Simpore SiN_x Nanoporous Membranes

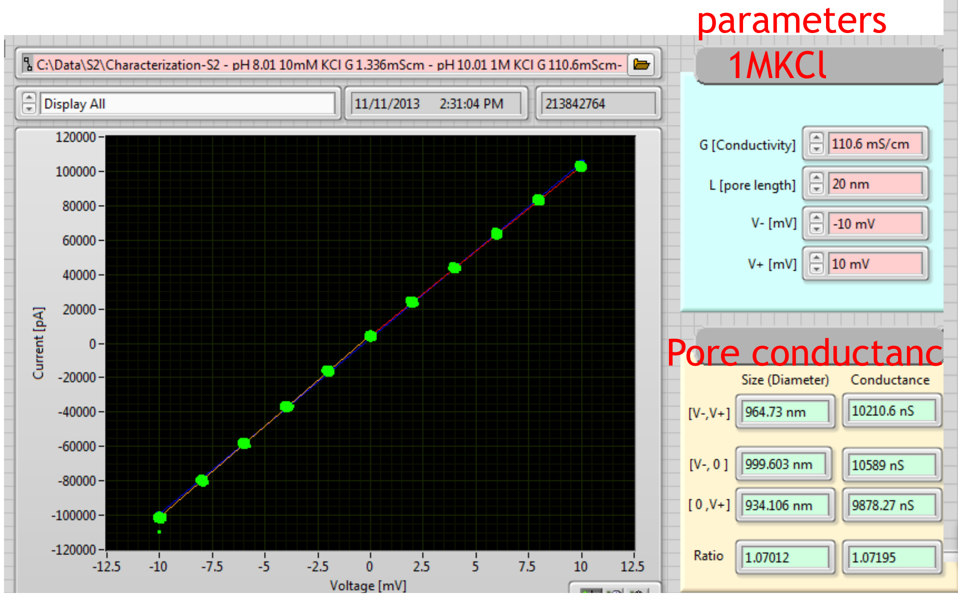
T-Cossa Lab

Data taken by Harold Kwok and Kyle Briggs

Protocol

- 120s at 100W O_2 Plasma
- Wetted with degassed/warm ethanol in vacuum (5 min)
- Perfused DI water
- Perfused 10mM KCl pH 8
- Perfused 1M KCl pH 10 OR 3.6M LiCl pH 8
- 6 membranes tested (2 shown here – results were consistent)

I-V curves and PSD (noise) in High Salt (1M KCl)



parameters

C:\Data\S2\Characterization-S2 - pH 8.01 10mM KCl G 1.336mScm - pH 10.01 1M KCl G 110.6mScm-

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1MKCl

G [Conductivity] 110.6 mS/cm

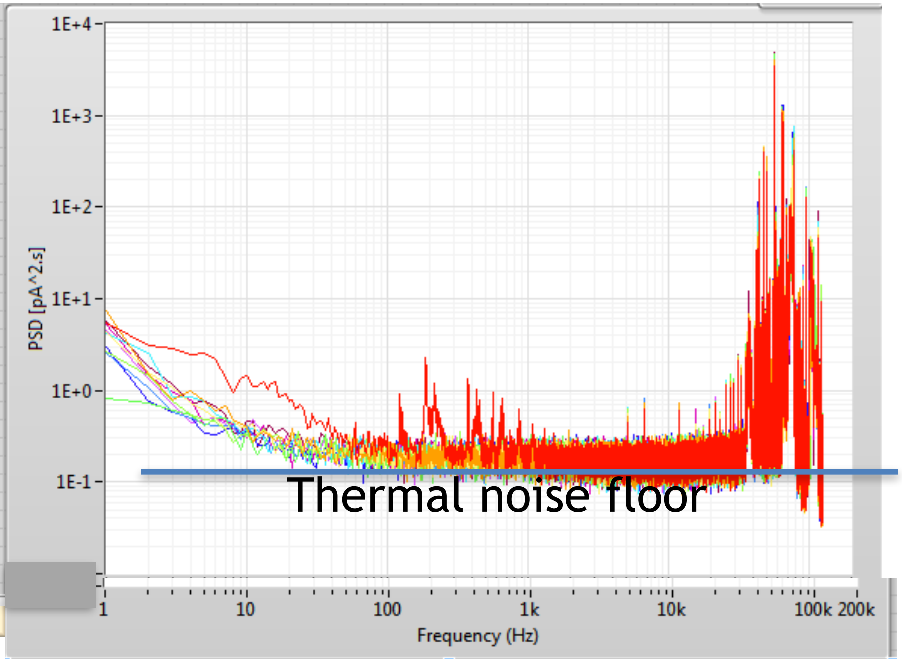
L [pore length] 20 nm

V- [mV] -10 mV

V+ [mV] 10 mV

Pore conductanc

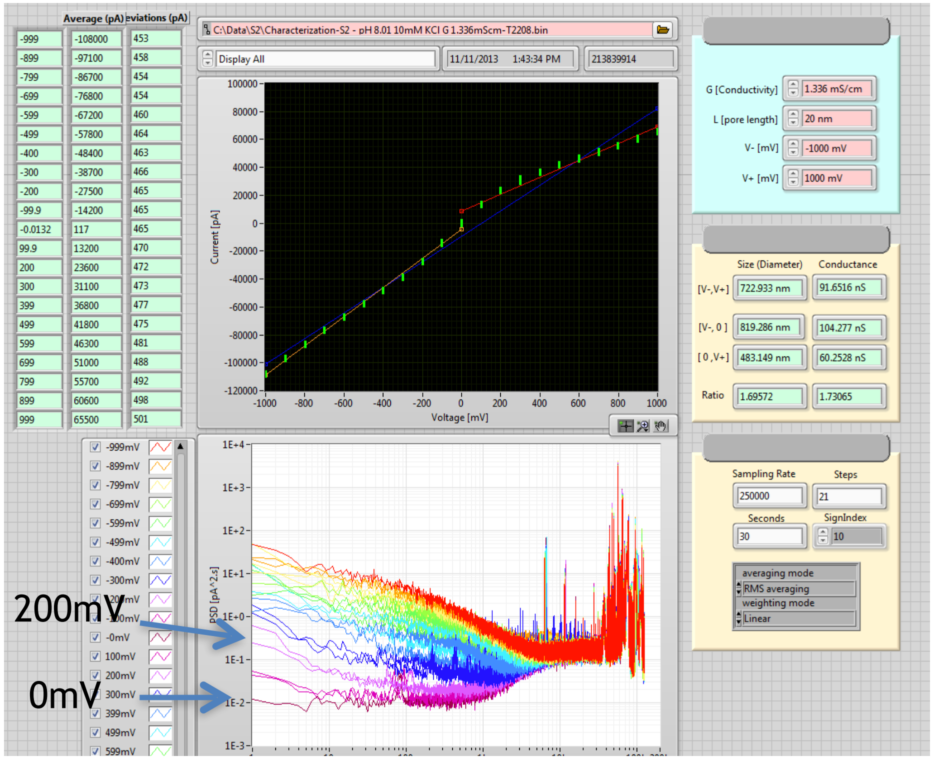
	Size (Diameter)	Conductance
[V-,V+]	964.73 nm	10210.6 nS
[V-, 0]	999.603 nm	10589 nS
[0 ,V+]	934.106 nm	9878.27 nS
Ratio	1.07012	1.07195



- conductance: 10,589-nS

Note that voltage range was limited to -10mV to +10mV because of the saturation of the Axoptach 200B current amplifier (max 200nA). The various colors of the PSDs are for different voltages.
Spikes in the >30kHz range is extra noise due to the external command being on (computer controlled amplifier), and is not related to the chip or the pore.

I-V curves and PSD (noise) in Low Salt (10mM)



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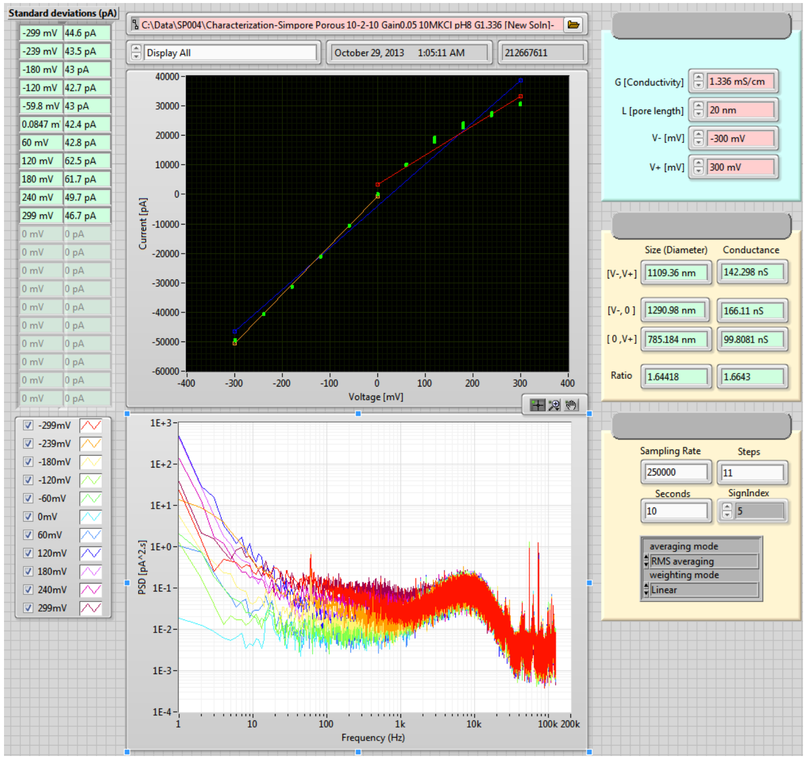
	Average (pA)	Deviations (pA)
-999	-108000	453
-899	-97100	458
-799	-86700	454
-699	-76800	454
-599	-67200	460
-499	-57800	464
-400	-48400	463
-300	-38700	466
-200	-27500	465
-99.9	-14200	465
-0.0132	117	465
99.9	13200	470
200	23600	472
300	31100	473
399	36800	477
499	41800	475
599	46300	481
699	51000	488
799	55700	492
899	60600	498
999	65500	501

G [Conductivity] 1.336 mS/cm
L [pore length] 20 nm
V- [mV] -1000 mV
V+ [mV] 1000 mV

	Size (Diameter)	Conductance
[V-,V+]	722.933 nm	91.6516 nS
[V-, 0]	819.286 nm	104.277 nS
[0 ,V+]	483.149 nm	60.2528 nS
Ratio	1.69572	1.73065

Sampling Rate 250000
Steps 21
Seconds 30
SignIndex 10
averaging mode RMS averaging
weighting mode Linear



C:\Data\SP004\Characterization-Simpore Porous 10-2-10 Gain0.05 10MKCl pH8 G1.336 [New Soln]-

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Standard deviations (pA)	
-299 mV	44.6 pA
-239 mV	43.5 pA
-180 mV	43 pA
-120 mV	42.7 pA
-59.8 mV	43 pA
0.0847 m	42.4 pA
60 mV	42.8 pA
120 mV	62.5 pA
180 mV	61.7 pA
240 mV	49.7 pA
299 mV	46.7 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA

G [Conductivity] 1.336 mS/cm
L [pore length] 20 nm
V- [mV] -300 mV
V+ [mV] 300 mV

	Size (Diameter)	Conductance
[V-,V+]	1109.36 nm	142.298 nS
[V-, 0]	1290.98 nm	166.11 nS
[0 ,V+]	785.184 nm	99.8081 nS
Ratio	1.64418	1.6643

Sampling Rate 250000
Steps 11
Seconds 10
SignIndex 5
averaging mode RMS averaging
weighting mode Linear

- conductance: 104-nS (right) and 166-nS (left)

Note that I-V range is now -1000mV to +1000mV. Pores show slight rectification, but are for the most part ohmic (linear for a large voltage window).
PSD on the right, the signal was low-pass filtered at 10kHz. Other data sets are LPF at 100kHz.

Noise Discussion

- >1kHz or 100Hz, power spectral density achieves a minimal amplitude dictated by thermal noise of the device (S [pA^2/Hz] = Sqrt(4kT/R), where kT is the thermal energy and R is the pore resistance). For the pore conductance (in 1M KCl) here, this is ~0.1 pA^2/Hz. At high salt, there is no sign of capacitive/dielectric noise. Devices are dominated by thermal noise.
- <1kHz, 1/f-type noise dominates (as expected). Devices have remarkably low 1/f noise amplitude considering there is multiple pores. It is at the level of a single nanopore device. This is possibly due to mutual cancellation between 1/f noise sources from individual pores. This is intriguing but a very good feature for Nanopore Force Spectroscopy).
- For more detail on noise sources, see: http://www.sciencedirect.com/science/article/pii/B9781437734737000030

Size Discussion

Given a pore conductance value G, membrane thickness L, and conductivity (sigma) it is possible to extract an effective diameter d for the combination of N pores via

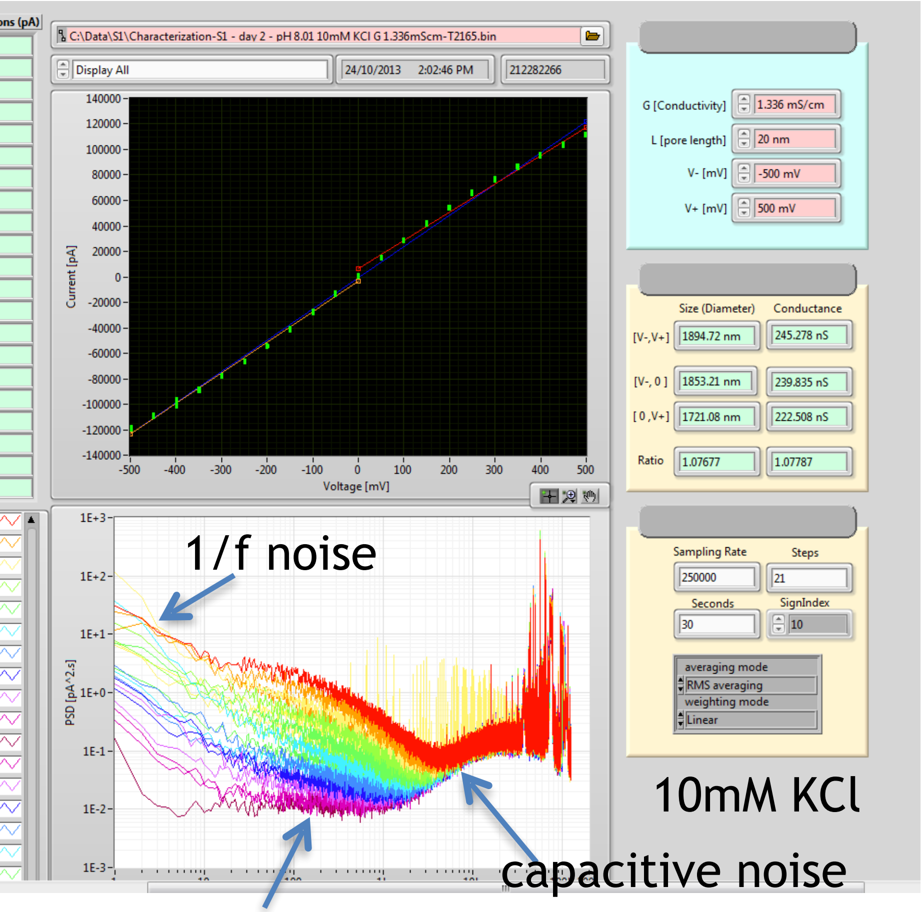
$$G = N\sigma\left(\frac{4L}{\pi d^2} + \frac{1}{d}\right)^{-1}$$

For N=900, at 1M KCl, 15-nm pores should have ~50,000-nS. For the 3.6M LiCl we expect 80,000-nS. However, we measure 10,000-nS and 22,500-nS respectively.

This means that: (1) either the model is inadequate due to overlapping access resistance due to proximate pores, or (2) not all the nanopores are wetted, or (3) there is a wide distribution of nanopore size. Because of the nonlinearity of the above equation, the details of the distribution of pore size are important. At the moment if we assume a fix pore size the pores appear to be 6-nm in size.

The difference in effective diameter extracted at low salt concentration indicates surface effects become dominant in this regime.

Other pores (S1-K)



C:\Data\S1\Characterization-S1 - day 2 - pH 8.01 10mM KCl G 1.336mScm-T2165.bin

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G [Conductivity]: 1.336 mS/cm
L [pore length]: 20 nm
V- [mV]: -500 mV
V+ [mV]: 500 mV

	Size (Diameter)	Conductance
[V-,V+]	1894.72 nm	245.278 nS
[V-, 0]	1853.21 nm	239.835 nS
[0 ,V+]	1721.08 nm	222.508 nS
Ratio	1.07677	1.07787

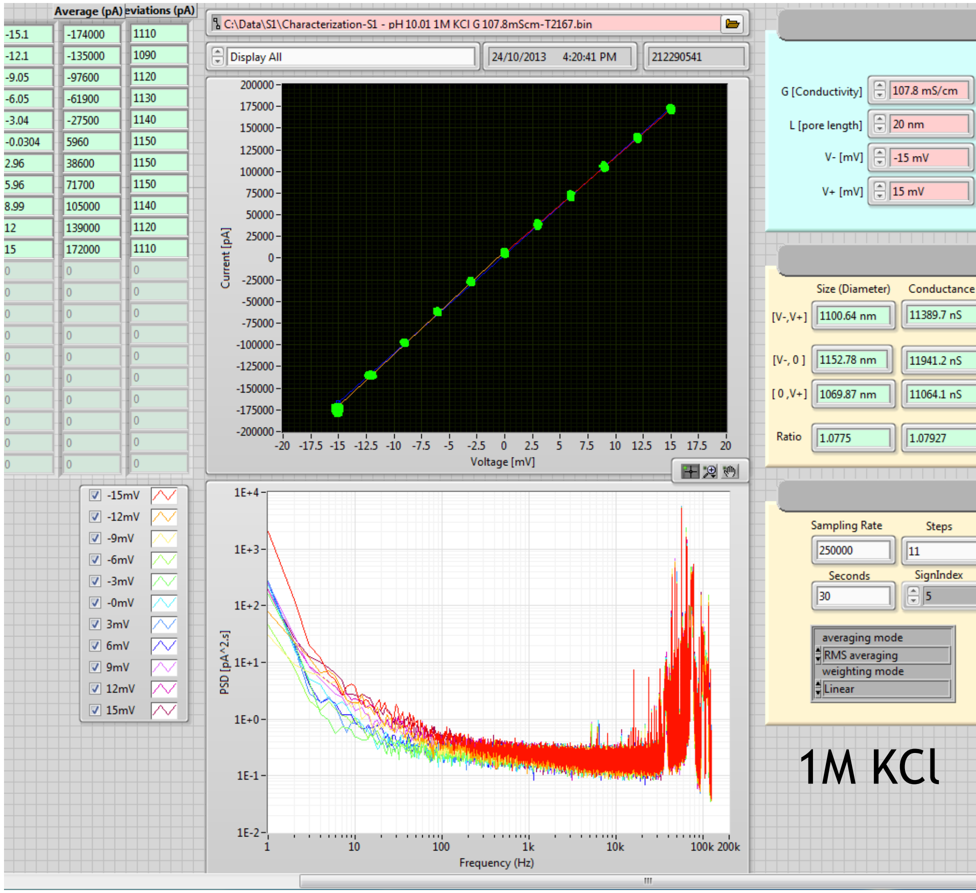
Sampling Rate: 250000
Steps: 21
Seconds: 30
SignIndex: 10
averaging mode: RMS averaging
weighting mode: Linear

1/f noise

10mM KCl

capacitive noise

Thermal noise



	Average (pA)	eviations (pA)
-15.1	-174000	1110
-12.1	-135000	1090
-9.05	-97600	1120
-6.05	-61900	1130
-3.04	-27500	1140
-0.0304	5960	1150
2.96	38600	1150
5.96	71700	1150
8.99	105000	1140
12	139000	1120
15	172000	1110
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0

- ☑ -15mV
- ☑ -12mV
- ☑ -9mV
- ☑ -6mV
- ☑ -3mV
- ☑ -0mV
- ☑ 3mV
- ☑ 6mV
- ☑ 9mV
- ☑ 12mV
- ☑ 15mV

C:\Data\S1\Characterization-S1 - pH 10.01 1M KCl G 107.8mScm-T2167.bin

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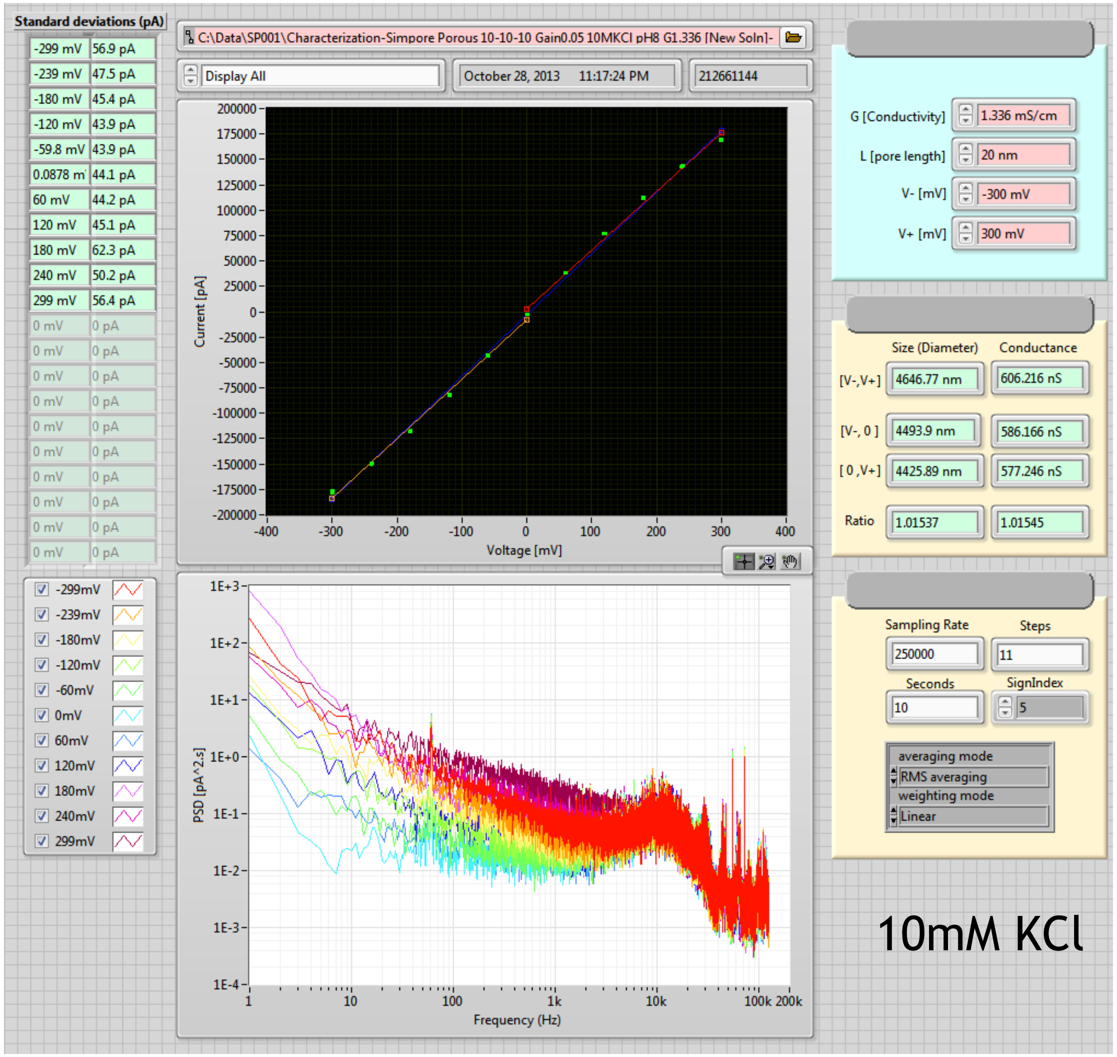
G [Conductivity]: 107.8 mS/cm
L [pore length]: 20 nm
V- [mV]: -15 mV
V+ [mV]: 15 mV

	Size (Diameter)	Conductance
[V-,V+]	1100.64 nm	11389.7 nS
[V-, 0]	1152.78 nm	11941.2 nS
[0 ,V+]	1069.87 nm	11064.1 nS
Ratio	1.0775	1.07927

Sampling Rate: 250000
Steps: 11
Seconds: 30
SignIndex: 5
averaging mode: RMS averaging
weighting mode: Linear

1M KCl

SP001-H



C:\Data\SP001\Characterization-Simpore Porous 10-10-10 Gain0.05 10MKCl pH8 G1.336 [New Soln]-

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Standard deviations (pA)

-299 mV	56.9 pA
-239 mV	47.5 pA
-180 mV	45.4 pA
-120 mV	43.9 pA
-59.8 mV	43.9 pA
0.0878 m	44.1 pA
60 mV	44.2 pA
120 mV	45.1 pA
180 mV	62.3 pA
240 mV	50.2 pA
299 mV	56.4 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA

- ☑ -299mV
- ☑ -239mV
- ☑ -180mV
- ☑ -120mV
- ☑ -60mV
- ☑ 0mV
- ☑ 60mV
- ☑ 120mV
- ☑ 180mV
- ☑ 240mV
- ☑ 299mV

G [Conductivity] 1.336 mS/cm

L [pore length] 20 nm

V- [mV] -300 mV

V+ [mV] 300 mV

	Size (Diameter)	Conductance
[V-,V+]	4646.77 nm	606.216 nS
[V-, 0]	4493.9 nm	586.166 nS
[0 ,V+]	4425.89 nm	577.246 nS
Ratio	1.01537	1.01545

Sampling Rate 250000

Steps 11

Seconds 10

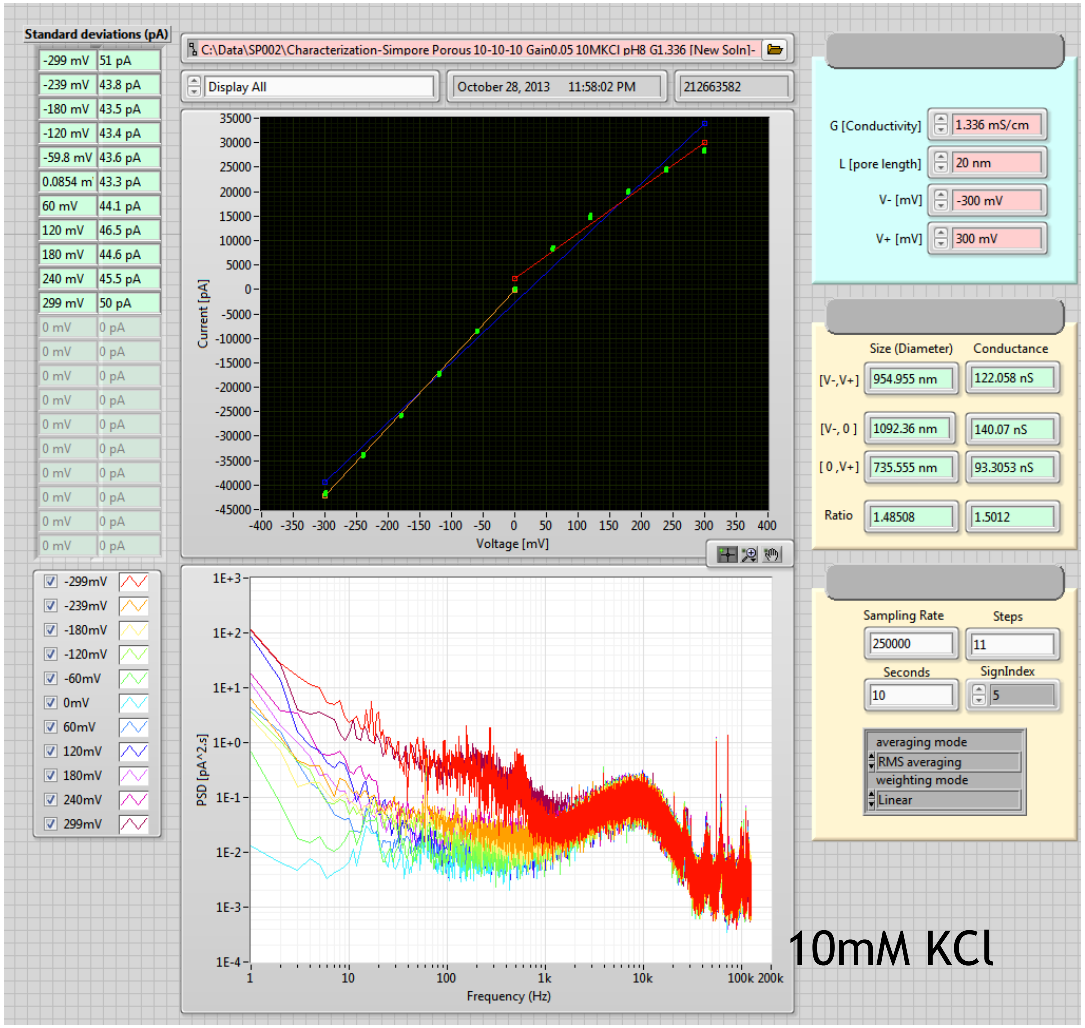
SignIndex 5

averaging mode: RMS averaging

weighting mode: Linear

10mM KCl

SP002-H



C:\Data\SP002\Characterization-Simpore Porous 10-10-10 Gain0.05 10MKCl pH8 G1.336 [New Soln]-

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Standard deviations (pA)

-299 mV	51 pA
-239 mV	43.8 pA
-180 mV	43.5 pA
-120 mV	43.4 pA
-59.8 mV	43.6 pA
0.0854 m	43.3 pA
60 mV	44.1 pA
120 mV	46.5 pA
180 mV	44.6 pA
240 mV	45.5 pA
299 mV	50 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA

G [Conductivity] 1.336 mS/cm

L [pore length] 20 nm

V- [mV] -300 mV

V+ [mV] 300 mV

	Size (Diameter)	Conductance
[V-,V+]	954.955 nm	122.058 nS
[V-, 0]	1092.36 nm	140.07 nS
[0 ,V+]	735.555 nm	93.3053 nS
Ratio	1.48508	1.5012

Sampling Rate	Steps
250000	11

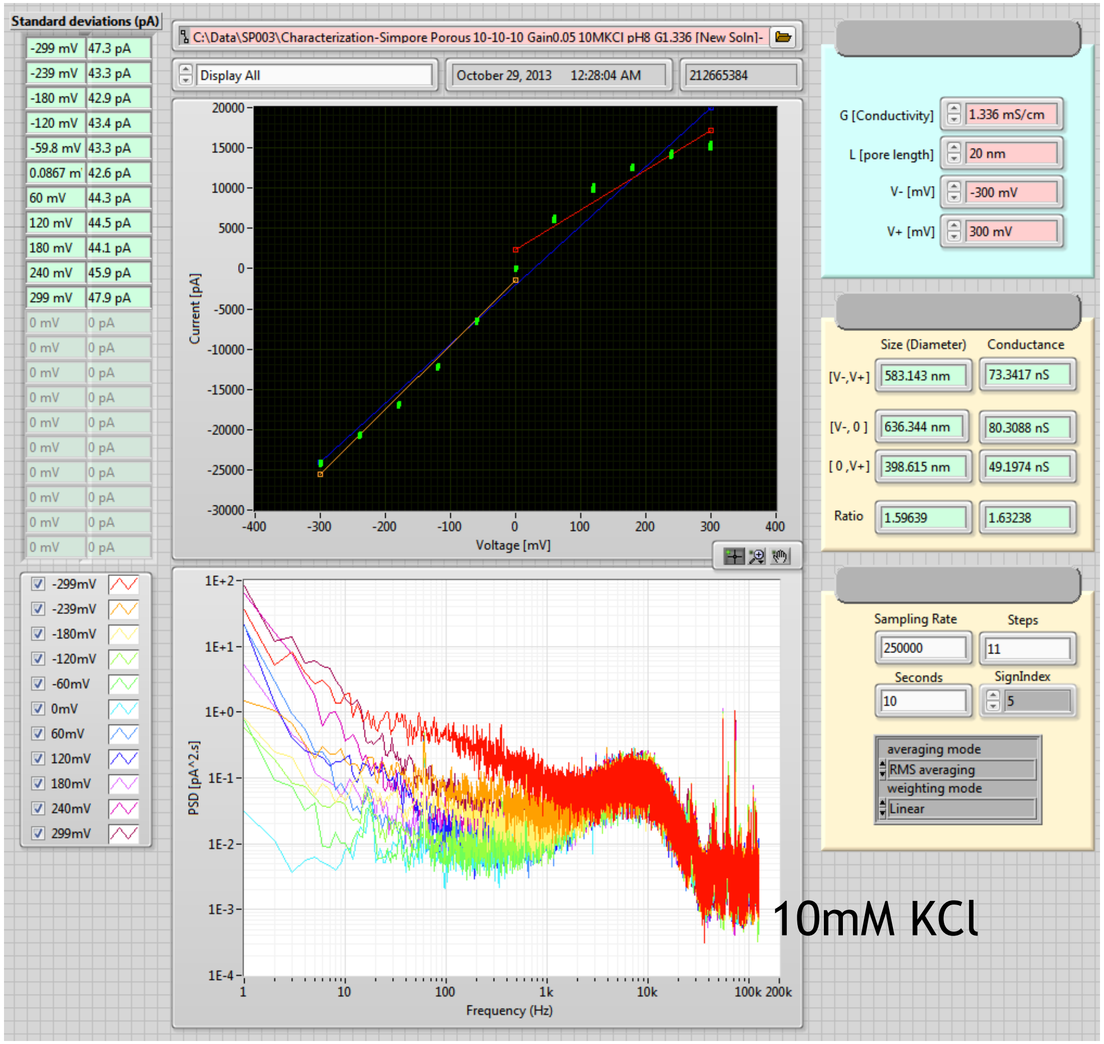
Seconds	SignIndex
10	5

averaging mode: RMS averaging

weighting mode: Linear

10mM KCl

SP003-H



Standard deviations (pA)

-299 mV	47.3 pA
-239 mV	43.3 pA
-180 mV	42.9 pA
-120 mV	43.4 pA
-59.8 mV	43.3 pA
0.0867 m	42.6 pA
60 mV	44.3 pA
120 mV	44.5 pA
180 mV	44.1 pA
240 mV	45.9 pA
299 mV	47.9 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA
0 mV	0 pA

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G [Conductivity] 1.336 mS/cm

L [pore length] 20 nm

V- [mV] -300 mV

V+ [mV] 300 mV

	Size (Diameter)	Conductance
[V-,V+]	583.143 nm	73.3417 nS
[V-, 0]	636.344 nm	80.3088 nS
[0 ,V+]	398.615 nm	49.1974 nS
Ratio	1.59639	1.63238

Sampling Rate 250000

Steps 11

Seconds 10

SignIndex 5

averaging mode RMS averaging

weighting mode Linear

☑ -299mV
☑ -239mV
☑ -180mV
☑ -120mV
☑ -60mV
☑ 0mV
☑ 60mV
☑ 120mV
☑ 180mV
☑ 240mV
☑ 299mV

10mM KCl