RAISING THE BAR ON REACTIVE DEPOSITION SPUTTER RATES

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ABSTRACT

Sputtering non-conductive oxides at a high deposition rate for a long period of time has always been a goal for process engineers. During sputtering of these types of processes using DC with one magnetron, the anode gets covered up with oxides, goes away, and the plasma dies. The proven solution for this is the use of AC power delivery using two magnetrons. We all know that, while effectively keeping the anode clean, the AC style of power delivery results in a loss of deposition rate of about 25% from the initial DC one magnetron design. If rotatable magnetrons are used in the AC delivery, the end blocks have limited inductive current capability. Substrate and sputter zone heating are also undesirable effects of the AC power-delivery system. Using two bipolar pulsed-DC power delivery systems and a floating anode added to the AC style dual magnetron sputtering zone, one can achieve high deposition rates by delivering more power than is possible with the AC solution. This can be as high as two times the deposition rate of AC. The floating anode stays thermally hot to desorb oxide deposited on it. Substrate temperature is about one half compared to traditional AC power delivery. The sputtering zone and end blocks no longer inductively heat, so higher power can be delivered, resulting in even more deposition rate. Methodology and results are presented.

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THE EMERGENCE OF DC REACTIVE SPUTTERING

DC reactive sputtering emerged on the scene in the mid to late 20th century. These were “medieval” times for this type of process. Deposition rates increased five times over RF sputtering. However, for processes using oxygen, the anode was increasingly covered with insulating material, making it more and more difficult for the electrons from the plasma to return back to the power supply. This caused the process voltage to go higher and higher. The process then started to arc heavily and eventually stopped due to too much insulating material buildup on the anode.

DC is considered “always on,” so as long as the anode is clean, a 100% deposition rate is possible. There were numerous ways to try to keep the anode clean, particularly for inline processes, with various results. Some ways were simple and some were complicated. None gave consistent results.

THE DEVELOPMENT OF PULSED DC

Pulsed DC became available in the late 20th century. The output signal periodically reversed the voltage 10 to 20%. This kept the anode cleaner longer, but inevitably, a vent and anode cleaning was still necessary. Since the power supply output signal pulses and reverses, no work is taking place during this reverse time, so the deposition rate would be 80 to 90% of DC.

THE ADVENT OF AC SPUTTERING

The late 20th century ushered in AC sputtering. Dr. Bill Westwood showed us that with two magnetrons, it is possible keep the anode clean, because every half cycle, one magnetron becomes a cathode while the other becomes the anode. Therefore, what was deposited from the previous half cycle is cleaned off during the next cathode’s turn to do the work. This type of power delivery is the mainstay of inline reactive sputtering, as it has proven to be robust and consistent.

Since two magnetrons are required, the initial expense is high. The output signal is a sine wave, so the resulting deposition rate of the dual magnetron AC style system is about 75% of a DC process. Also, the inductively transferred heat load on the substrate is much higher than with DC. While this is not a problem for most of the traditional reactive processes, for glass coating, it is indeed a problem for the high-temperature-adverse substrates used in web coating. The magnetrons are used only half of the time in this process, as the output signal moves the work between the two. The components in the power delivery today are designed specifically for the high-heat AC style of delivery, but they ultimately are the limiting factor for high power.

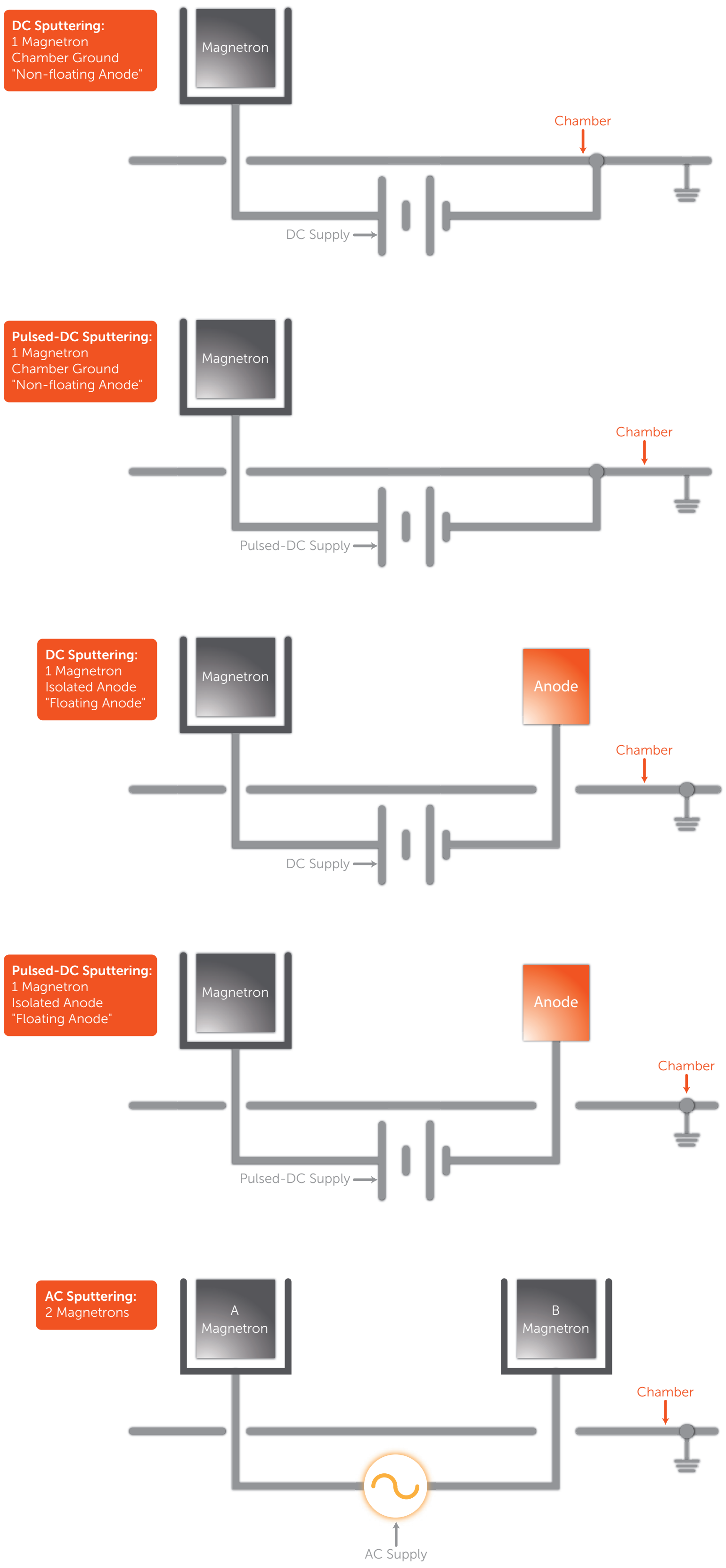

Figure 1. Various depictions of DC and AC sputtering

BIPOLAR PULSED DC MAKES ITS MARK

Jumping ahead into the early 21st Century, bipolar pulsed DC is starting to make its mark on the industry. It offers a sputtering rate comparable to the AC delivery style, with the added benefit of being able to adjust the duty cycle between the two magnetrons. The heat load of the substrate is still high. Even though it is pulsed DC, it still has an AC-type component that tends to inductively heat power-delivery components and the substrates. As with AC delivery, the magnetrons are only used half of the time. It too has a sputtering rate of 75% of DC.

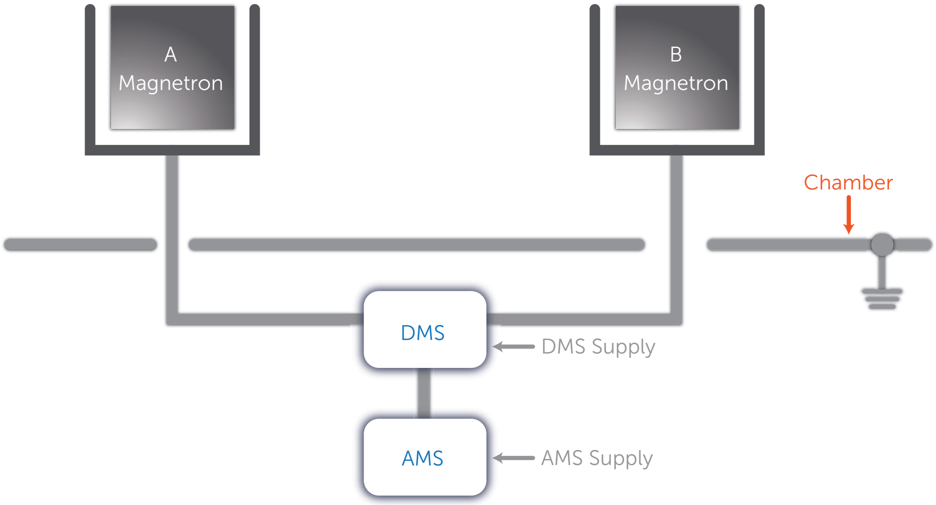

Figure 2. AMS/DMS sputtering

TODAY'S EMERGING TECHNOLOGY

Enough of the history lesson; The following section presents the central purpose of this paper.

The Advanced Energy® AMS/DMS stack has been proven to replace the AC-style power-delivery system. This stack was chosen for this particular test because the duty cycle can be adjusted and it was readily available to this author. As described above, with the stack used as an AC replacement, some inductive heating still existed, and the cathodes were still being used only one half of the time. The DMS was then essentially turned 90 degrees, and another AMS/DMS stack was added, with its DMS turned 90 degrees. A floating anode also was added. Side B of each DMS was tied together and connected to the floating anode. Side A of each DMS was connected to a cathode in a C-Mag style lid. The duty cycle on each DMS was set to 80% on Side A and therefore 20% on Side B. At 40 kHz, the floating anode stayed hot enough to desorb any reactive insulating material that was deposited on it, as both DMS units would each be delivering full power to it for 20% of the time.

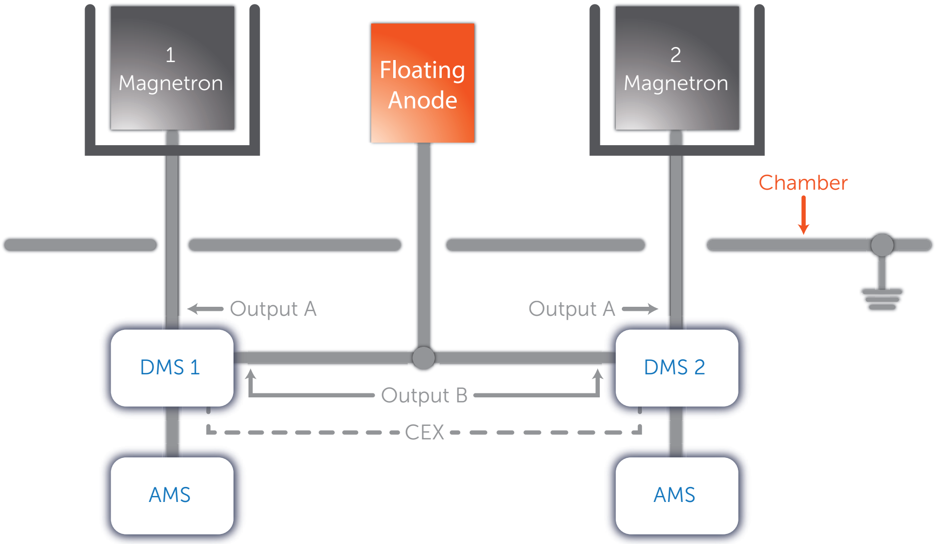

Figure 3. AMS/DMS Dual Reverse Pulse (DRP) patent-pending sputtering technology

The DMS units need to pulse in exactly the same way at exactly the same time, so Pulse Sync was used to connect them. One unit was set as the transmitter and the other as the receiver.

This setup was run on a sputter-down machine with smaller magnetrons, so process power was limited. An Advanced Energy PEII 10 kW AC power supply provided a baseline to measure the heat and deposition rates of the dual DMS setup.

THE MACHINE SETUP

- TiOx target material
- 6.4 mTorr using 126 SCCM argon and 100 SCCM oxygen
- 4 kW per magnetron with a floating anode sitting between them
- 10″ per minute line speed

OBSERVATIONS AT FIRST PLASMA

ITEM	VOLTAGE	CURRENT
Cathode 1	-535 V	7.2 A
Cathode 2	-565 V	7.1 A
Anode to Ground	850 V	NA
Anode	-680 V	2.2 A
Cathode to Ground	-720 V	NA

This verified that the DMS was trying to deliver full power to the anode. Of course there are no magnetic enhancements on the anode, so it would take very high voltages to do any more work than just heat it up. This was exactly what we were looking for.

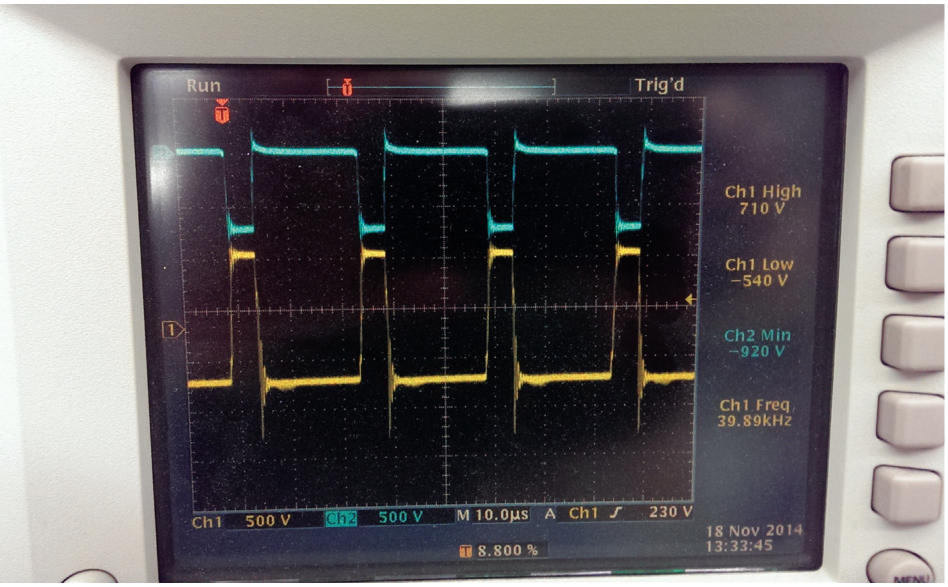

Figure 4. Voltage signal of DMS (lower trace) and anode signal to ground (upper trace)

Since the DMS is frequency agile, the two stacks were run at 20 kHz, 30 kHz, and 40 kHz with as much Side A ON time as possible. The baseline would be the PEII, so to compare deposition rates and heat loads, the DMS 40 kHz would be targeted for comparison.

To get thickness measurements, a Dektak® profilometer was used, with a Sharpie® mark on the bare glass. Scrubbing the coated glass over the Sharpie mark removes the coating so a good thickness step can be obtained.

The heat load on the substrate was measured by a SuperM.O.L.E.® This is a circuit board encased by many heat shields with a type K thermocouple super-glued to the glass substrate. The SuperM.O.L.E. takes real-time temperature measurements through the plasma and the data is then downloaded onto a PC.

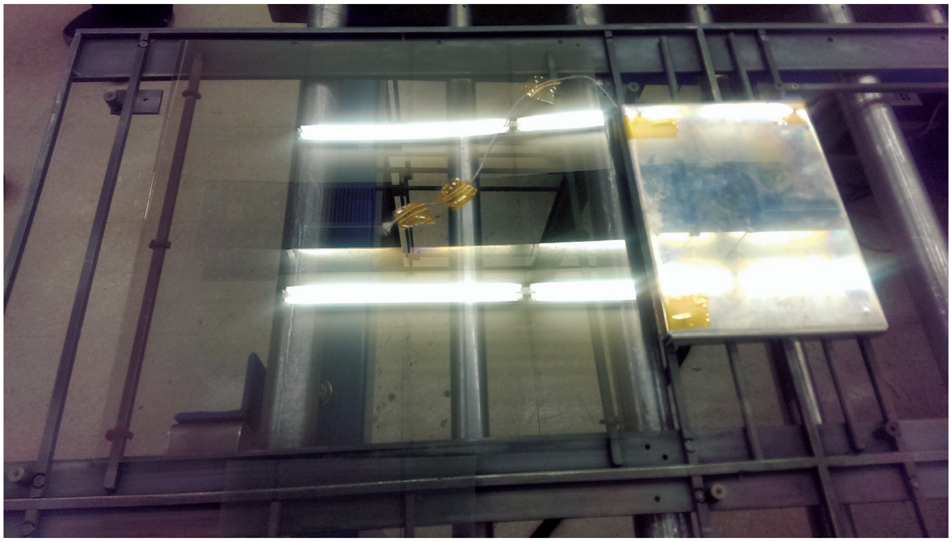

Figure 5. SuperM.O.L.E.® setup

THE RESULTS

Five runs were made. All machine setups were as described above.

RUN #1

AMS SETTINGS	POWER	VOLTAGE	CURRENT
AMS 1	4 kW	513 V	7.8 A
AMS 2	4 kW	526 V	7.7 A

DMS SETTINGS	FREQUENCY	SIDE A	SIDE B	BOOST
DMS 1	20 kHz	90%	10%	50%
DMS 2				

DMS SIDE B ANODE	VOLTAGE	CURRENT
DMS 1	589 V	2.8 A
DMS 2	598 V	3.4 A

RUN #2

AMS SETTINGS	POWER	VOLTAGE	CURRENT
AMS 1	4 kW	527 V	7.6 A
AMS 2	4 kW	542 V	7.4 A

DMS SETTINGS	FREQUENCY	SIDE A	SIDE B	BOOST
DMS 1	30 kHz	85%	15%	50%
DMS 2				

DMS SIDE B ANODE	VOLTAGE	CURRENT
DMS 1	637 V	2.2 A
DMS 2	647 V	2.2 A

RUN #3

AMS SETTINGS	POWER	VOLTAGE	CURRENT
AMS 1	4 kW	545 V	7.3 A
AMS 2	4 kW	552 V	7.2 A

DMS SETTINGS	FREQUENCY	SIDE A	SIDE B	BOOST
DMS 1	40 kHz	80%	20%	50%
DMS 2				

DMS SIDE B ANODE	VOLTAGE	CURRENT
DMS 1	678 V	2.2 A
DMS 2	680 V	2.2 A

RUN #4

PEII SETTINGS	POWER	VOLTAGE	CURRENT
PEII	4 kW	570 V	7.6 A

RUN #5

PEII SETTINGS	POWER	VOLTAGE	CURRENT
PEII	8 kW	630 V	14 A

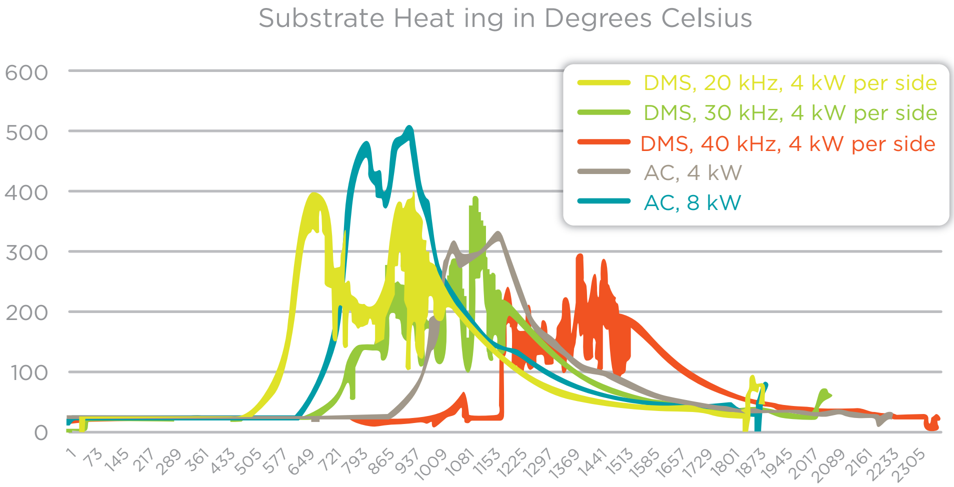

Figure 6. Substrate heat load, all runs

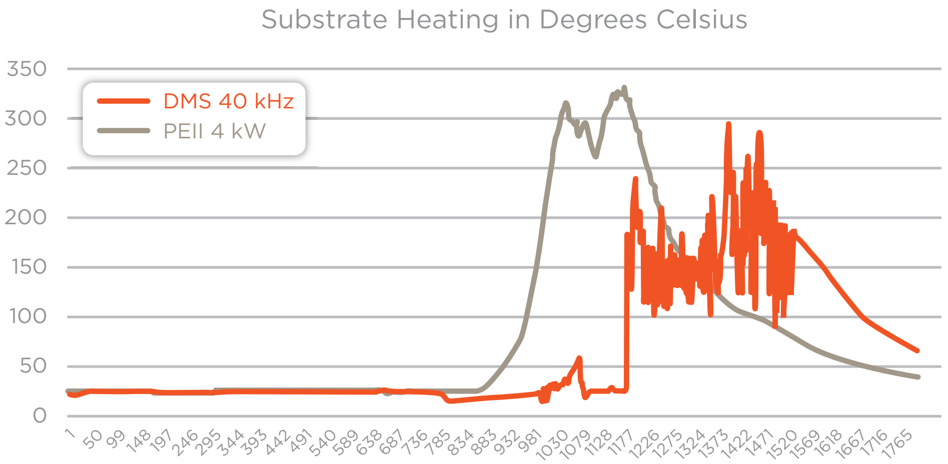

Figure 7. Substrate heat load, DMS 40 kHz 4 kW to AC 4 kW

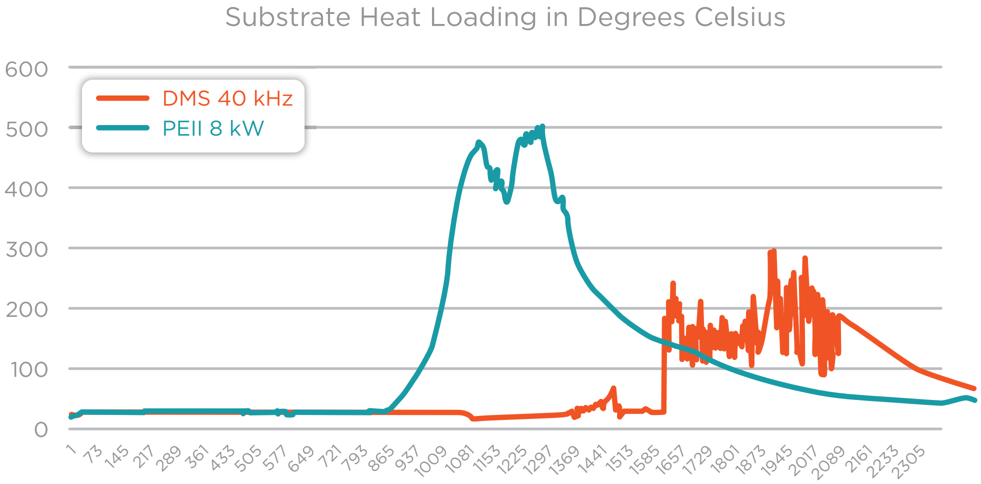

Figure 8. Substrate heat load, DMS 40 kHz 4 kW to AC 8 kW

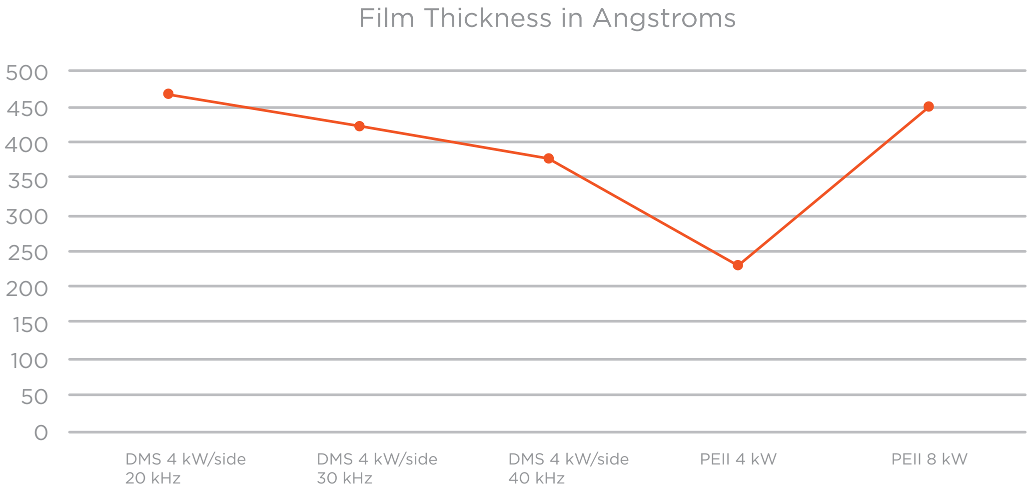

Figure 9. Thickness measurements

FILM THICKNESS

RUN #	TYPE	FREQUENCY	POWER	CURRENT	THICKNESS	HEAT LOAD
1	DMS	20 kHz	4 kW per side	7.8 A per side	460 Å	360°C
2	DMS	30 kHz	4 kW per side	7.5 A per side	425 Å	320°C
3	DMS	40 kHz	4 kW per side	7.3 A per side	380 Å	230°C
4	AC	40 kHz	4 kW_{RMS}	7.6 A_{RMS}	230 Å	310°C
5	AC	40 kHz	8 kW_{RMS}	14.0 A_{RMS}	450 Å	480°C

CONCLUSION

Of all the pretty pictures and graphs in this paper, the last table is the most informative. Running the dual AMS/DMS stacks as described certainly lowers the heat load and increases the deposition rates.

In a comparison of runs 3 and 4 (DMS 40 kHz, 4 kW per side and AC 40 kHz, 4 kW RMS), it was possible to double the current on the magnetron pair with the DMS. This increases the deposition rate per pair and the heat load goes down drastically.

In a comparison of runs 3 and 5 (DMS 40 kHz, 4 kW per side and AC 40 kHz, 8 kW RMS), the deposition rate was a bit more with AC, as expected, but the heat load was half on the DMS. While this is interesting, it is not where a usual process engineer would be when an AC power or current limit is hit and more deposition rate is required. For example, if a sputtering zone is running at 90 kW and hitting the 300 A, AC current limit, a pair of AMS/DMS stacks could be used. Placing two 120 kW AMS/DMS stacks in place of a 120 kW AC delivery system will actually be more like comparing runs 3 and 4. It is possible to push more power into the power-delivery system without worrying about being up at the top end of the inductive heating current limit. This type of delivery system will add more production speed, be able to add deposition rates without adding cathode lids, use existing cathodes to their fullest extent, and keep substrates and power delivery components much cooler.

Looking at runs 1, 2, and 3, one can deduce that these AMS/DMS stacks can run at most any frequency and give a much better Angstrom/substrate temperature profile consistently over traditional AC power delivery.

ADDENDUM

Moving the anode closer to the cathodes can cause a noticeable drop in Side B Anode voltage. It is important to locate the anode so the anode voltage is slightly higher than the Side A cathode voltages. This will ensure that the arc sensing circuit will trip on the Side A cathode and not on the Side B anode.

ACKNOWLEDGEMENTS

A heartfelt *thank you* goes to Colorado Concept Coatings in Loveland, CO for the use of their coater and facilities for this test. Also, a big *thank you* goes to Ken Nauman of VAA North America for the help in acquiring the CCC agreement, as well as supplying the SuperM.O.L.E. and the much-needed manpower for completing the testing for this paper in a timely fashion.

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