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Characterization of Sputtering Copper Using the Denton Explorer-14 System

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Characterization of Sputtering Copper Using the Denton Explorer-14 System

Disciplines
Nanoscience and Nanotechnology

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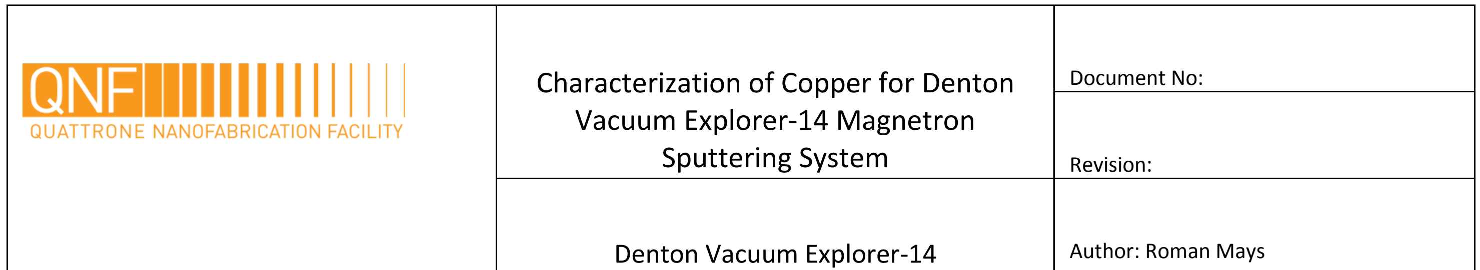

QUATTRONE NANOFABRICATION FACILITY	Characterization of Copper for Denton Vacuum Explorer-14 Magnetron Sputtering System	Document No:
		Revision:
	Denton Vacuum Explorer-14	Author: Roman Mays

Goal:

To characterize the deposition rates of copper within the Explorer 14 as a function of supplied power and gas pressure, and the resulting film stress.

Materials:

- Copper target
- Diamond Scribe/Cleaver
- Acetone
- 3 inch Patterned Silicon Wafers
- 4 inch Silicon Wafers

Equipment:

- Explorer 14 Magnetron Sputterer
- KLA Stress Profilometer

Units:

- Pressure: milliTorr (mT)
- Cathode Power: Watts
- Time: Seconds (s)
- Stress: MegaPascals (MPa)
- Thickness: nanometers (nm)

Protocol:

Pre Measurement

Pre Measurement steps are noted in the *Measurement of residual stress in deposited films* document in the *Pre-Deposition wafer bow measurement* section.

Deposition

1. Cleave 3 samples from the 3 inch patterned silicon wafer
2. Orient the wafer and sample pieces on opposite ends of the plate, as seen in Fig.1
3. Deposit copper onto the 4 inch wafer and three sample pieces

Post Measurement

Post Measurement steps are noted in the *Measurement of residual stress in deposited films* document in the *Post-Deposition film thickness measurement* & the *Post-Deposition Wafer bow measurement and stress calculation* sections.

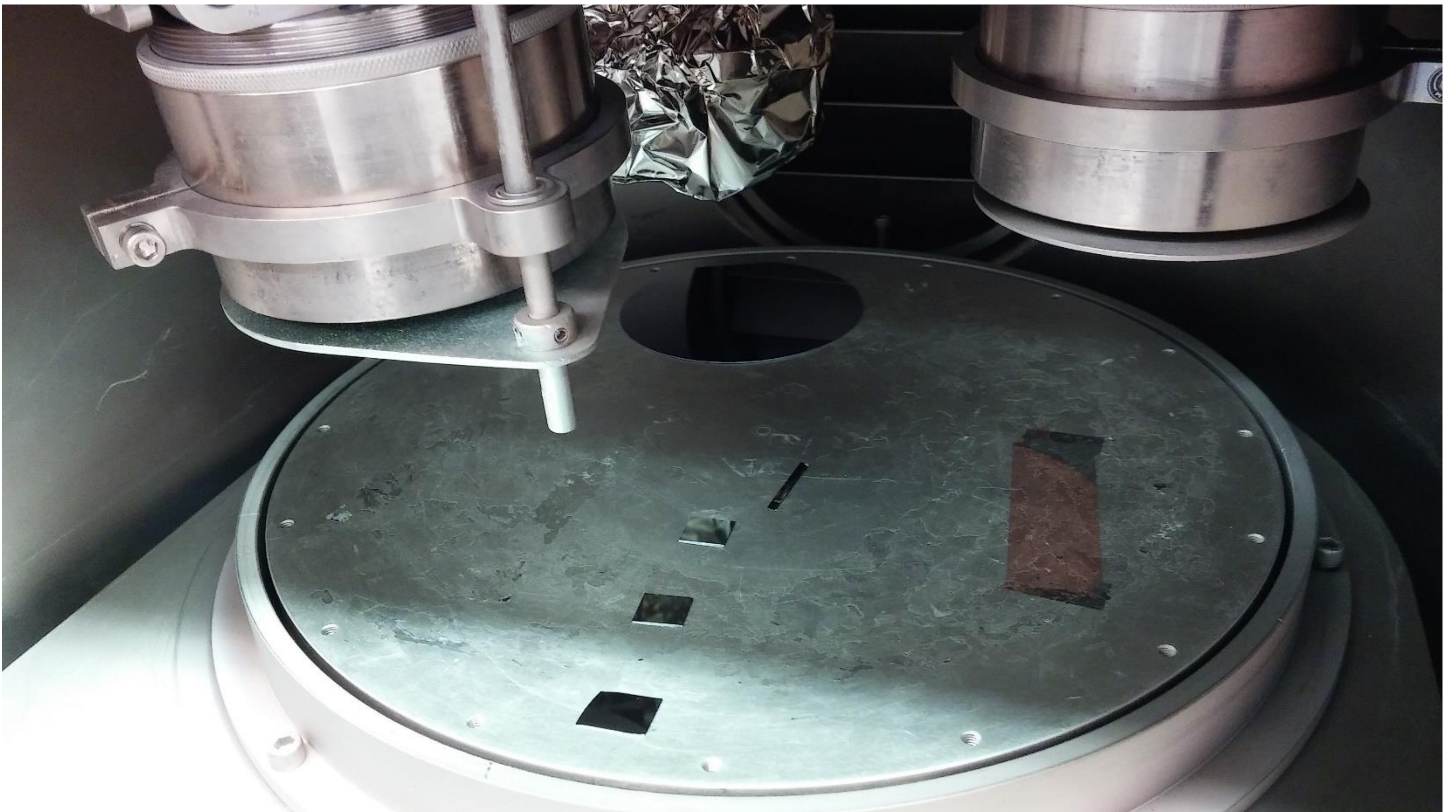

Fig.1. The general orientation of the 4 inch wafer and the samples from the 3 inch wafer. Note the positioning, which, due to the rotation of the plate, allow the samples to map to the different positions of the wafer (Major flat, Center, and Far from Major Flat)

Results:

The goal of this study was to obtain an understanding of the stress and thickness properties of a deposited copper film at varying powers and pressures. Towards this end, depositions were done by varying the cathode power and gas pressure while depositing for 600 seconds. From this data, predictions can be made about how the deposition rates and stresses of the film vary with gas pressure and cathode power.

The following results were obtained using cathode powers of 400W, 450W, and 500W, as well as having gas pressures of 3 mTorr, 5mTorr, 7 mTorr, 8 mTorr, and 10 mTorr for each power setting. Fig.2 denotes the deposition rates as a function of supplied power and gas pressure with relevant data being in Table 1. Fig.3 denotes the stress trend that was obtained from the deposited films.

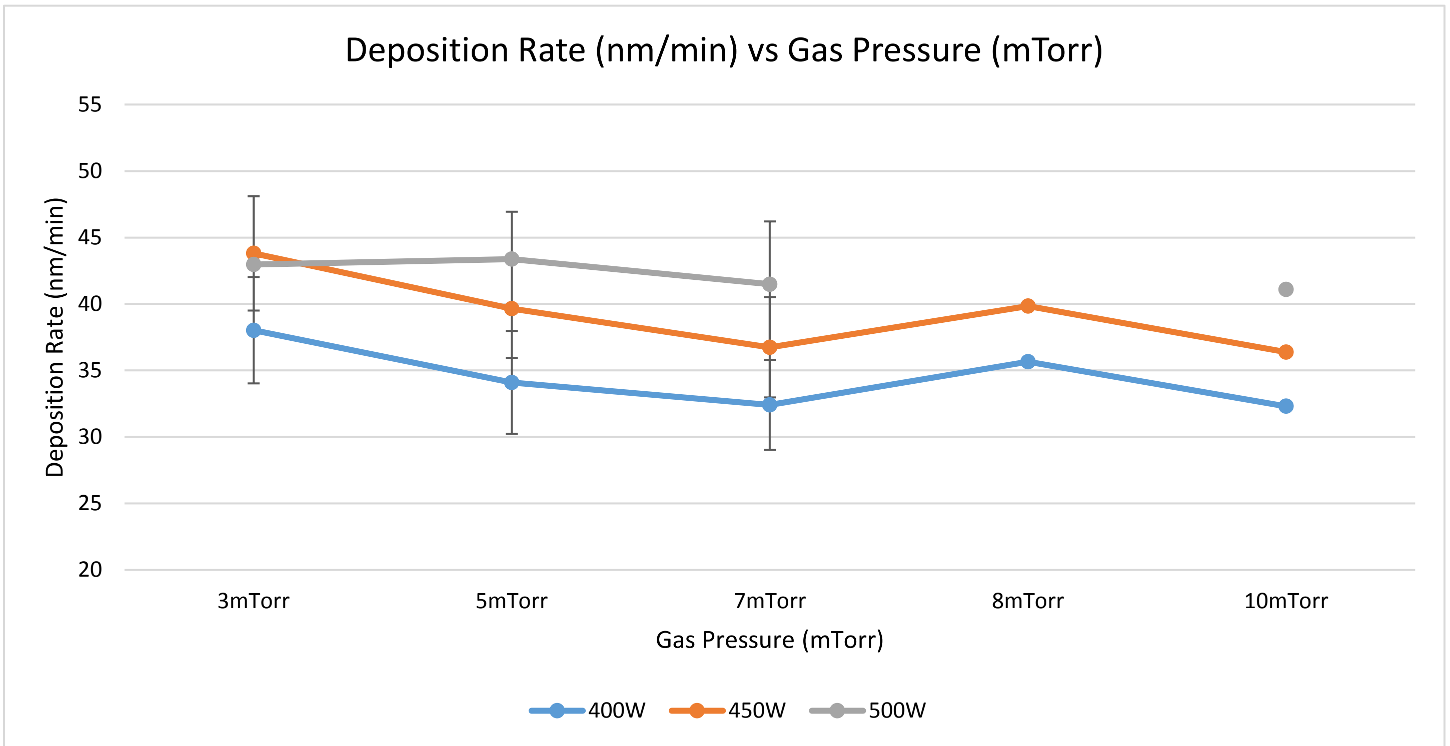

Fig. 2. The deposition rate of copper (nm/min) as a function of gas pressure and cathode power. Each point is an average of measurements taken from representative samples of the major flat, center, and far end of the substrate.

Power	3mTorr	5mTorr	7mTorr	8mTorr	10mTorr
400W	38.03	34.10	32.41	35.66	32.30
450W	43.81	39.65	36.74	39.85	36.38
500W	42.97	43.37	41.49	-------	41.10

Table.1. The (averaged) values of the copper deposition rates (nm/min) for different cathode power values and different pressure

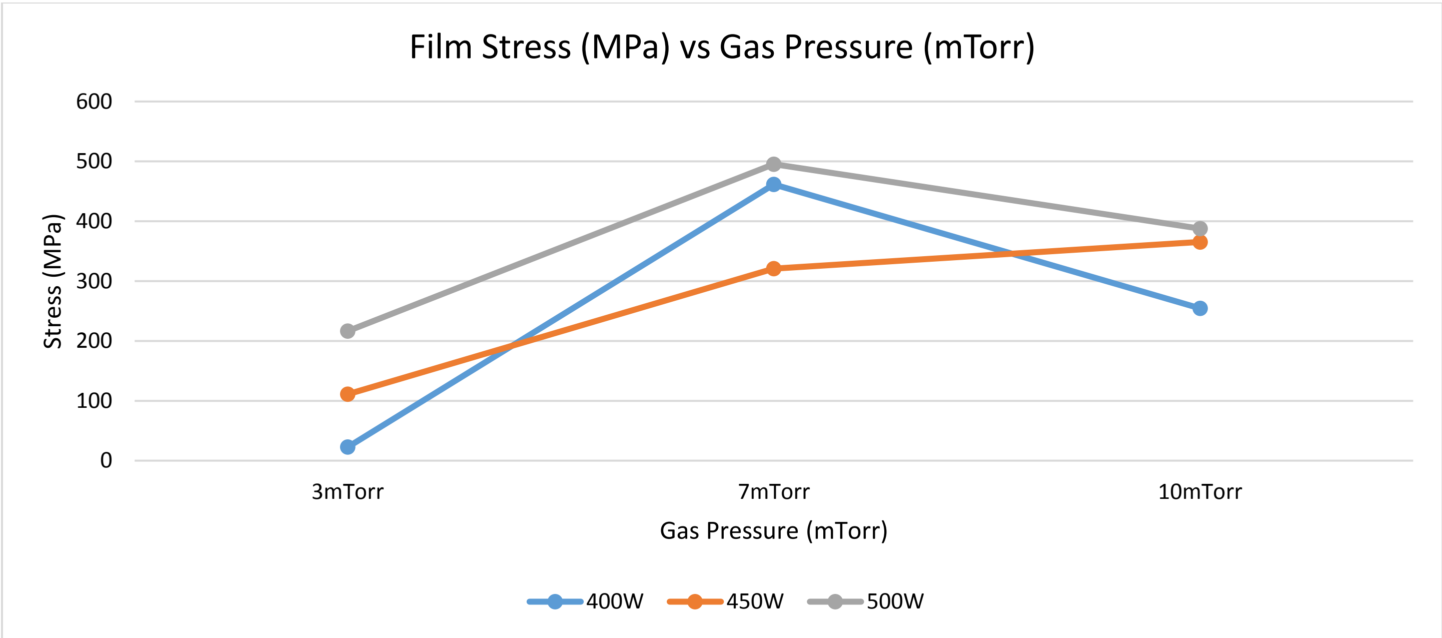

Fig. 3. The film stress (MPa) as a function of gas pressure (mTorr).

Power	3mTorr	7mTorr	10mTorr
400W	22.68	461.5	254.6
450W	111	320.6	365.4
500W	216.5	495.3	387.8

Table 2. The (Average) values of the film stress (MPa) for differing values of cathode power and gas pressure.

Discussion:

In Fig.2, note that the deposition rate increases as a function of cathode power but decreases as a function of gas pressure. Also, the amount of uncertainty that is attached to these values are in the range of 2.0 ± 0.5 nm/min.

In Table.1, the values are averaged taken from each of the three samples. 3mTorr, 7mTorr, and 10mTorr values, however, use only an averaging of 1 point per sample, rather than the other points, 5mTorr and 7mTorr, that utilize 3 points per sample for averaging.

In Fig.3, note that the film stress values are positive, because copper is a tensile film, which expands and cups downwards. Also note that the stress of the film lies for each pressure point lie somewhere within a 200 MPa difference. However, the difference between the highest and lowest stress point is a 472.6 MPa difference. These discrete points, however, do have their own uncertainties attached to them, as can be obtained through the methods discussed in *Error propagation for Substrate Thickness post-deposition (Stoney Equation Analysis)*. From this, we would obtain overlapping error bars, which allows for a rough range as to what the film stress would be.

Additional Data:

Sample#	Major (nm)	Center (nm)	Far (nm)	Mean (nm)	Standard Dev (nm)	Error (nm)
12	286.1	404.1	450.6	380.27	69.24	39.98
13	234.8	341.5	395.9	324.07	66.91	38.63
14	245.8	336.3	387	323.03	58.40	33.72
15	338.7	457.5	518.1	438.1	74.51	43.02
16	279.6	391.4	431.3	367.43	64.21	37.07
17	275.3	385.4	430.8	363.83	65.29	37.69
18	328.5	438.4	546	437.63	88.80	51.27
19	357.8	496.1	480.1	426.95	61.77	35.66
20	349.9	495.6	541.6	462.37	81.71	47.18

Table.2. The raw data for the film thicknesses for the copper depositions for the 3mTorr, 7mTorr, and 10mTorr cases. Here, Major, refers to Major Flat, Center refers to center, and Far refers to the furthest part from the major flat.

Power(W)/ Pressure(mTorr)	MF (measured @ major flat)			CENT (measured @ center)			Far (measured @ opposite of major flat)			Average	std. dev.	Error	nm/min
500/3	375.6	367.4	356.2	460.0	457.5	449.4	470.9	470.1	460.4	429.72	45.41	15.14	42.97
500/7	353.7	360.5	369.5	435.6	444.3	445.0	441.1	440.0	444.4	414.90	38.23	12.74	41.49
500/10	359.2	358.7	366.8	442.7	440.8	439.5	432.8	430.5	427.6	410.96	35.29	11.76	41.10
400/5	286.3	292.8	301.2	365.2	361.4	347.9	379.1	368.5	366.8	341.02	34.68	11.56	34.10
400/8	373.5	374.4	381.6	321.6	305.1	289.8	379.7	383.7	399.9	356.59	37.58	12.53	35.66
450/5	358.9	350.8	344.1	421.6	421.0	416.4	415.6	418.0	421.9	396.48	32.23	10.74	39.65
450/8	351.9	353.0	362.0	425.1	424.0	423.7	418.4	416.9	411.9	398.54	30.70	10.23	39.85
500/5	376.6	386.0	394.9	455.8	460.9	462.9	458.8	456.0	451.8	433.74	34.28	11.43	43.37
100/3	87.3	85.2	82.7	104.9	104.1	101.9	110.6	113.9	109.5	100.01	11.15	3.72	10.00

Table.3. The raw data for the 5mTorr and 8mTorr cases, as well as a redone 500 W testing. Note the data point for copper deposition at 100 W as well

Sample #	Average Stress (MFD)(mTorr)	Max Stress (MFD)(mTorr)	Center Stress (MFD)(mTorr)	Average Stress (MFR)(mTorr)	Max Stress (MFR)(mTorr)	Center Stress (MFR)(mTorr)
12	22.68	29.65	28.88	2.884	-33.83	7.095
13	461.5	515	484.1	359.7	457.6	367.2
14	254.6	322.3	236.3	277.3	302.8	284.8
15	111	122.2	111.1	97.17	157.7	89.95
16	320.6	369.7	309.9	378	399.9	397.4
17	365.4	427.3	364.8	343.4	403	372.1
18	216.5	277.7	237.8	106.6	157	103.8
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	526.9
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	385.3

Table.3. The raw data of the stress measurements across the wafers for the 3mTorr, 7mTorr, and 10mTorr cases, where MFD refers to major flat down and MFR refers to major flat right. For the stress measurements and graphs, the average values were utilized.