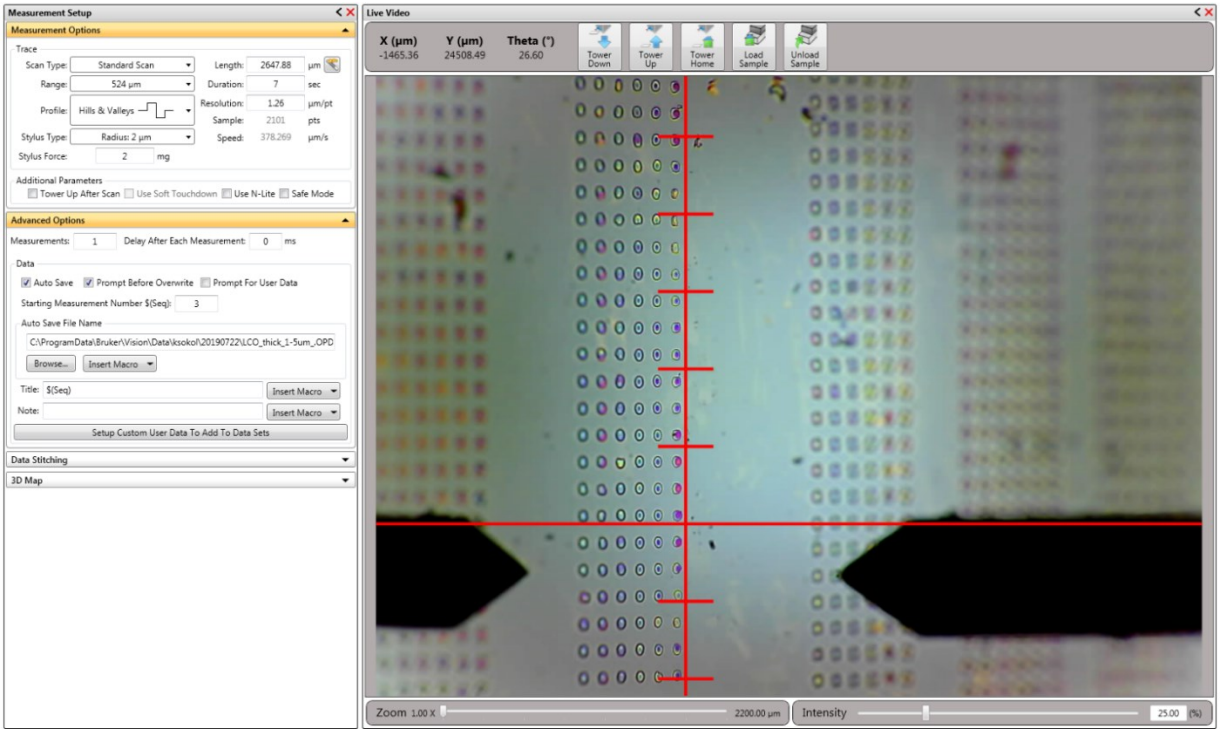

Figure S82: Set-up for profilometer instrument before a map scan. The sample shown is arrays of 6, 5, 4, 3, and 2 layers of CMC printed onto an SiO_2 wafer.

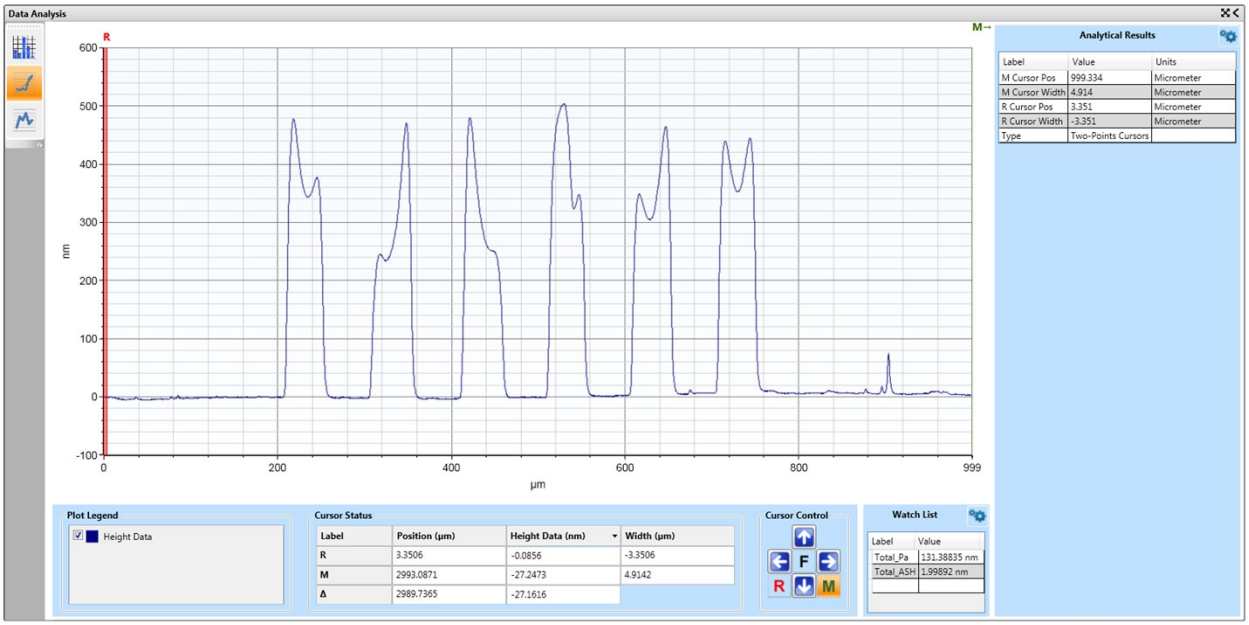

Figure S83: Linear profile 1 for 6 layers of CMC printed onto an SiO_2 wafer.

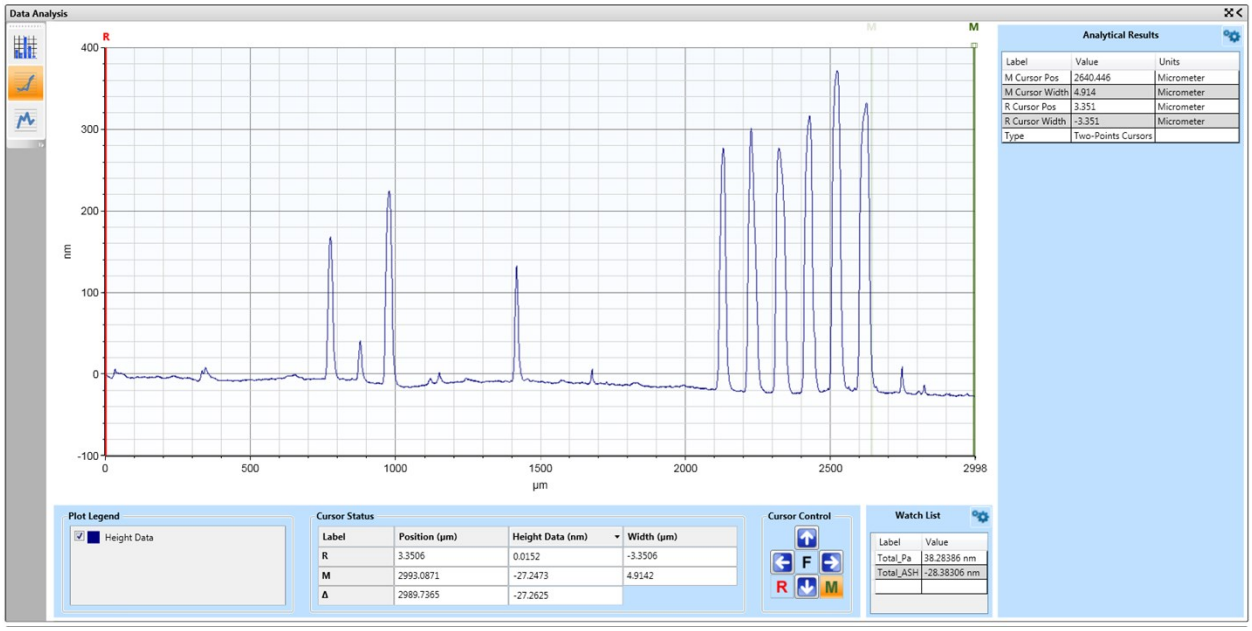

Figure S84: Linear profile 2 for 6 layers of CMC printed onto an SiO_2 wafer.

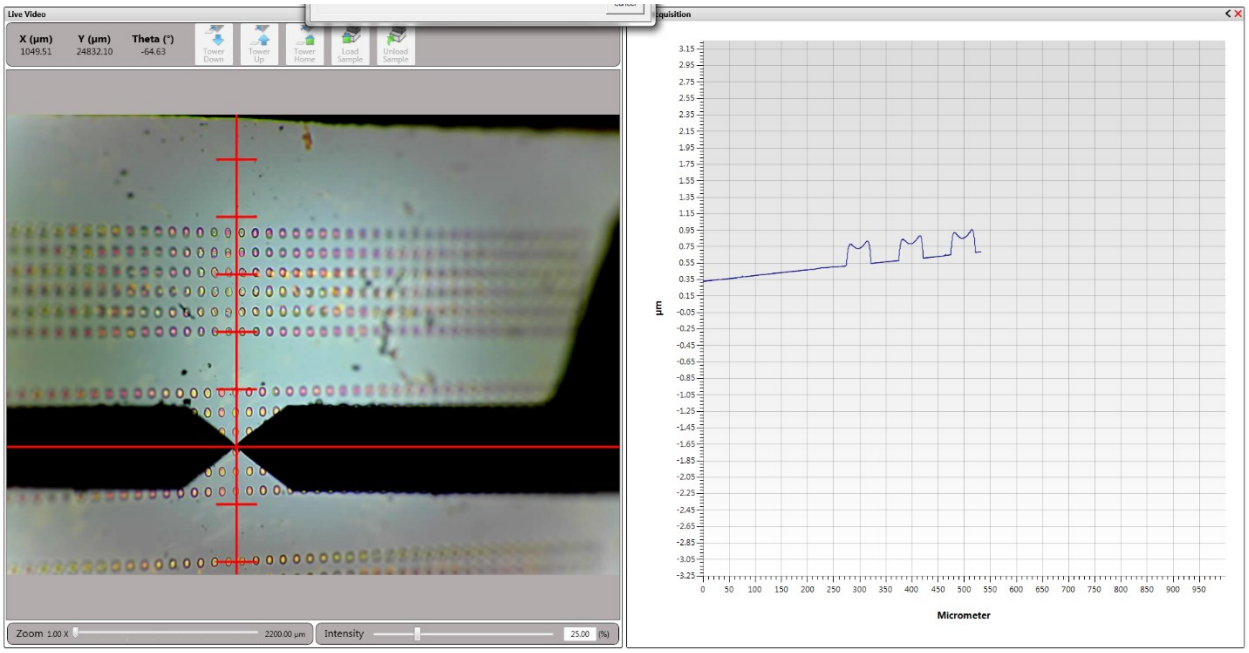

Figure S85: Set-up for profilometer instrument during a linear scan. The left shows the needle on a sample of 5 layers of CMC printed onto an SiO_2 wafer. The right shows a linear scan in progress.

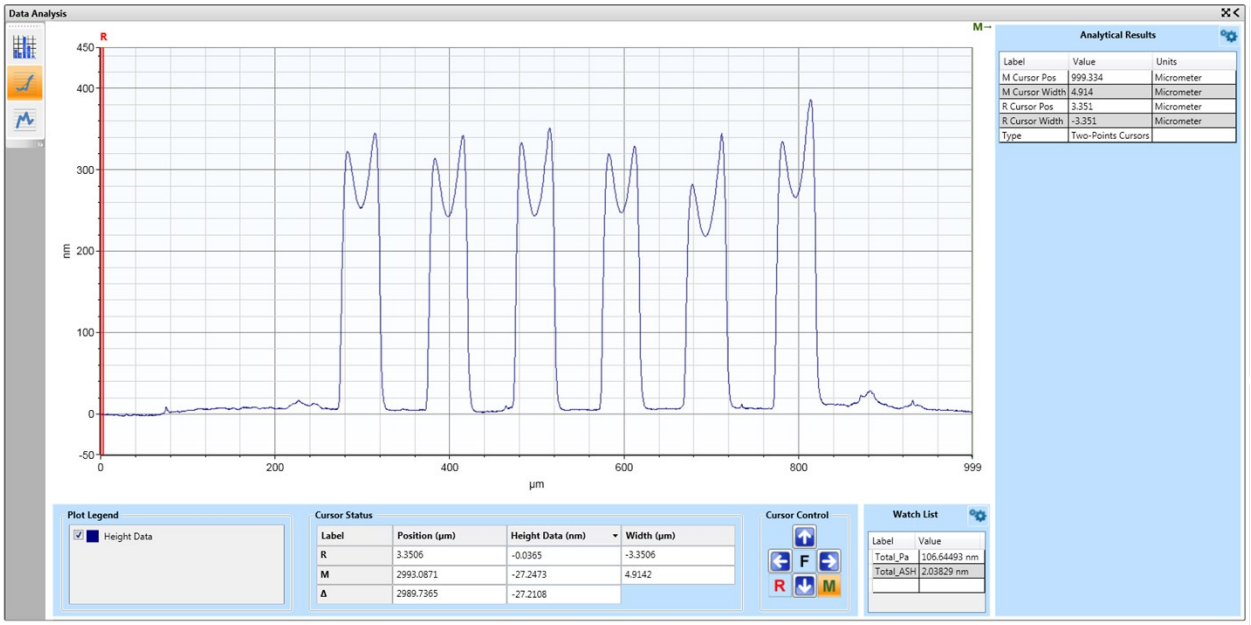

Figure S86: Linear profile for 5 layers of CMC printed onto an SiO_2 wafer.

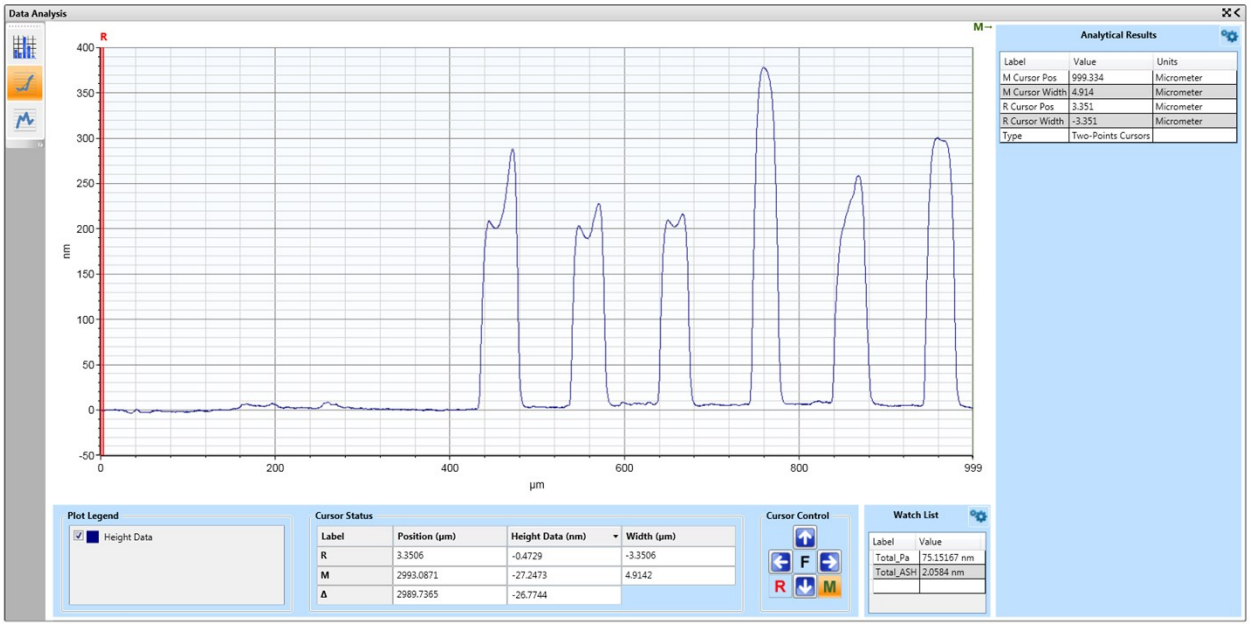

Figure S87: Linear profile for 4 layers of CMC printed onto an SiO_2 wafer.

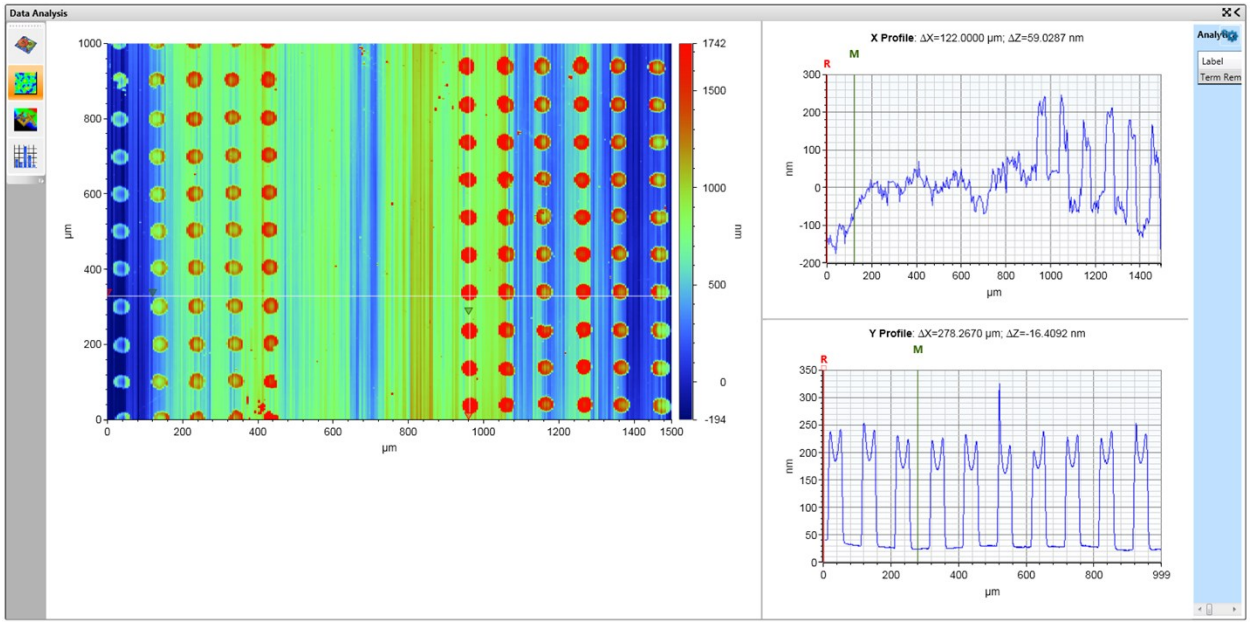

Figure S88: Map scan for 3 layers of CMC printed onto an SiO_2 wafer.

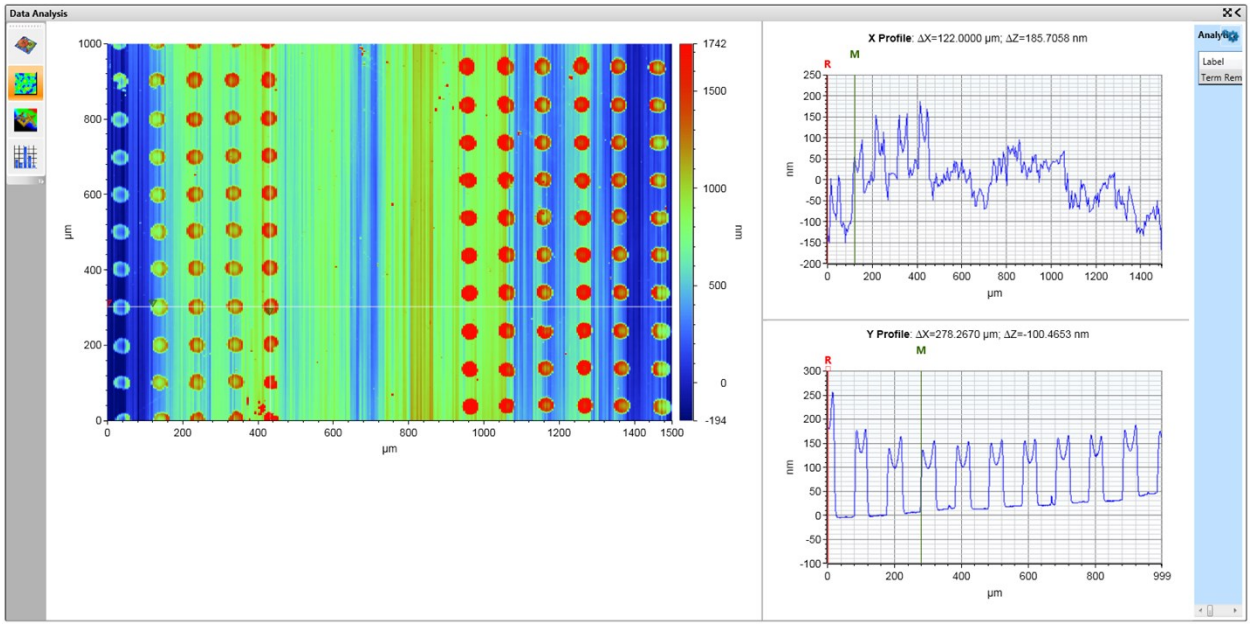

Figure S89: Map scan for 2 layers of CMC printed onto an SiO_2 wafer.

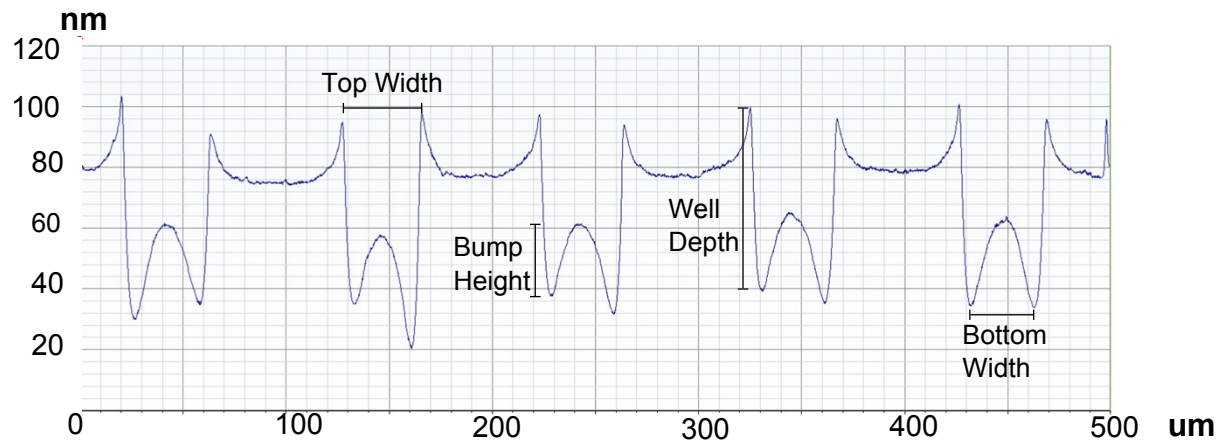

Figure S90: Example of profilometer dimensions of interest from a linear scan. The dimensions of interest include the width at the top and bottom of the well, the well depth, and the height of the bump formed at the base of each well.

3. *Tabulated data for PMMA well dimensions*

	Well Depth		
	4000	2500	1000
2	28.63333	18.70833	20.73333
3	23.6	20.20833	32.93333
4	32.9	26.5	31.93333
5	39.6	36.41667	40.76667
6	49.16667	35.04167	50.26667

Table S1: Well depth for PMMA wells prepared with various layers of CMC and spin-coated with 2% PMMA at various spin-rates. Well depth is defined in Figure S90.

	Well depth		
	2	4	7
2	28.63333	32.93333	31.5
3	23.6	62.86667	40.58333
4	32.9	57.26667	83.54167
5	39.6	63.6	66.5
6	49.16667	78.93333	121.6667

Table S2: Well depth for PMMA wells prepared with various layers of CMC and spin-coated with various concentrations of PMMA at 4000 rpm. Well depth is defined in Figure S90.

	Bump Height		
	4000	2500	1000
2	11.23333	13.25	11.7
3	15.2	12.625	20.1
4	15.26667	13	16.3
5	18.36667	13.75	19.4
6	20.93333	15.5	22.53333

Table S3: Bump Height for PMMA wells prepared with various layers of CMC and spin-coated with 2% PMMA at various spin-rates. Well depth is defined in Figure S90.

	Bump Height		
	2	4	7
2	11.23333	19.23333	16.20833
3	15.2	28.5	19.79167
4	15.26667	30.26667	39.79167
5	18.36667	18.46667	22.79167
6	20.93333	28.86667	44.83333

Table S4: Bump Height for PMMA wells prepared with various layers of CMC and spin-coated with various concentrations of PMMA at 4000 rpm. Well depth is defined in Figure S90.

Layers	Well depth	STD	Layers	Bump Height	STD
2	31.5	6.553972	2	16.20833	7.935702791
3	40.58333	8.857029	3	19.79167	6.817285295
4	83.54167	11.01334	4	39.79167	7.460375123
5	66.5	8.854891	5	22.79167	10.57109768
6	121.6667	23.21083	6	44.83333	8.122173168
Layers	Top Width	STD	Layers	Bottom Width	STD
2	53.91667	7.415688	2	35.33333	11.5941469
3	45.66667	4.53939	3	32.58333	6.388317937
4	49	3.384456	4	34.83333	3.069892901
5	44.16667	3.785939	5	29.25	5.310795181
6	48.75	3.621276	6	33.75	2.378884383

Table S5: Well depth, bump height, top width, and bottom width for PMMA wells prepared with various layers of CMC and spin-coated with 7% PMMA at 4000 rpm.

Layers	Well Depth	STD	Layers	Bump Height	STD
2	32.93333	5.734814	2	19.23333	2.258845
3	62.86667	18.26048	3	28.5	5.784832
4	57.26667	5.202563	4	30.26667	6.355163
5	63.6	3.983	5	18.46667	7.958523
6	78.93333	9.17852	6	28.86667	13.04589
Layers	Top Width	STD	Layers	Bottom Width	STD
2	39.33333	3.352327	2	29.6	3.5817
3	36.66667	2.690371	3	26.26667	3.239635
4	40.46667	1.959106	4	29.8	2.17781
5	38.53333	2.996824	5	25.6	4.777925
6	39.13333	4.172472	6	25.33333	3.41565

Table S6: Well depth, bump height, top width, and bottom width for PMMA wells prepared with various layers of CMC and spin-coated with 4% PMMA at 4000 rpm.

Layers	Well Depth	STD	Layers	Bump Height	STD
2	28.63333	15.37329	2	11.23333	6.505126
3	23.6	2.977295	3	15.2	4.780167
4	32.9	5.862106	4	15.26667	7.912167
5	39.6	7.67696	5	18.36667	3.476794
6	49.16667	10.29679	6	20.93333	8.552081
Layers	Top Width	STD	Layers	Bottom Width	STD
2	29.86667	8.078779	2	20.4	7.500476
3	36.4	3.621365	3	27.2	3.447566
4	36.06667	4.415341	4	25.13333	4.389381
5	36.53333	4.323799	5	25.93333	4.697517
6	38.33333	5.639993	6	25.13333	7.160074

Table S7: Well depth, bump height, top width, and bottom width for PMMA wells prepared with various layers of CMC and spin-coated with 2% PMMA at 4000 rpm.

Layers	Well Depth	STD	Layers	Bump Height	STD
2	18.70833	5.898607	2	13.25	2.981000442
3	20.20833	1.157158	3	12.625	0.74238559
4	26.5	1.381699	4	13	1.796461168
5	36.41667	4.893564	5	13.75	10.78403702
6	35.04167	3.018566	6	15.5	6.03775997
Layers	Top Width	STD	Layers	Bottom Width	STD
2	44	2.486326	2	32.58333	2.64431924
3	44.5	2.067058	3	33	2.044949433
4	43.41667	2.193309	4	30.16667	2.40580107
5	40.33333	4.792671	5	25.83333	6.793490646
6	46.5	5.744563	6	31.75	6.355026643

Table S8: Well depth, bump height, top width, and bottom width for PMMA wells prepared with various layers of CMC and spin-coated with 2% PMMA at 2500 rpm.

Layers	Well Depth	STD	Layers	Bump Height	STD
2	20.73333	1.821172	2	11.7	1.698739
3	32.93333	3.369329	3	20.1	3.531491
4	31.93333	7.020039	4	16.3	8.641263
5	40.76667	4.254689	5	19.4	5.039841
6	50.26667	7.694772	6	22.53333	8.844826
Layers	Top Width	STD	Layers	Bottom Width	STD
2	46.66667	3.57904	2	33.66667	4.064949
3	47.66667	1.112697	3	34.33333	1.496026
4	47.53333	3.961722	4	32.46667	5.040786
5	49.73333	3.807261	5	34.26667	3.217512
6	49.26667	5.284298	6	31.53333	6.401637

Table S9: Well depth, bump height, top width, and bottom width for PMMA wells prepared with various layers of CMC and spin-coated with 2% PMMA at 1000 rpm.

4. *Platinum deposition time series for various conditions*

Figure S91: Platinum time series for sample prepared with 2 layers of CMC and 2% PMMA spin-coated for 1 minute at 1000 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 300 s, and 360 s.

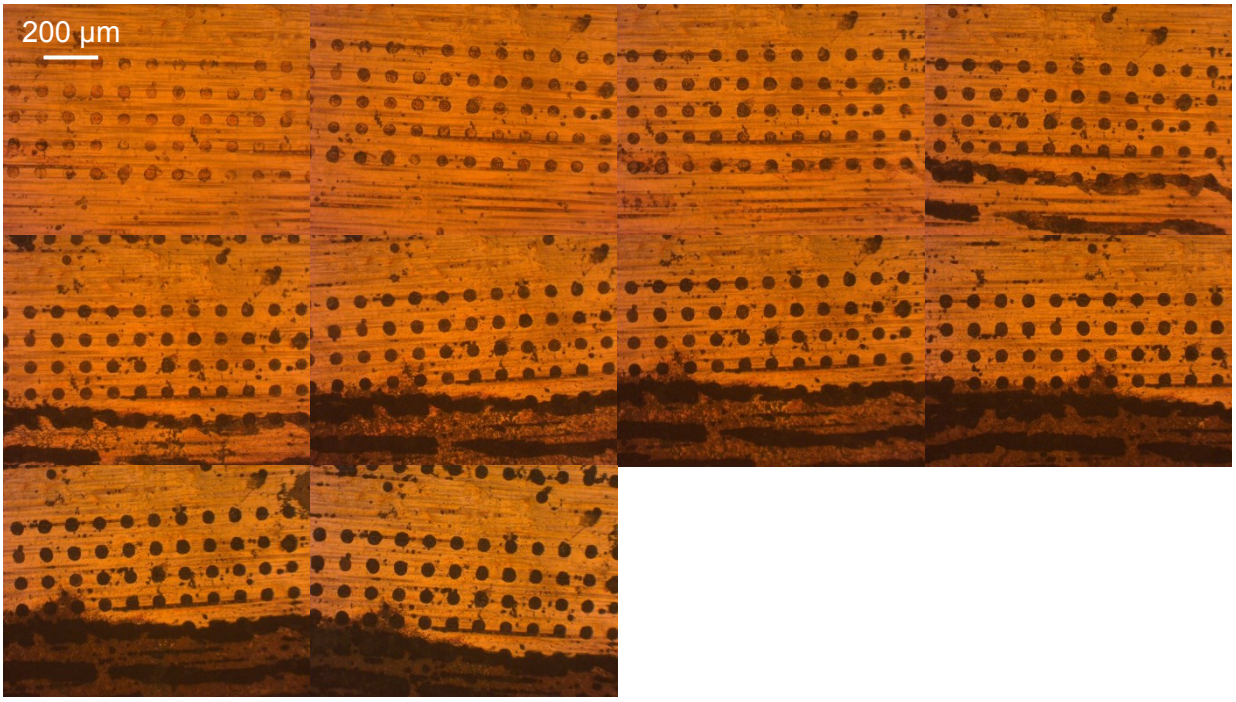

Figure S92: Platinum time series for sample prepared with 3 layers of CMC and 2% PMMA spin-coated for 1 minute at 1000 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 300 s, and 360 s.

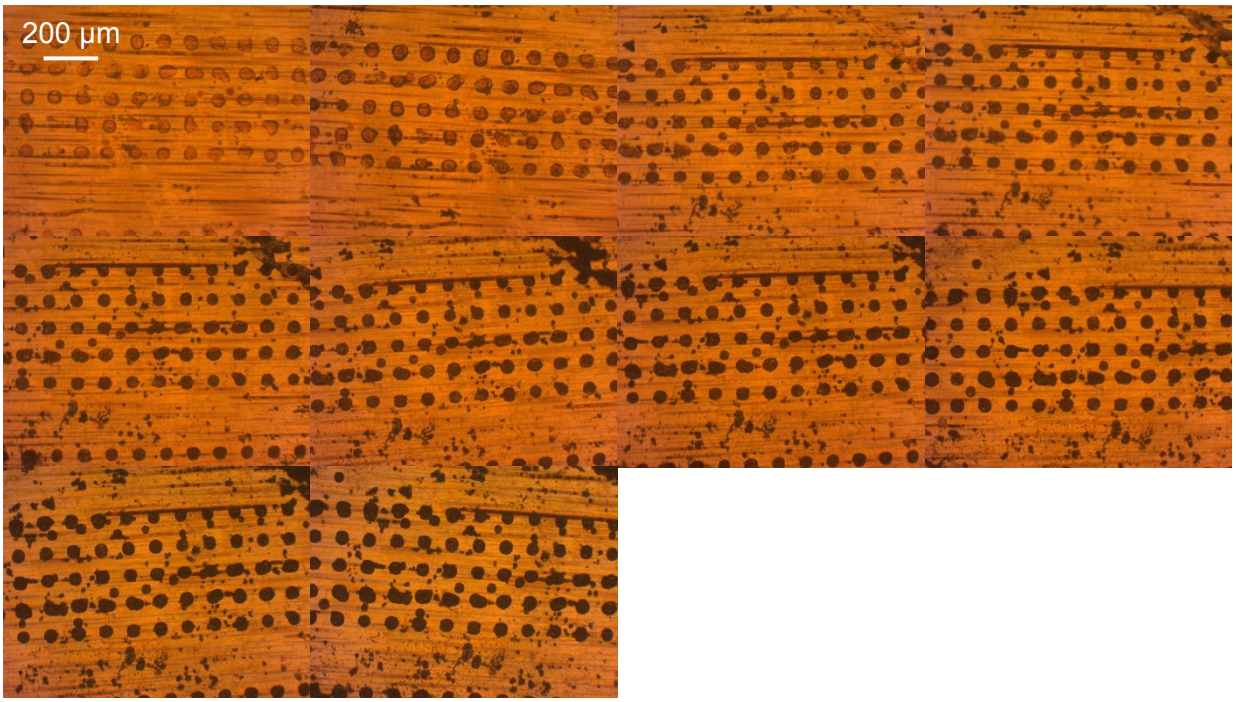

Figure S93: Platinum time series for sample prepared with 4 layers of CMC and 2% PMMA spin-coated for 1 minute at 1000 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 300 s, and 360 s.

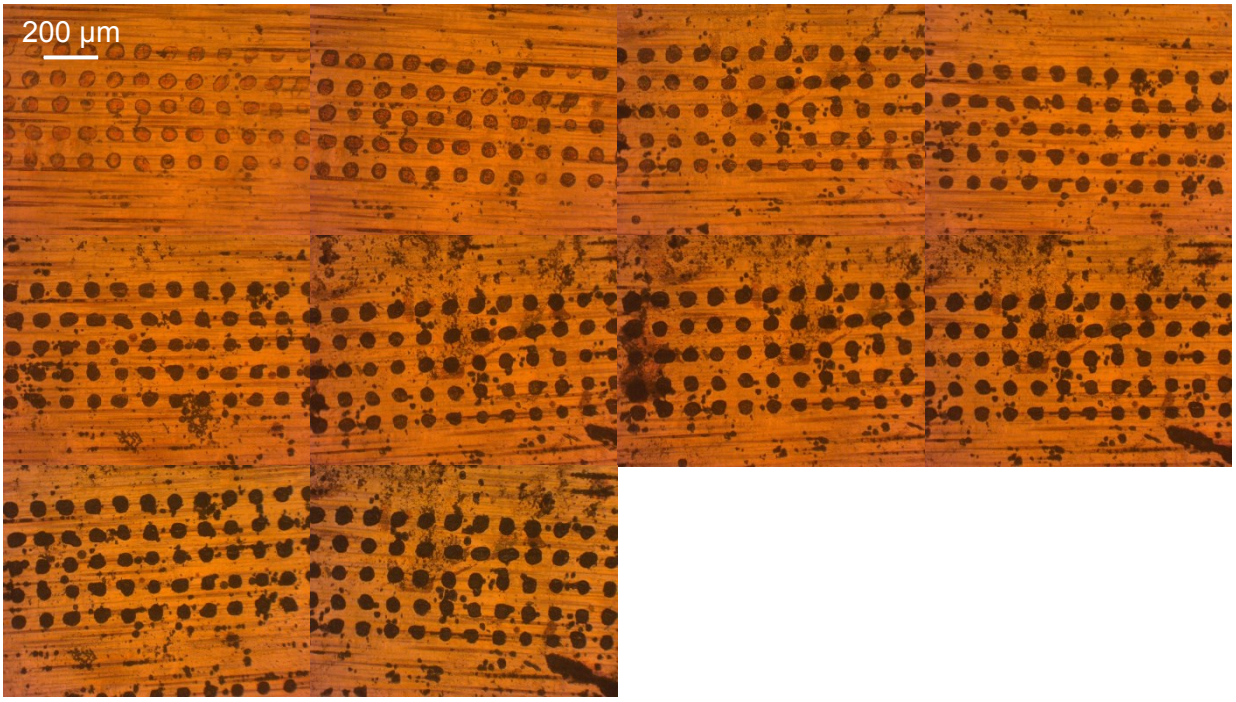

Figure S94: Platinum time series for sample prepared with 5 layers of CMC and 2% PMMA spin-coated for 1 minute at 1000 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 300 s, and 360 s.

Figure S95: Platinum time series for sample prepared with 6 layers of CMC and 2% PMMA spin-coated for 1 minute at 1000 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 300 s, and 360 s.

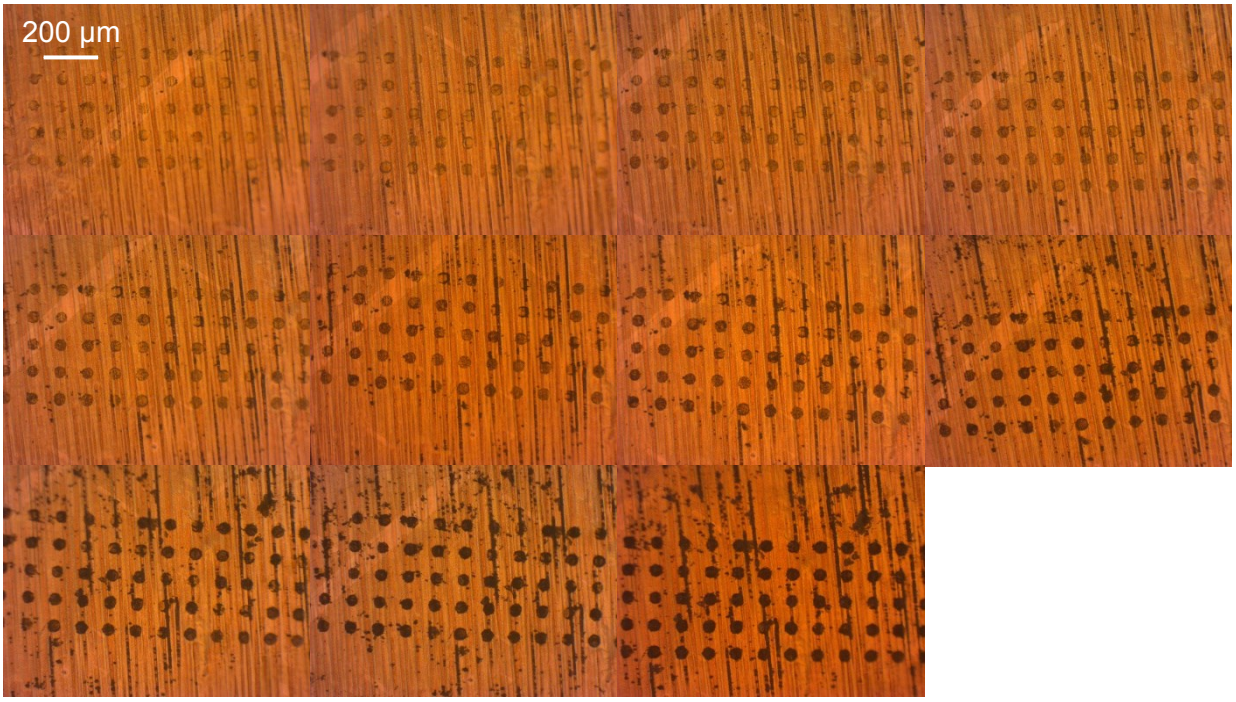

Figure S96: Platinum time series for sample prepared with 2 layers of CMC and 2% PMMA spin-coated for 1 minute at 2500 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, 300 s, 360 s, 420 s, and 720 s.

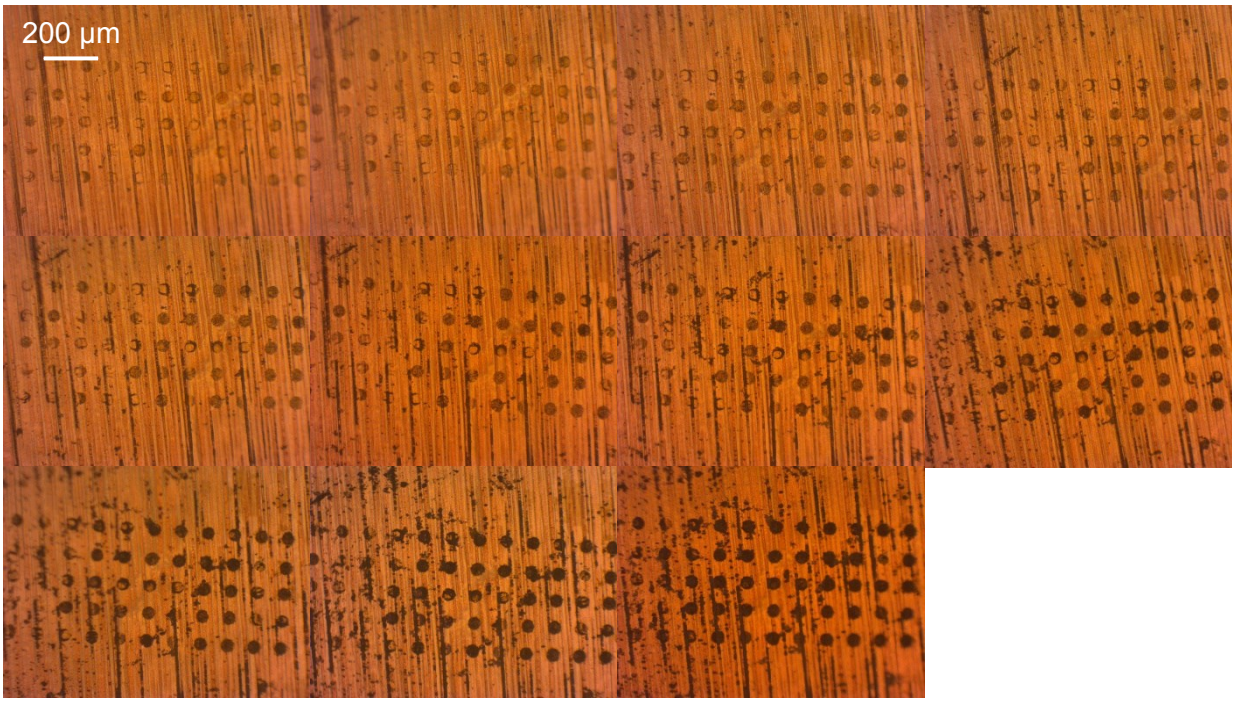

Figure S97: Platinum time series for sample prepared with 3 layers of CMC and 2% PMMA spin-coated for 1 minute at 2500 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, 300 s, 360 s, 420 s, and 720 s.

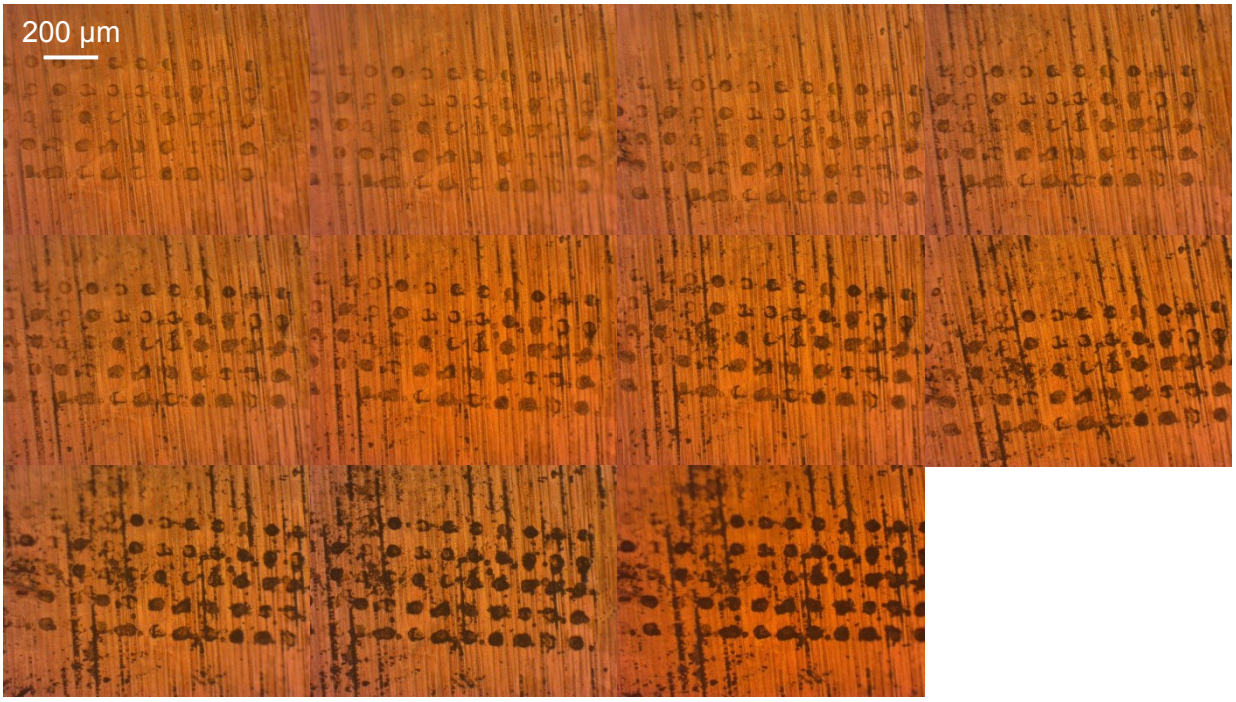

Figure S98: Platinum time series for sample prepared with 4 layers of CMC and 2% PMMA spin-coated for 1 minute at 2500 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, 300 s, 360 s, 420 s, and 720 s.

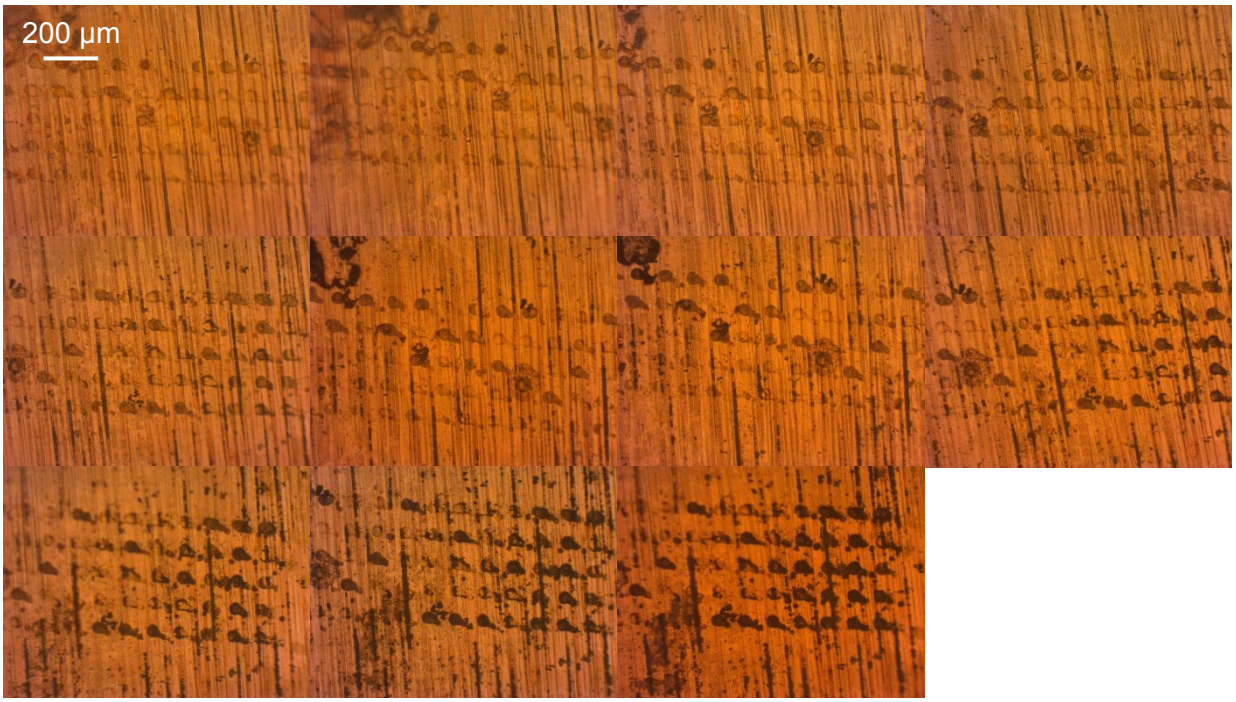

Figure S99: Platinum time series for sample prepared with 5 layers of CMC and 2% PMMA spin-coated for 1 minute at 2500 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, 300 s, 360 s, 420 s, and 720 s.

Figure S100: Platinum time series for sample prepared with 6 layers of CMC and 2% PMMA spin-coated for 1 minute at 2500 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, 300 s, 360 s, 420 s, and 720 s.

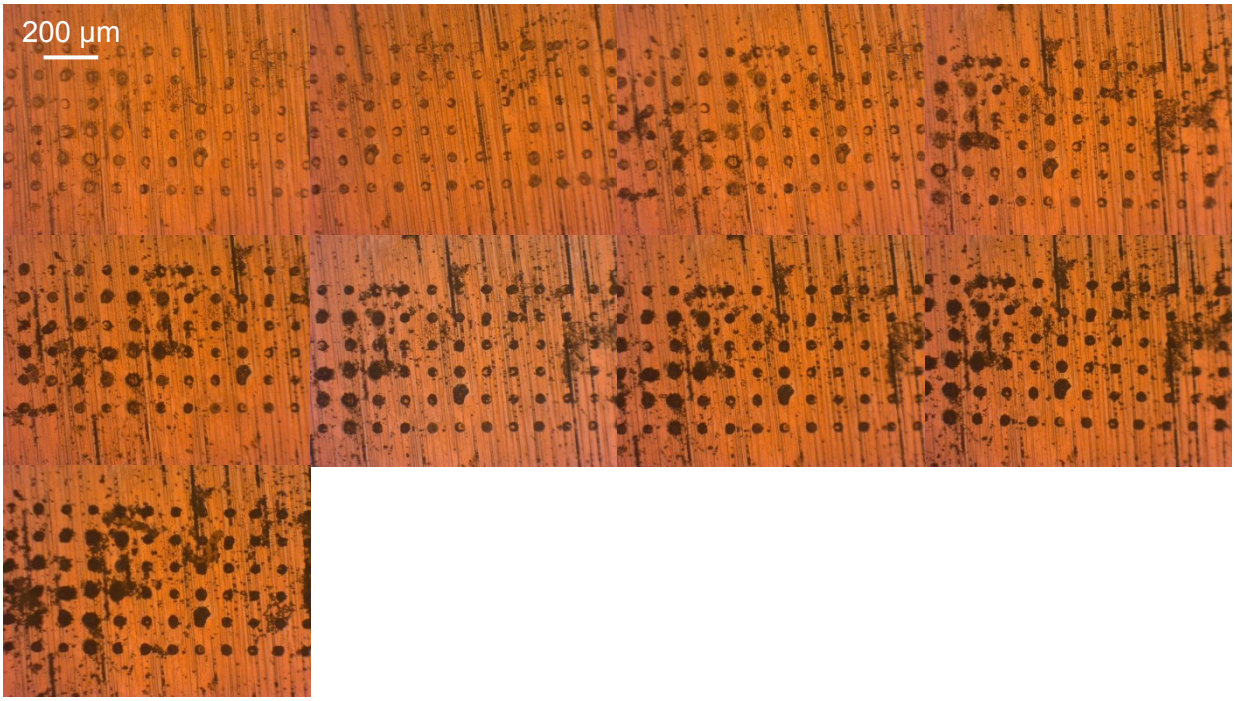

Figure S101: Platinum time series for sample prepared with 2 layers of CMC and 2% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, 300 s, and 360 s.

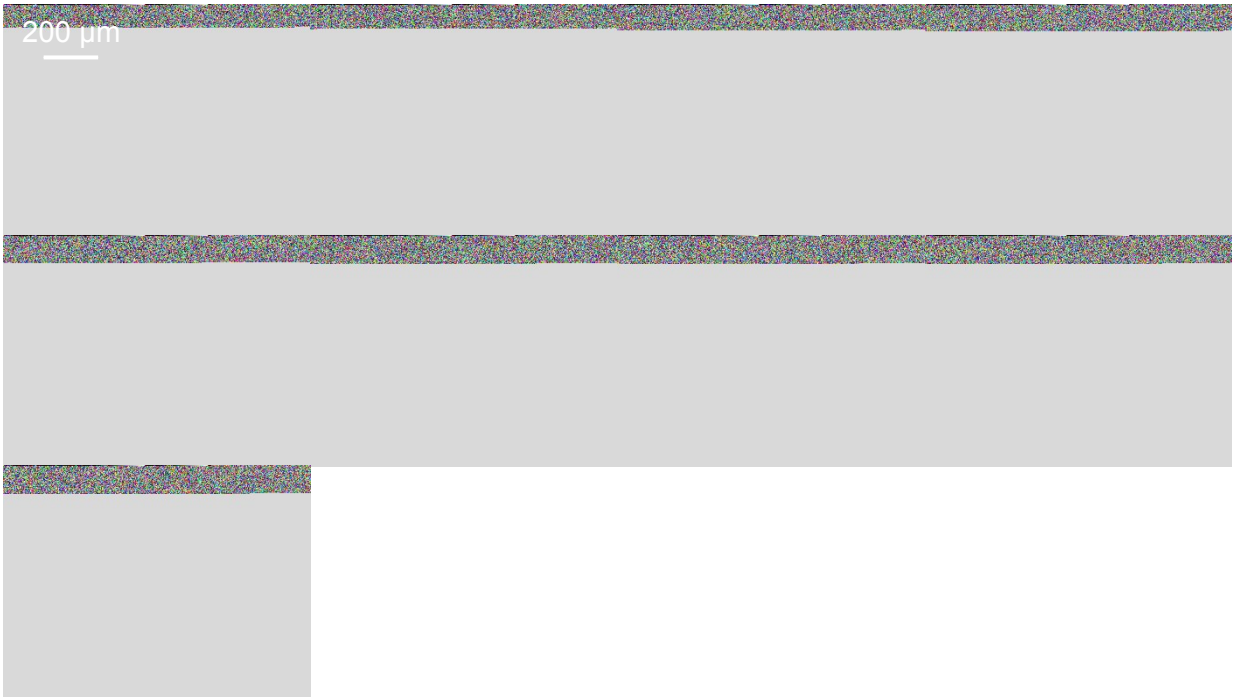

Figure S102: Platinum time series for sample prepared with 3 layers of CMC and 2% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, 300 s, and 360 s.

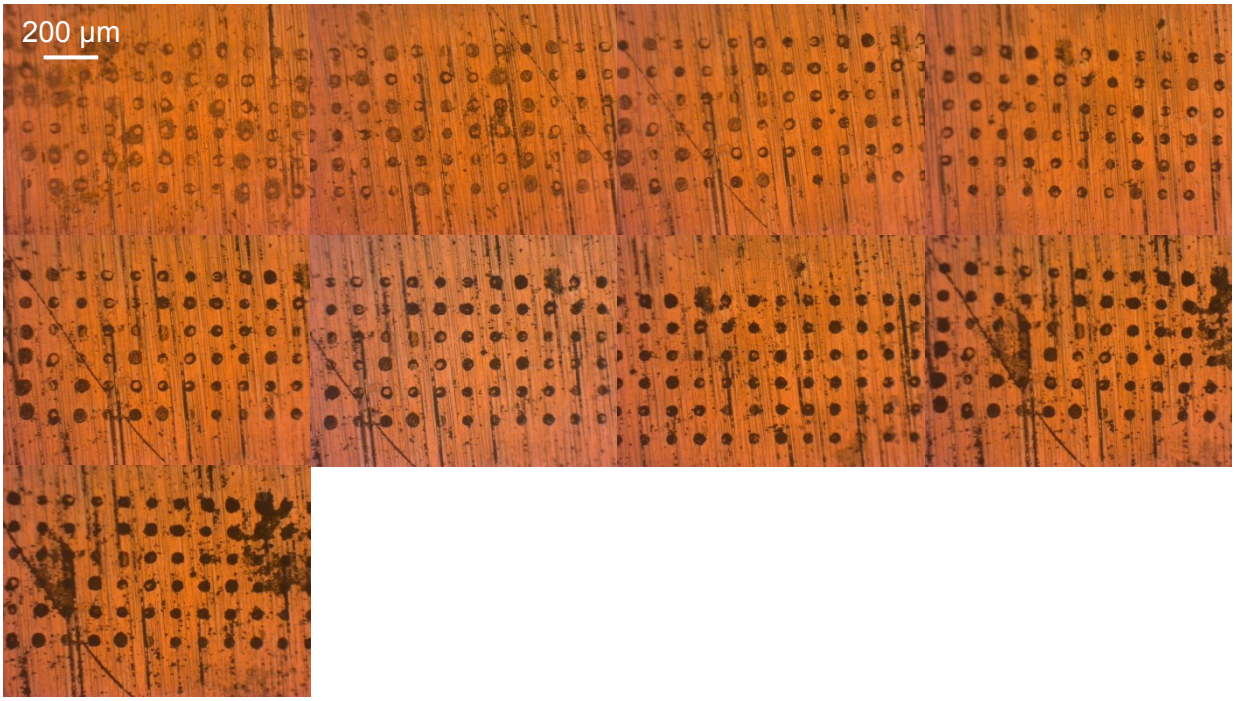

Figure S103: Platinum time series for sample prepared with 4 layers of CMC and 2% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, 300 s, and 360 s.

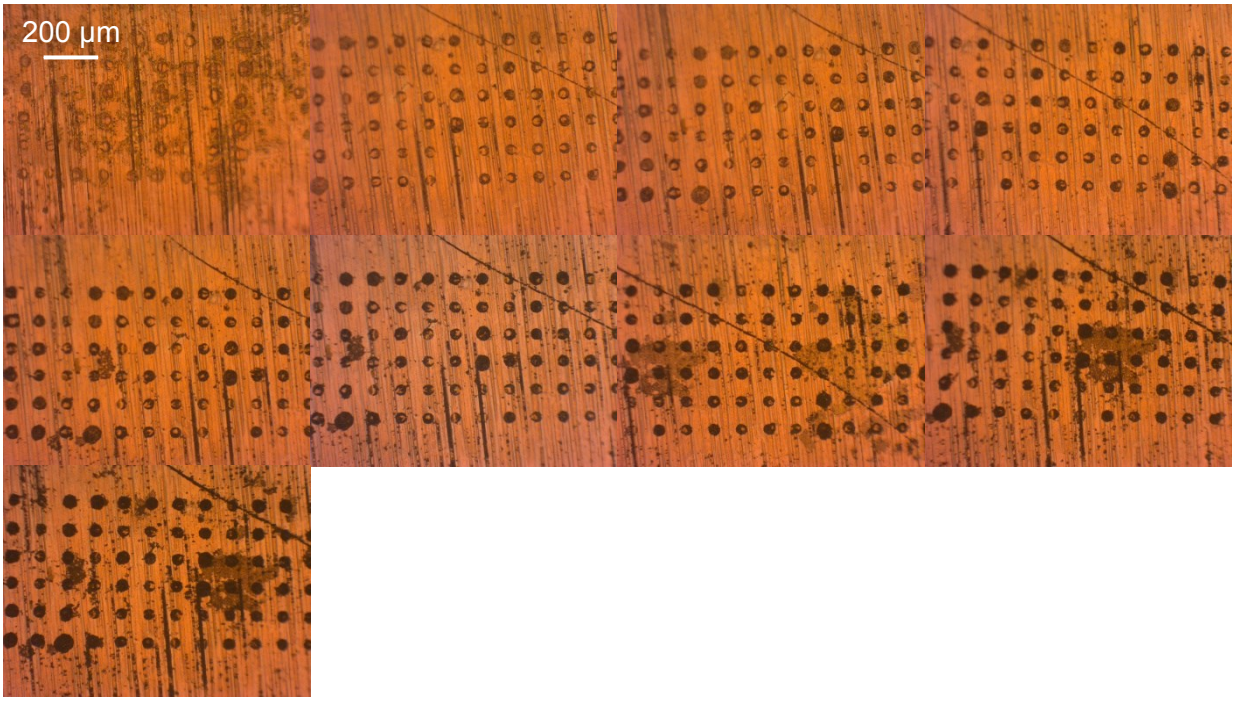

Figure S104: Platinum time series for sample prepared with 5 layers of CMC and 2% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, 300 s, and 360 s.

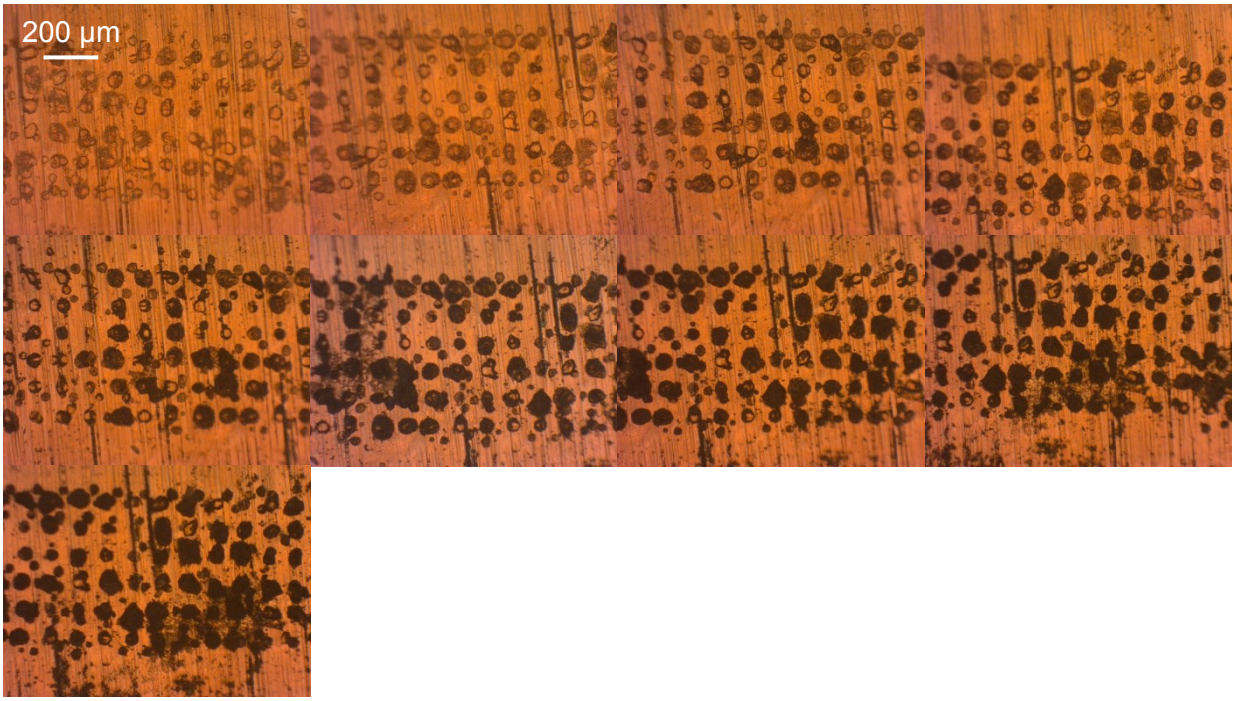

Figure S105: Platinum time series for sample prepared with 6 layers of CMC and 2% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 30 s, 60 s, 90 s, 120 s, 150 s, 180 s, 240 s, 300 s, and 360 s.

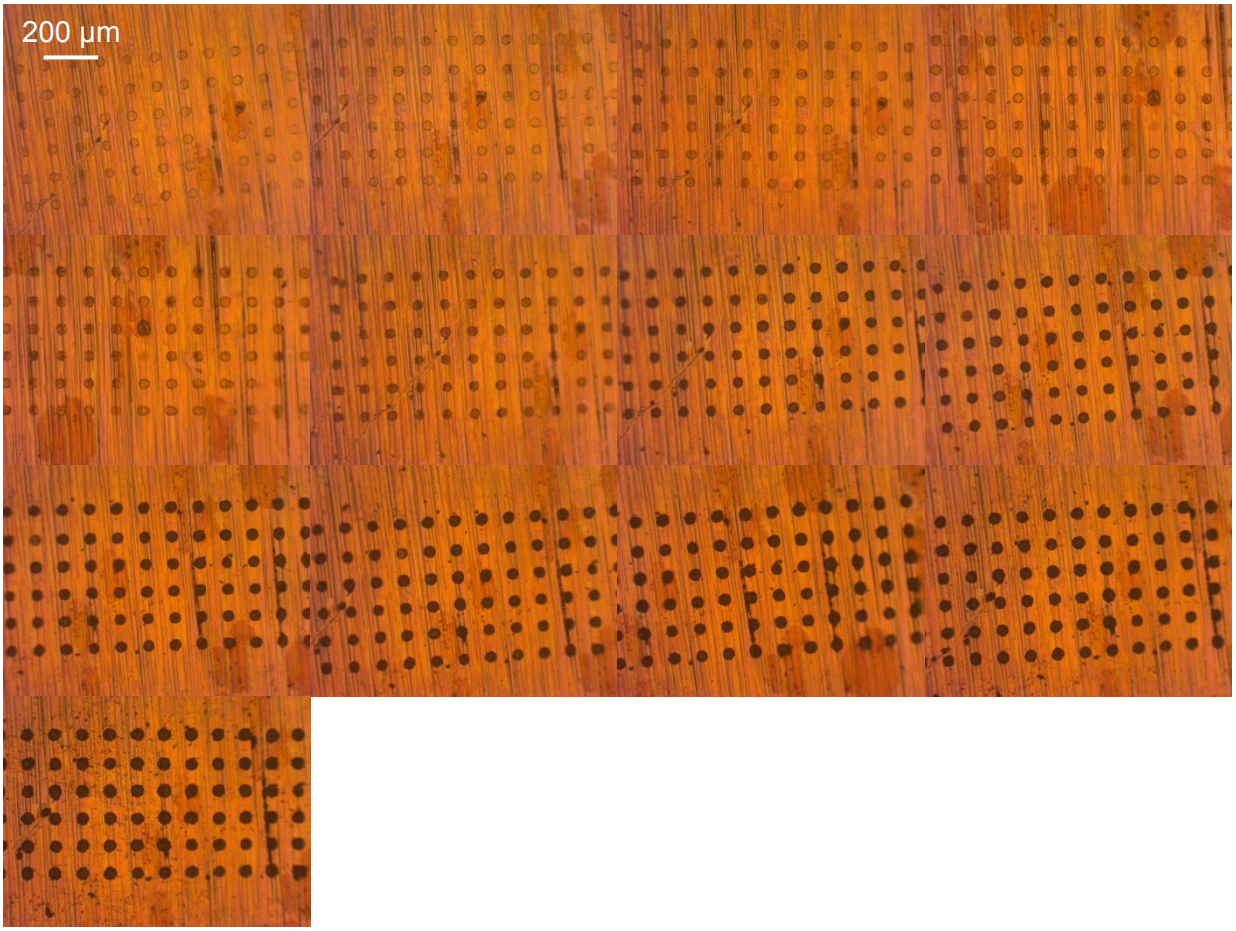

Figure S106: Platinum time series for sample prepared with 2 layers of CMC and 4% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 15 s, 30 s, 45 s, 60 s, 90 s, 120 s, 180 s, 240 s, 300 s, 360 s, 420 s, 540 s, and 660 s.

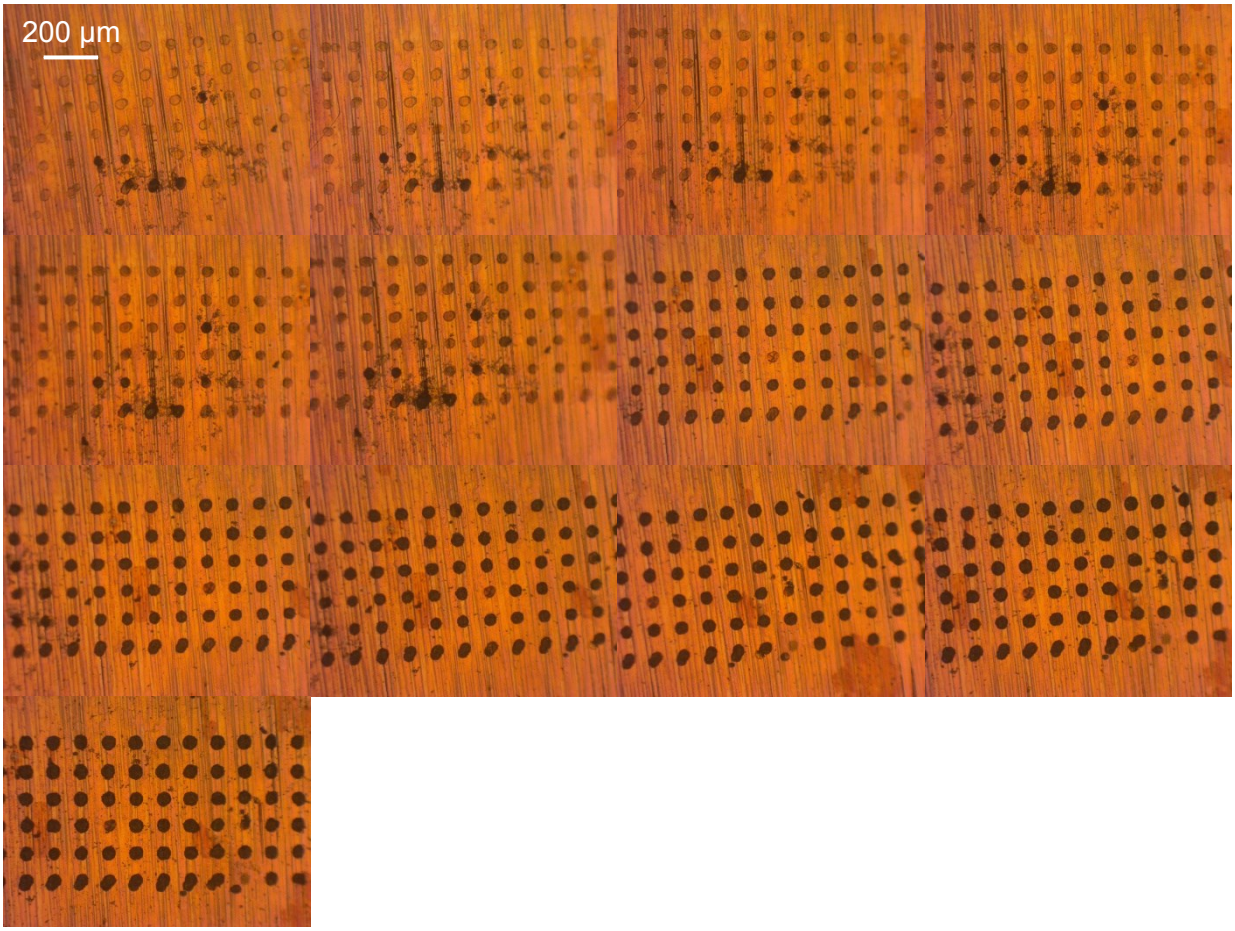

Figure S107: Platinum time series for sample prepared with 3 layers of CMC and 4% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 15 s, 30 s, 45 s, 60 s, 90 s, 120 s, 180 s, 240 s, 300 s, 360 s, 420 s, 540 s, and 660 s.

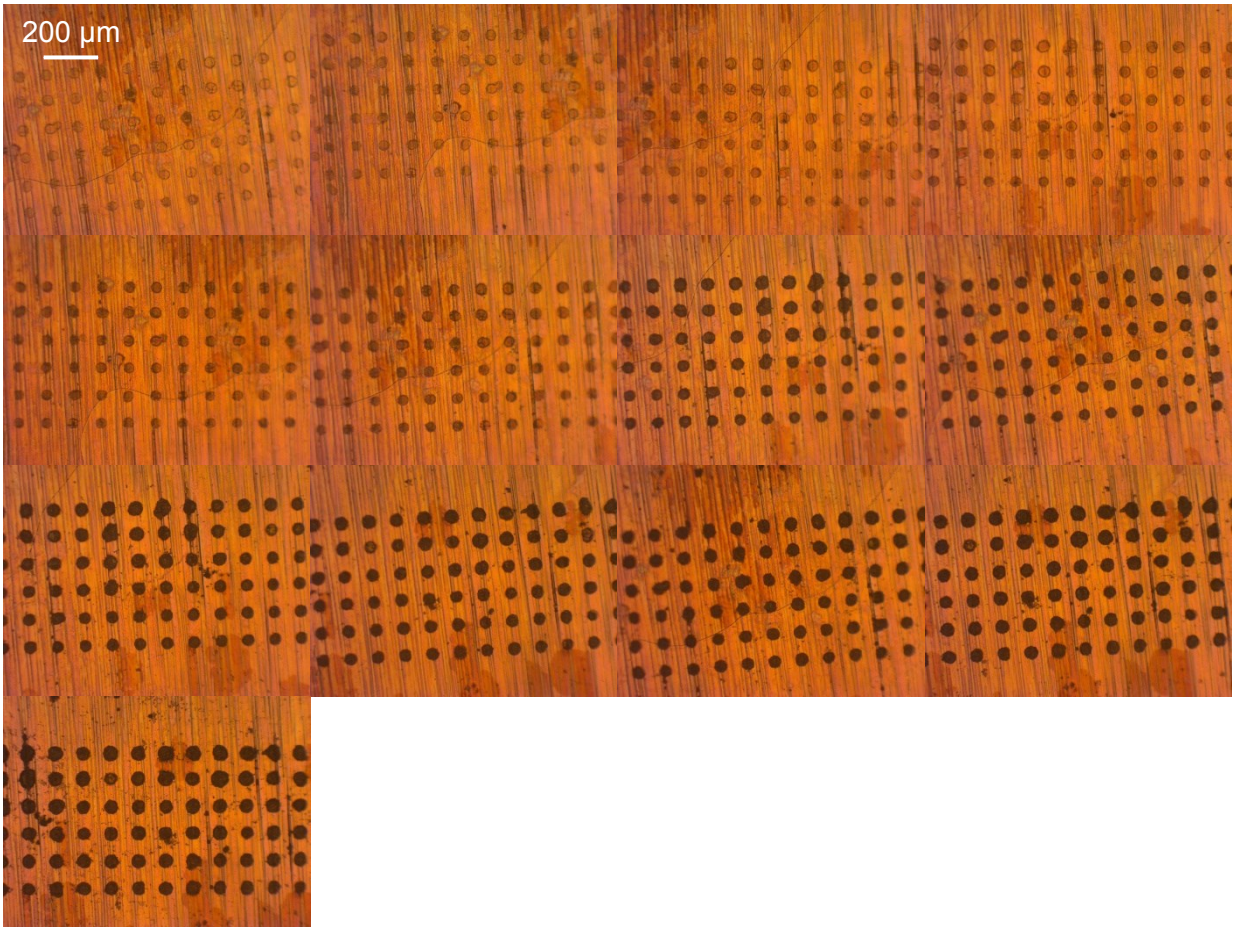

Figure S108: Platinum time series for sample prepared with 4 layers of CMC and 4% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 15 s, 30 s, 45 s, 60 s, 90 s, 120 s, 180 s, 240 s, 300 s, 360 s, 420 s, 540 s, and 660 s.

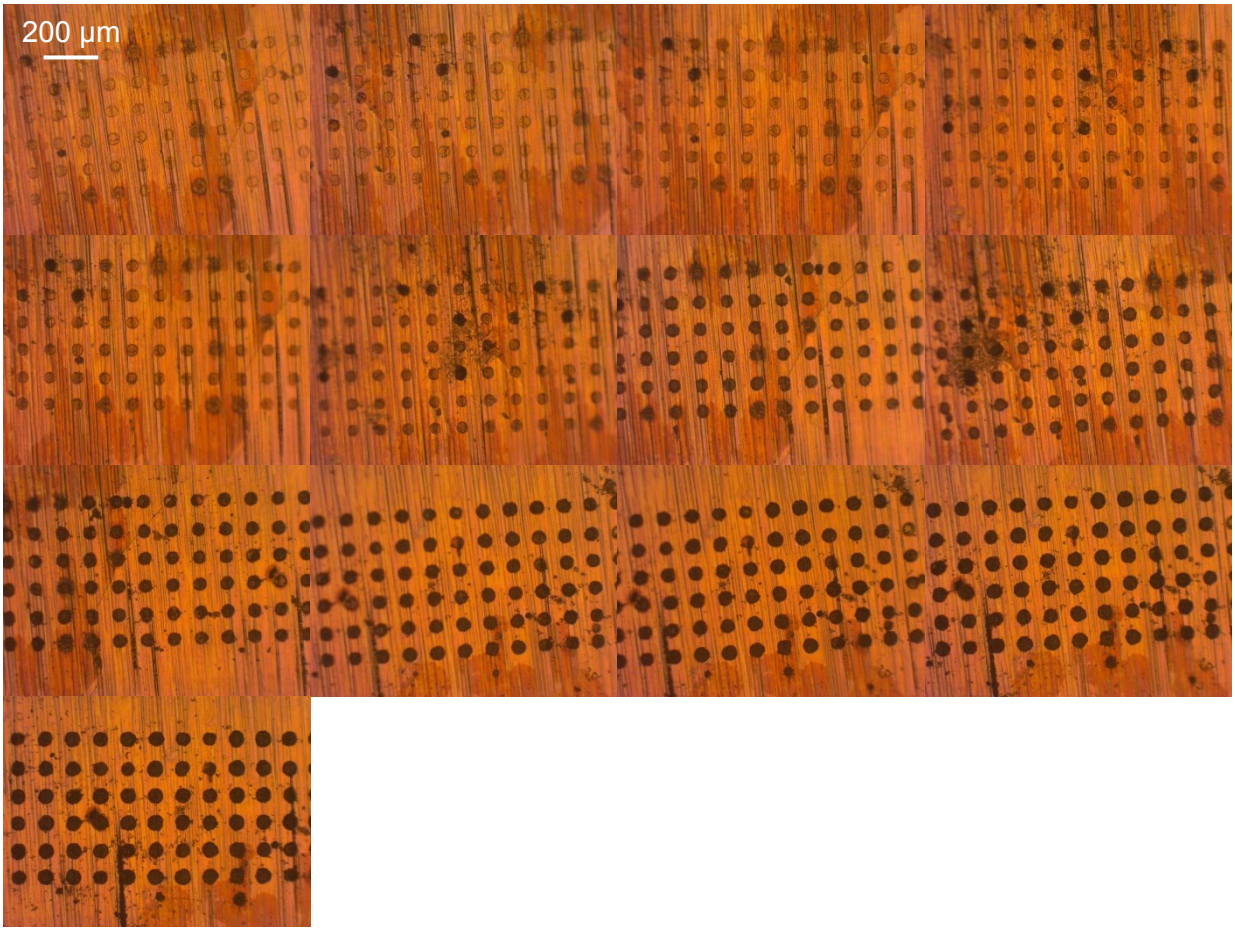

Figure S109: Platinum time series for sample prepared with 5 layers of CMC and 4% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 15 s, 30 s, 45 s, 60 s, 90 s, 120 s, 180 s, 240 s, 300 s, 360 s, 420 s, 540 s, and 660 s.

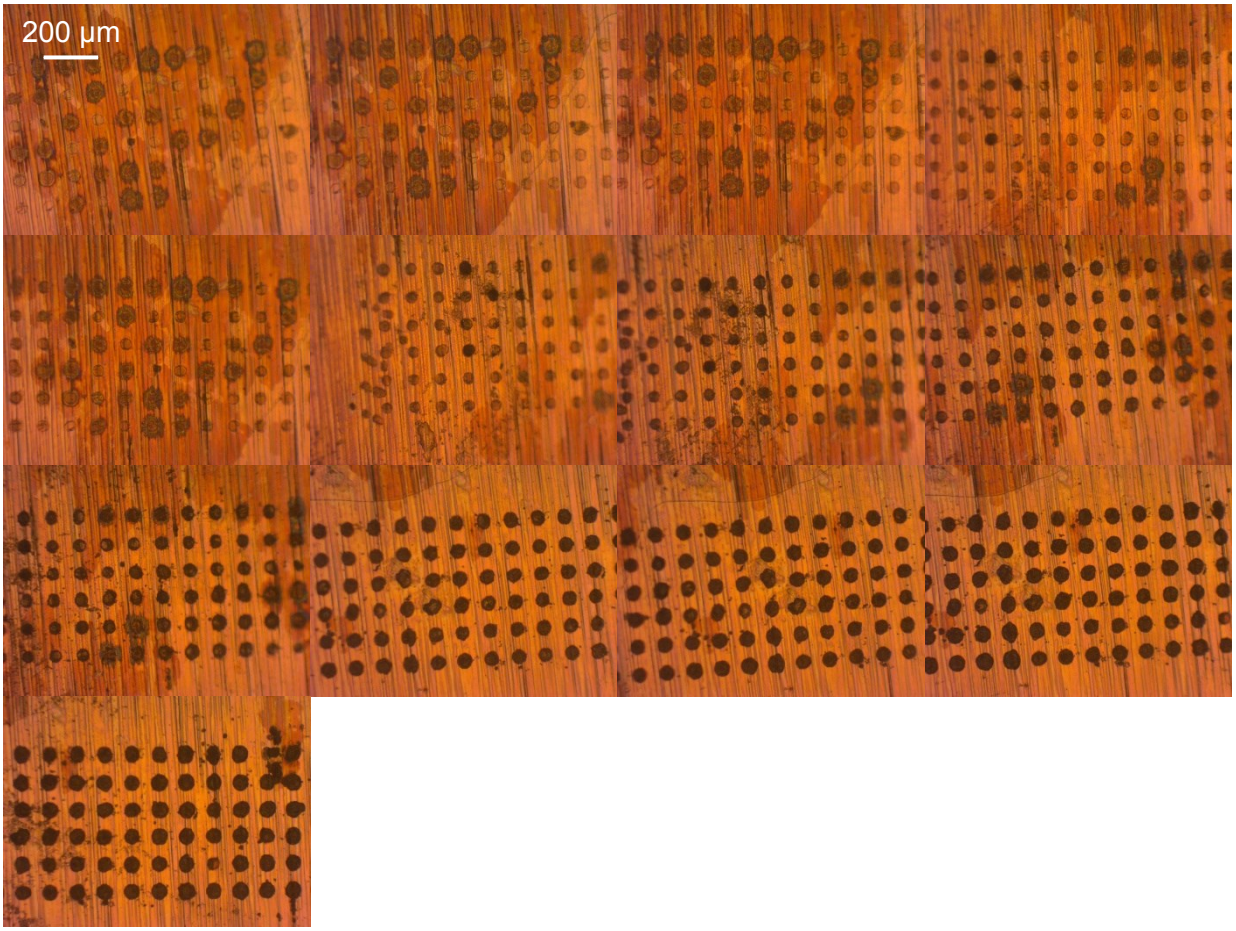

Figure S110: Platinum time series for sample prepared with 6 layers of CMC and 4% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 15 s, 30 s, 45 s, 60 s, 90 s, 120 s, 180 s, 240 s, 300 s, 360 s, 420 s, 540 s, and 660 s.

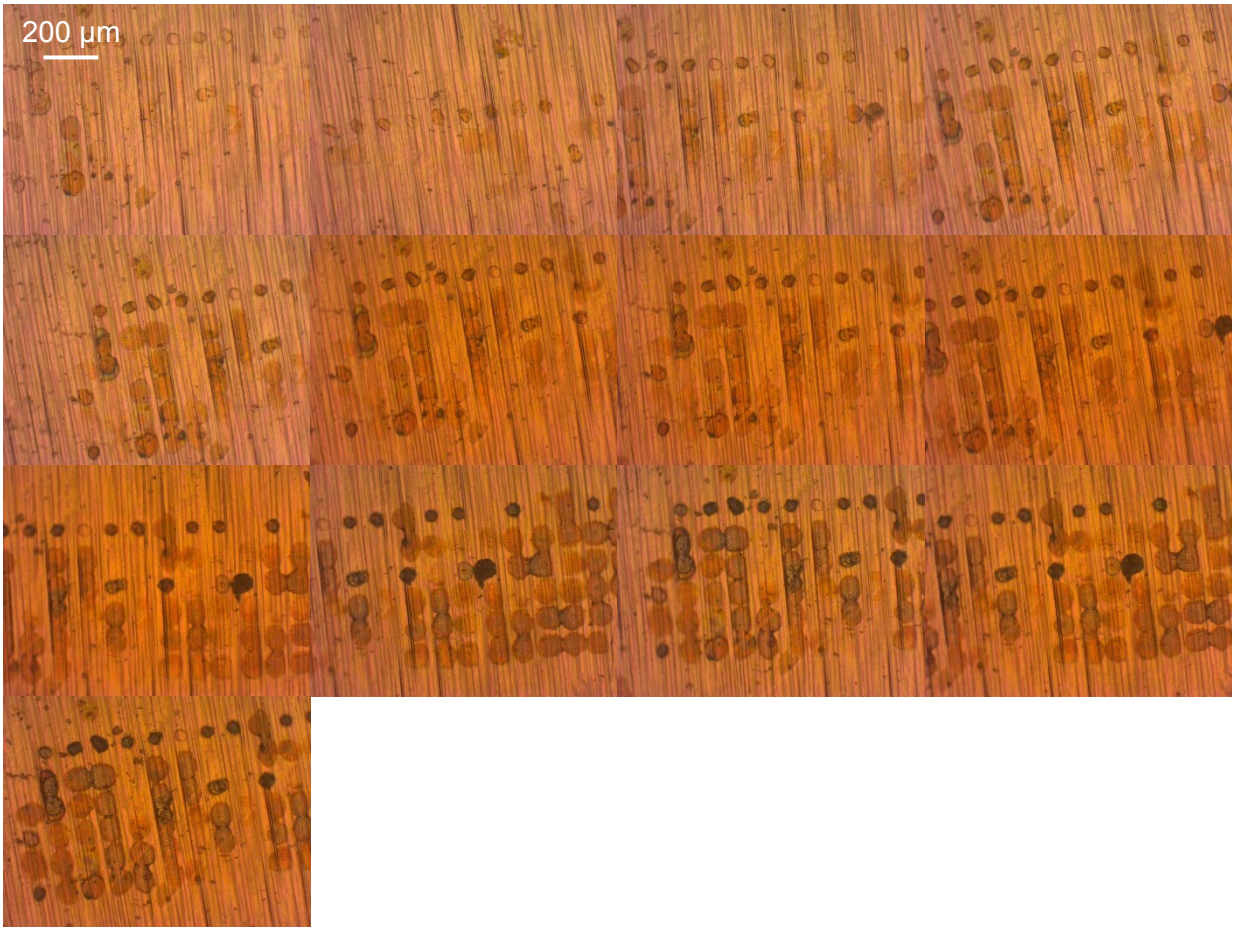

Figure S111: Platinum time series for sample prepared with 2 layers of CMC and 7% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 15 s, 30 s, 45 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 270 s, 300 s, and 360 s.

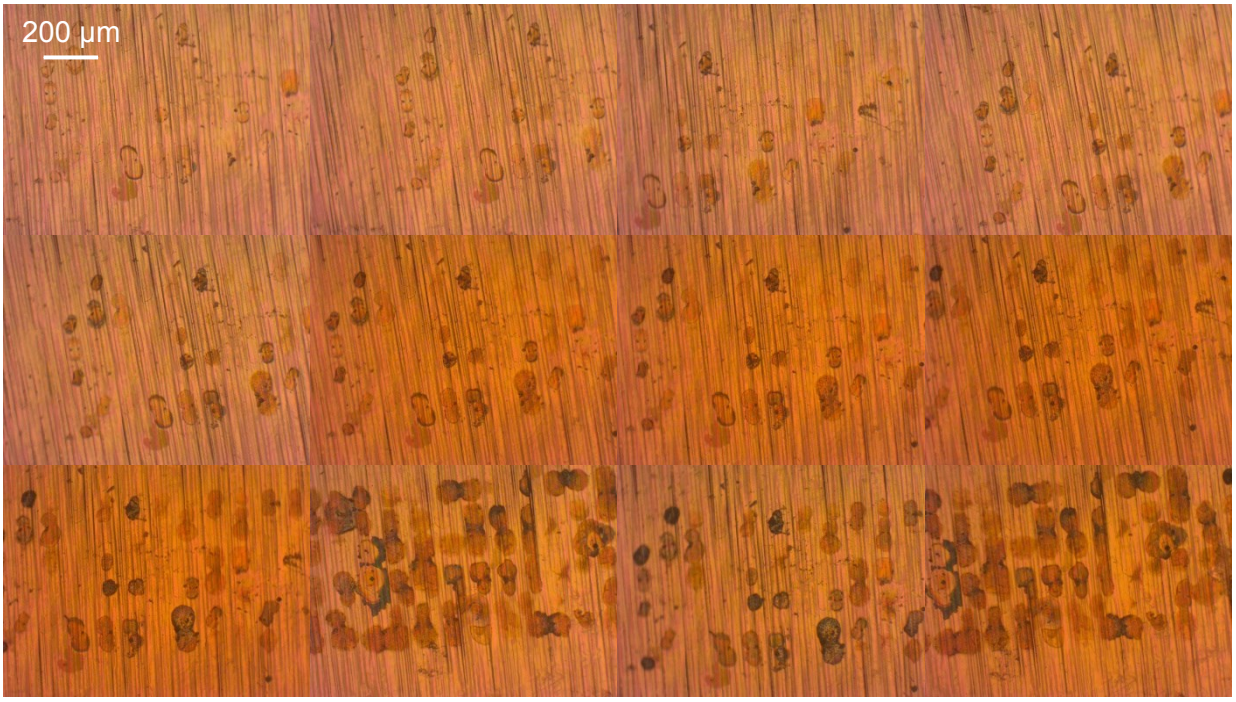

Figure S112: Platinum time series for sample prepared with 3 layers of CMC and 7% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 15 s, 30 s, 45 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 270 s, and 300 s.

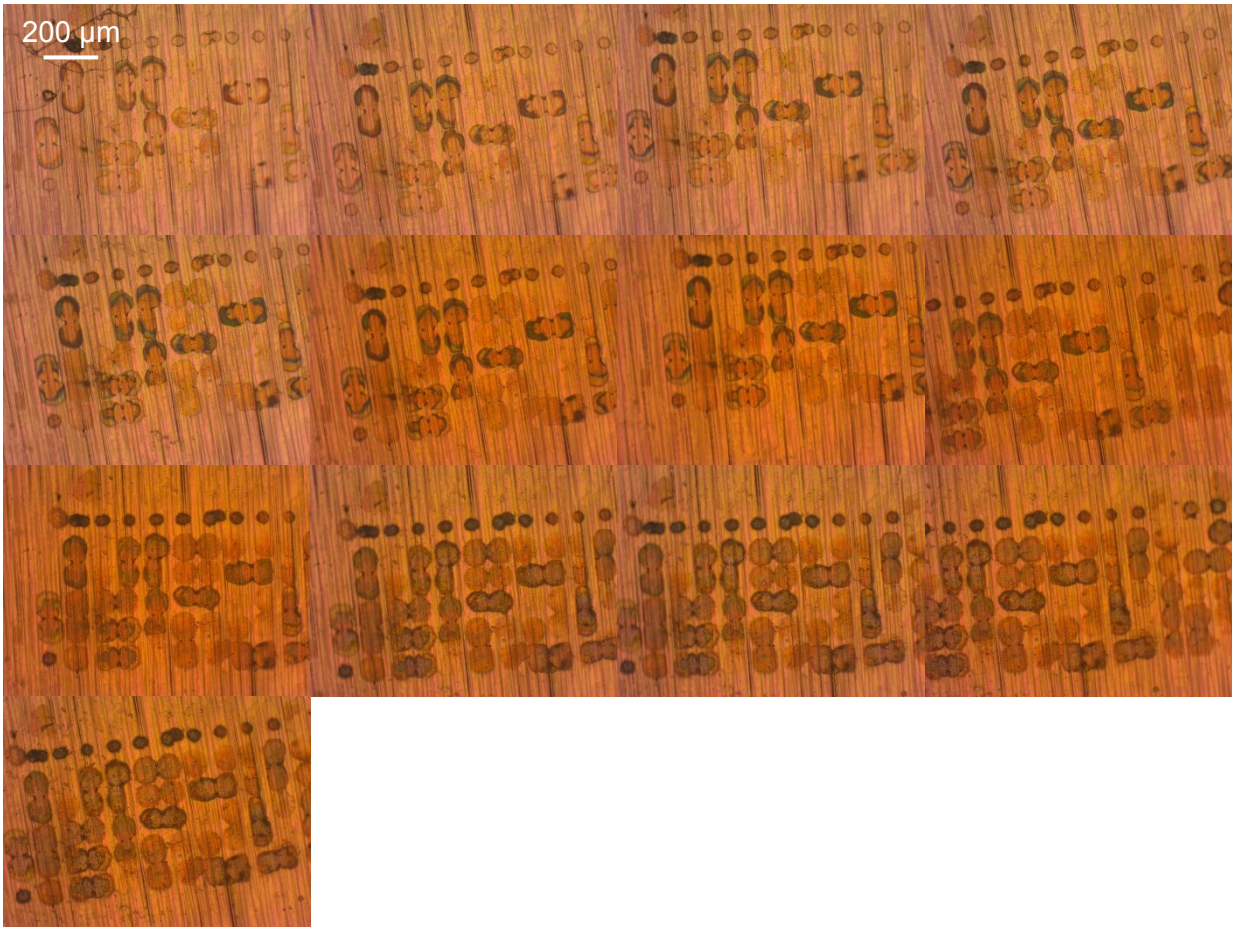

Figure S113: Platinum time series for sample prepared with 4 layers of CMC and 7% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 15 s, 30 s, 45 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 270 s, 300 s, and 360 s.

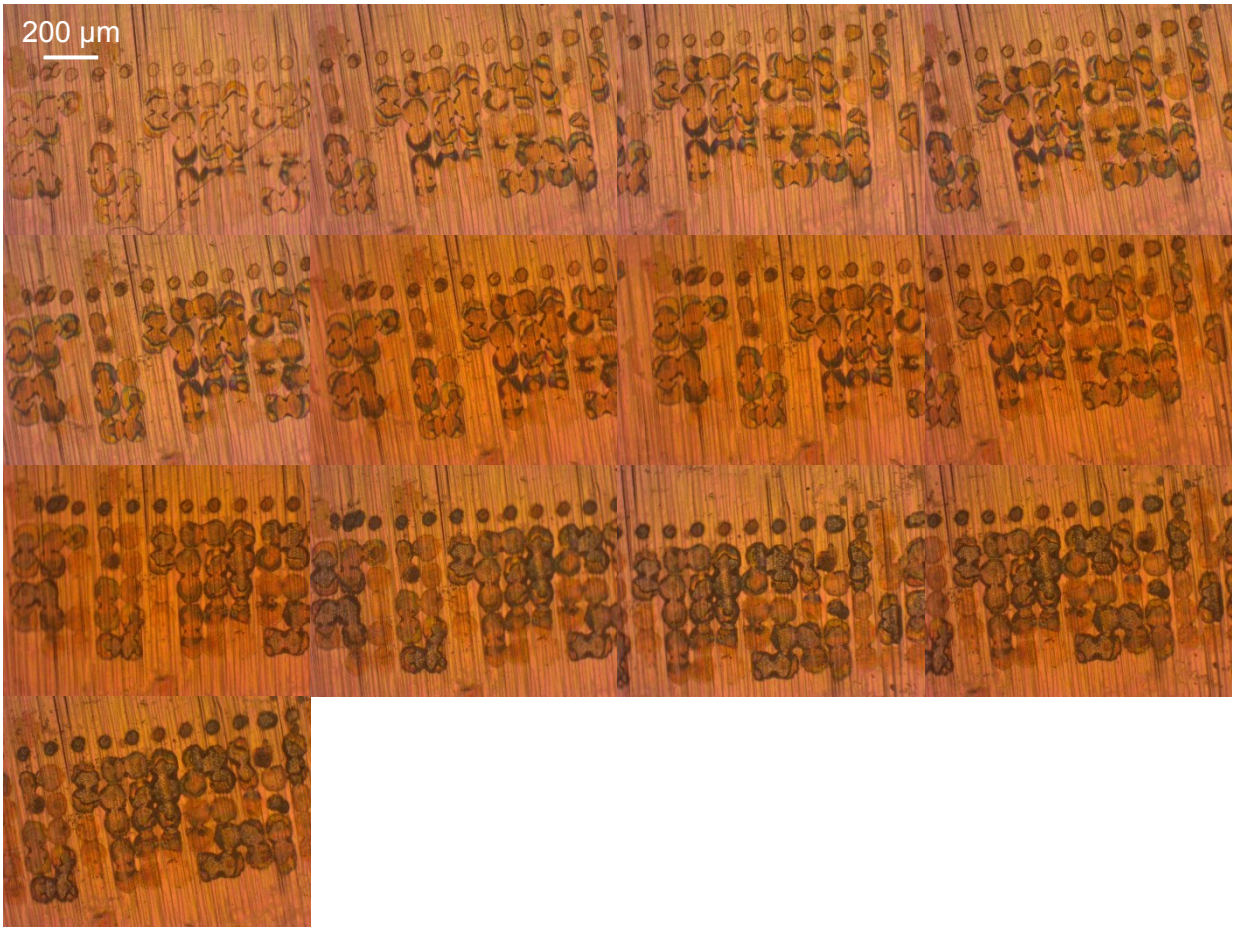

Figure S114: Platinum time series for sample prepared with 5 layers of CMC and 7% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 15 s, 30 s, 45 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 270 s, 300 s, and 360 s.

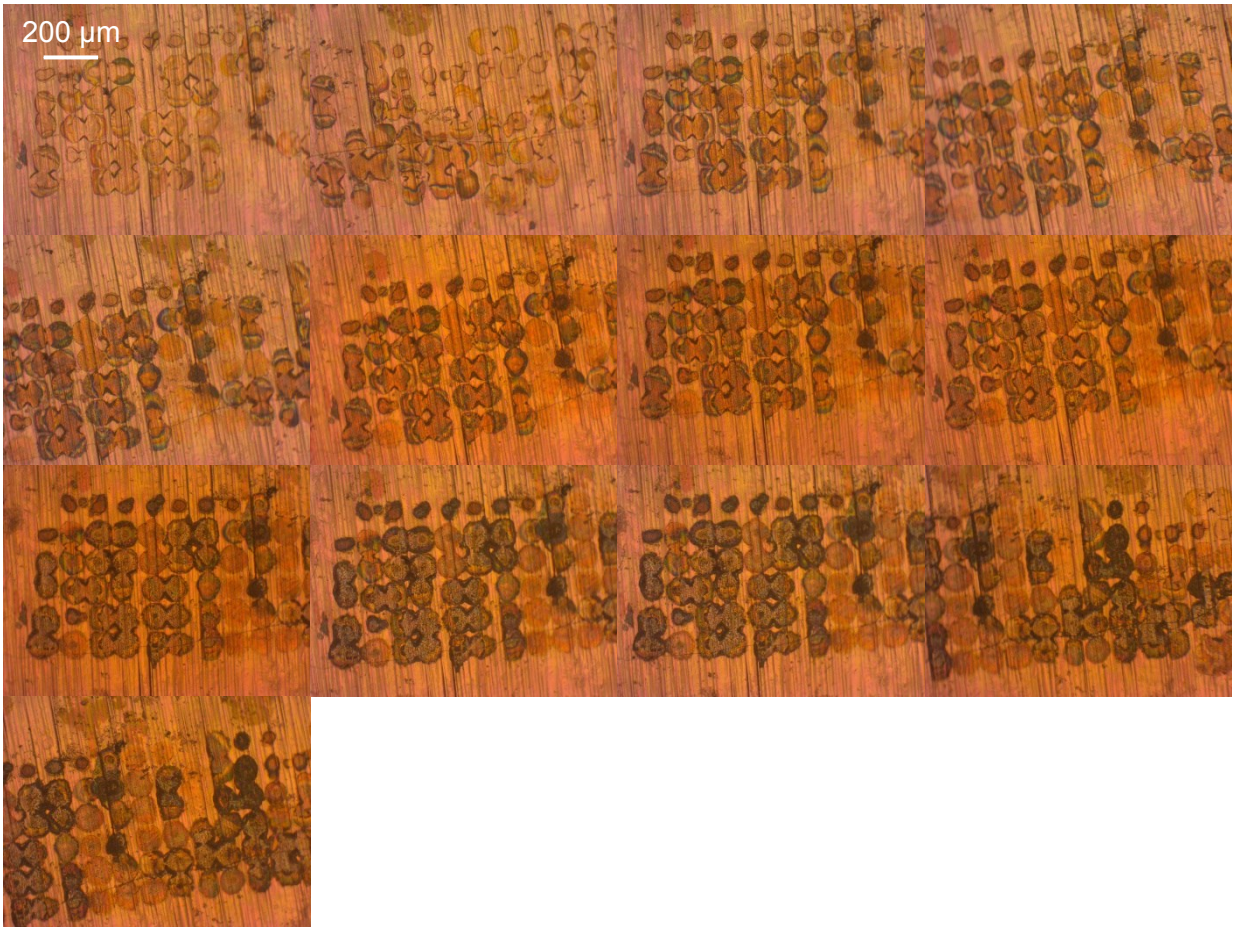

Figure S115: Platinum time series for sample prepared with 6 layers of CMC and 7% PMMA spin-coated for 1 minute at 4000 rpm. Images were taken after electroplating for 15 s, 30 s, 45 s, 60 s, 90 s, 120 s, 150 s, 180 s, 210 s, 240 s, 270 s, 300 s, and 360 s.