APPLICATION NOTE

Highly Uniform Dielectric Films Using a Combined Linear Scanning, Velocity Profiling, and Planetary Rotating Motion

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Exceptionally high uniformities and tight repeatabilities have been achieved for dielectric films on KDF 900 series sputtering tools using a proprietary ERPP (enhanced rotating planetary pallet) in conjunction with the tool's standard linear scanning mode. We have developed reactive and non- reactive processes for materials such as SiO_2, Si_3N_4, TiO_2, and Al_2O_3, with uniformities better than ± 1% over the pallet and repeatabilities of better than ± 0.5% from pallet to pallet. This performance enables us to provide production processes for multilayer dielectric mirrors and filters to the optoelectronics and display industry, as well as high-quality silicon nitride passivation layers and antireflective coatings for compound semiconductors and solar cells. Specific reactive and non-reactive processes will be discussed in depth. Additionally, a new system capability that allows the scan velocity to be programmed flexibly will be discussed with respect to its potential for further uniformity improvement.

As thin-film device capabilities expand, requirements on tool manufacturers become ever tighter to provide better uniformities and higher repeatabilities for deposited thin films. A combination of longer cathodes and complex substrate motion is utilized to meet some of these requirements on KDF 900 series down-sputtering tools, shown schematically in **Figure 1**.

Extension of the rectangular cathodes from the standard 15” to 17”, combined with a novel scanning planetary substrate motion provided by an enhanced rotating planetary pallet (ERPP), has yielded pallet uniformities and run-to-run repeatabilities on the order of ± 1% for a range of dielectric processes such as SiO_2, TiO_2, and Si_3N_4. Complex multilayer dielectric coatings such as mirrors and filters can now be processed in a highly uniform and repeatable manner utilizing these system advances. The processes developed will be detailed here.

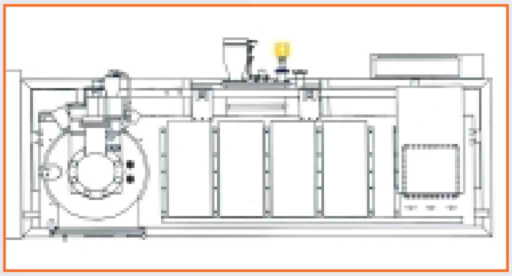

Figure 1. KDF 954 NTX four-target sputtering system with 17” cathode.

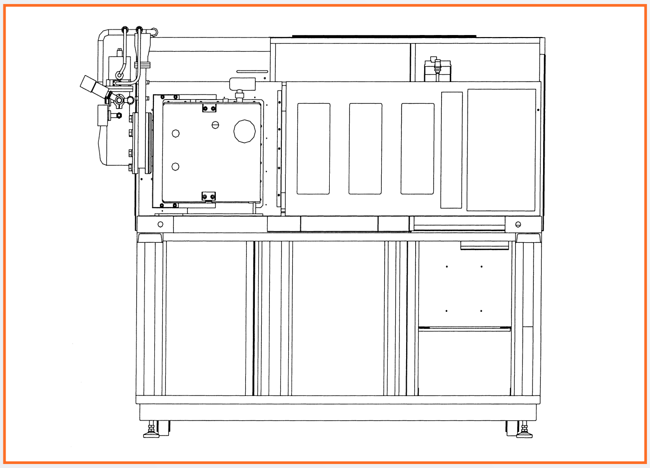

Figure 2. KDF 643 NT three-target side-sputtering tool with 15” cathode.

STANDARD DIELECTRIC PROCESSES

Typically, on standard KDF side-sputtering tools (643 NT shown in **Figure 2**) or down-sputtering tools (943 NT), dielectric films such as SiO_2 [1] and TiO_2 [2] are deposited onto a pallet with a 12” x 12” deposition zone that scans past a 15” long by 5” wide rectangular magnetron cathode called the KDF Mark II™. The deposition mode is RF magnetron sputtering, either reactively with oxygen or nitrogen from an elemental target or non-reactively from a compound target. The cathode is optimized to yield good uniformity for dielectric sputtering, with an average uniformity of about ± 10% over the 12” x 12” pallet area. **Figure 3** shows the uniformity profile in the direction perpendicular to the scan direction for SiO_2 films sputtered from a quartz target. This uniformity is greatly improved to less than ± 5% by extending the cathode length to 17”, in KDF NTX series tools, as shown in **Figure 4**.

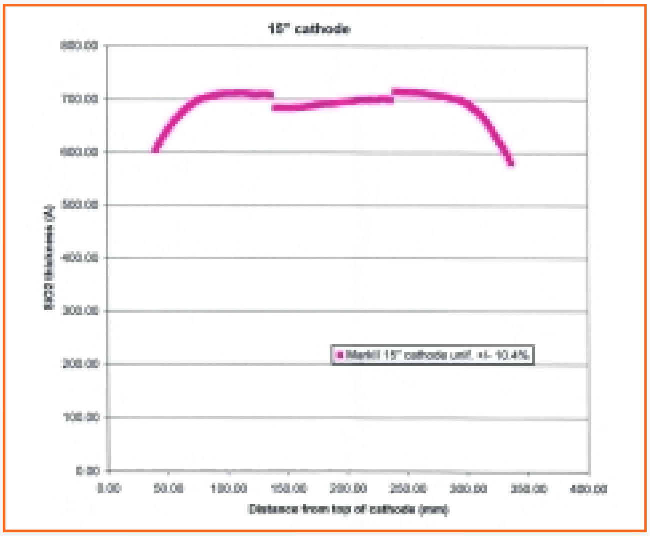

Figure 3. SiO_2 uniformity profile across a 12” x 12” pallet with a 15” cathode.

SYSTEM ENHANCEMENTS

Enhanced Rotating Planetary Pallet (ERPP™)

For special applications in the optical networking industry, precise quarter-wavelength thicknesses of dielectrics with exceptional uniformities and run-to-run repeatabilities of ± 1% are required to create multilayer stacks for filters and mirrors. In such applications, 25 to 30 alternating bilayers of SiO_2 and TiO_2, making a total of 50 to 60 layers, could be required. The three- or four- target KDF 943 NT or KDF 954 NTX systems with multistep recipe capability and high scan speeds for precise resolution of film thicknesses can easily perform such depositions. However, in order to meet the very tight film uniformity requirements without having to add uniformity apertures into the system, a new pallet design was created: the enhanced rotating planetary pallet.

The planetary pallet is capable of linear translation, as in a standard KDF system. Mounted on the pallet is a rotation platform, called the “sun,” that is capable of being rotated over a continuous range of speeds. Four, four-inch-diameter wafer “planets” are attached to the sun. These planets can spin individually at a fixed gear ratio to the sun, resulting in a full planetary motion of the wafer in the plane of deposition superimposed on the standard linear pallet translation. The planetary motion serves to integrate the high and low rates of deposition from the cathode over the wafers as they rotate while being translated under the cathode. A schematic drawing of the ERPP is shown in **Figure 5**.

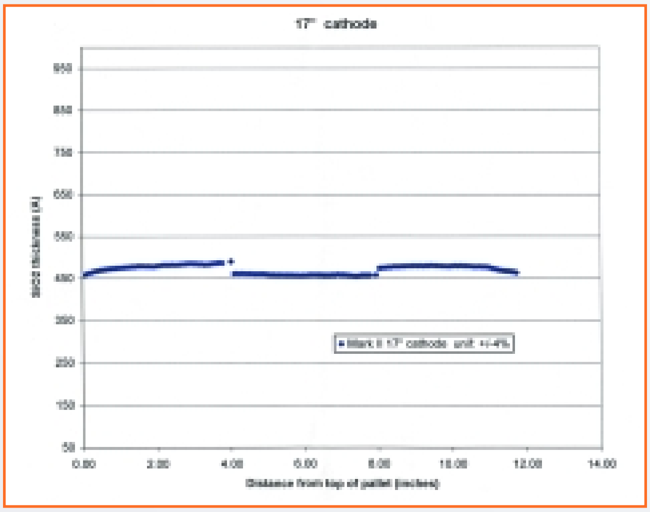

Figure 4. SiO_2 thickness profile across a 12” x 12” pallet with a 17” cathode.

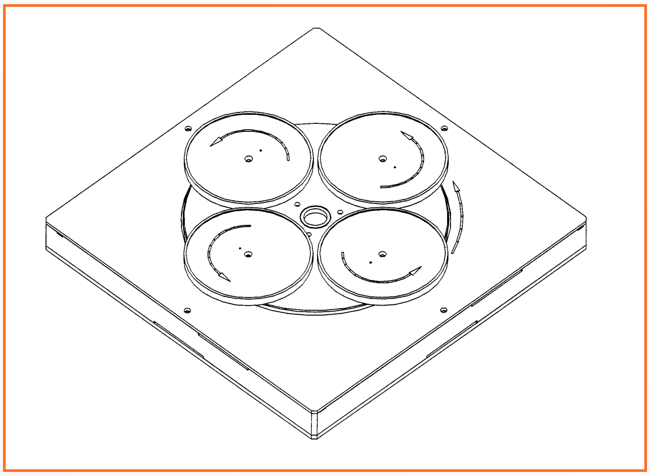

Figure 5. Enhanced rotating planetary pallet.

Scan Velocity Profiling

A recent software advancement now allows us to flexibly program the linear scan speed of the pallet, such that up to 50 different scan speeds can be programmed into each scan in each direction. This, when correctly applied, would allow us to eliminate leading edge-trailing edge non-uniformities and further improve uniformities on all films. **Figures 5 and 6** show the left-to-right uniformity profile of aluminum deposited without scan velocity profiling (SVP) and with SVP to demonstrate the potential of this capability for uniformity improvement.

RESULTS

Non-Reactive or Minimally Reactive Depositions

With the ERPP, within-wafer uniformities of less than ±1% and over pallet uniformities of less than ±2% have been achieved, even with the 15” cathode, where standard uniformities over the pallet for SiO_2 are on the order of ±12 to 15%. Pallet-to-pallet repeatabilities of less than ±2% have been achieved. The tables below summarize results from deposition of SiO_2 and TiO_2 using the planetary pallet. These depositions were done non-reactively (or with minimal amounts of reactive gas) using quartz and titanium dioxide targets.

SiO_2 and TiO_2 from Standard 15” Cathodes

Tables 1 and 2 summarize planetary scanning results for SiO_2 and TiO_2, respectively, using standard 15” cathodes.

SiO_2 and TiO_2 from Extended 17” Cathodes

The uniformities and repeatabilities shown in **Table 3** were

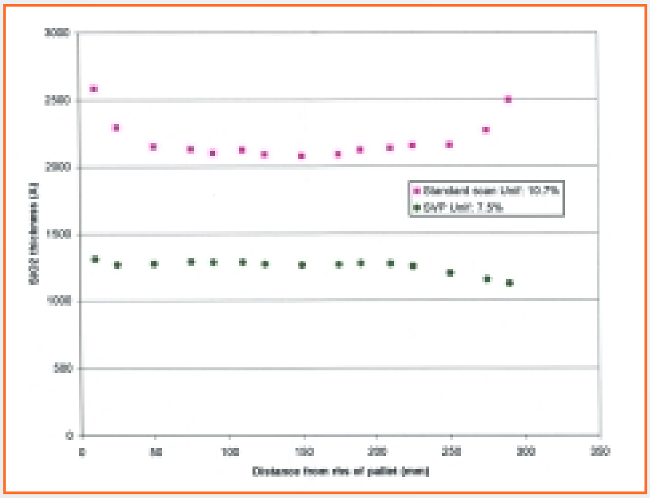

Figure 6. SiO_2 R-L profiles with and without scan velocity profiling.

achieved for SiO_2 sputtered from quartz with the longer 17" cathode in a 954 NTX system. **Table 3** summarizes the data for films sputtered with 100% Ar.

SiO_2 films sputtered from a quartz target with pure argon are oxygen-depleted and have a slightly high refractive index of 1.55, as tabulated above. In order to achieve stoichiometric SiO_2 films with a refractive index of 1.46, about 10% oxygen should be mixed in with the sputtering argon. The uniformity and repeatability of these runs using the planetary rotation is tabulated in **Table 4**. The reduction is average film thickness in **Table 4** compared with **Table 3** is caused by fewer scans (37 scans in **Table 4** versus 66 scans in **Table 3**), as well as the addition of oxygen. **Figure 7** graphs the repeatability and uniformity summarized in **Table 4**.

Table 1. SiO_2 uniformity data with 15" cathode

Position on wafer	Wafer #1	Wafer #2	Wafer #3	Wafer #4
North	3826	3826	3779	3774
South	3833	3833	3778	3779
East	3821	3821	3799	3832
West	3876	3790	3791	3757
Center	3789	3798	3730	3728
Ave	3829	3813.6	3775.4	3774
Unif. (H-L)/(H+L)*100%	**± 1.1%**	**± 0.6%**	**± 0.9%**	**± 1.4%**
Pallet unif. %	**0.7%**	(based on wafer averages)		
Pallet-to-pallet % repeatability %	**0.7%**	(based on average thickness per pallet for three 2000 Å repeat runs)		

Table 2. TiO_2 uniformity data with 15" cathode

Position on wafer	Wafer #1	Wafer #2	Wafer #3	Wafer #4
North	1828	1847	1840	1836
South	1810	1861	1859	1860
East	1816	1836	1845	1859
West	1822	1874	1853	1836
Center	1814	1824	1819	1819
Ave	1818	1848	1843	1842
Unif. (H-L)/(H+L)*100%	**± 0.5%**	**± 1.4%**	**± 1.1%**	**± 1.1%**
Pallet unif. %	**0.8%**	(based on wafer averages)		
Pallet-to-pallet repeatability %	**1.4%**	(based on average thickness per pallet for three 1800 Å repeat runs)		

Table 3. SiO_2 uniformity data with 17" cathode

Run #	Wafer #	Thickness (Å)	Refractive index	Unif. within pallet (%)	Pallet-to-pallet repeatability (%)
1	1	1625	1.55	**0.34**	
	2	1622	1.55		
	3	1632	1.55		
	4	1633	1.55		
Average #1		**1628**			
2	1	1642	1.55	**0.24**	
	2	1636	1.55		
	3	1644	1.55		
	4	1639	1.55		
Average #2		**1640**			
3	1	1634	1.55	**0.24**	
	2	1642	1.55		
	3	1638	1.55		
	4	1638	1.55		
Average #3		**1638**			
4	1	1639	1.55	**0.37**	
	2	1627	1.55		
	3	1632	1.55		
	4	1631	1.55		
Average #4		**1632**			**0.37**

Titanium dioxide sputtered from a compound 17" target withscanning planetary motion also exhibits excellent uniformity and repeatability, as shown in **Table 5.** We have found the repeatability is significantly improved by the addition of about 5% oxygen.

Silicon Nitride Reactive Deposition

For reactive deposition processes [3] where uniformities over the pallet can be worsened by non-uniformities in reactive gas flow distribution, the planetary scanning motion provides consistently excellent uniformity. We have developed a production process for silicon nitride reactively sputtered from a silicon target. We have good uniformity and repeatability on silicon dioxide and aluminum oxide sputtered reactively from elemental targets as well.

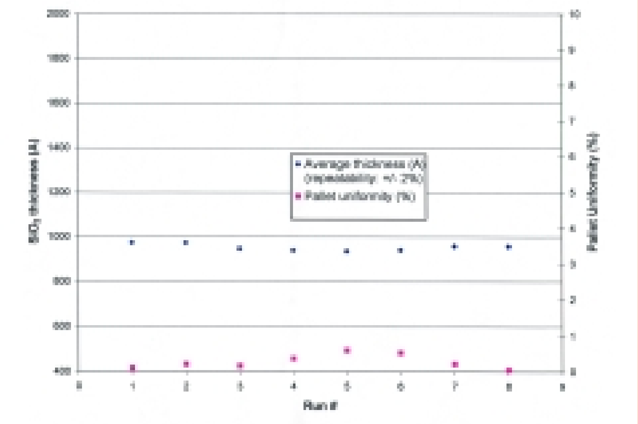

Figure 7. Uniformity and repeatability of SiO_2 with planetary pallet.

Table 4. SiO_2 uniformity data with 17” cathode

Run #	Wafer #	Thk. (Å)	Ref. index	Uniformity(%)	Repeatability (%)
1	1	974	1.46	0.1	
	2	973	1.46		
	3	975	1.46		
	4	973	1.46		
Average #1		**974**			
2	1	971	1.46	0.21	
	2	973	1.46		
	3	973	1.46		
	4	975	1.46		
Average #2		**973**			
3	1	946	1.46	0.16	
	2	947	1.46		
	3	949	1.46		
	4	947	1.46		
Average #3		**947**			
4	1	936	1.46	0.37	
	2	943	1.46		
	3	939	1.46		
	4	942	1.46		
Average #4		**940**			
5	1	937	1.46	0.59	
	2	929	1.46		
	3	940	1.46		
	4	937	1.46		
Average #5		**936**			
6	1	936	1.46	0.53	
	2	946	1.46		
	3	940	1.46		
	4	942	1.46		
Average #6		**941**			
7	1	956	1.46	0.21	
	2	960	1.46		
	3	957	1.46		
	4	959	1.46		
Average #7		**958**			
8	1	956	1.46	0.05	
	2	957	1.46		
	3	957	1.46		
	4	956	1.46		
Average #8		**957**			**1.99**

Table 5. TiO_2 uniformity data with 17” cathode

Run #	Wafer #	Thickness (Å)	Refractive index	Unif. within pallet (%)	Pallet-to-pallet repeatability (%)
1	1	509	2.55	0.20	
	2	507	2.55		
	3	508	2.55		
	4	508	2.55		
Average #1		**508**			
2	1	497	2.55	0.30	
	2	500	2.55		
	3	499	2.55		
	4	498	2.55		
Average #2		**499**			
3	1	494	2.55	0.10	
	2	495	2.55		
	3	494	2.55		
	4	494	2.55		
Average #3		**495**			
4	1	501	2.55	0	
	2	501	2.55		
	3	501	2.55		
	4	501	2.55		
Average #4		**501**			**1.5**

Table 5. Reactive Si_3N_4 uniformity data with 17” cathode

Run #	Wafer #	Max. (Å)	Min. (Å)	Average (Å)	Unif. (%)	Pallet-to-pallet repeatability (%)
1	1	1315	1275	1292	1.5	
	2	1317	1267	1292	1.9	
	3	1319	1292	1303	1.1	
	4	1320	1289	1304	1.2	
Pallet #1		1320	1267	**1298**	**2.0**	
2	1	1300	1252	1267	1.9	
	2	1295	1246	1269	1.9	
	3	1295	1246	1267	1.9	
	4	1302	1270	1289	1.2	
Pallet #2		1302	1246	**1273**	**2.2**	
3	1	1286	1254	1266	1.3	
	2	1292	1253	1268	1.5	
	3	1288	1256	1269	1.3	
	4	1295	1263	1279	1.3	
Pallet #3		1295	1253	**1271**	**1.6**	
Run-to-run repeatability						**1.0**

Conclusions

We have discussed in detail results for dielectric film deposition using standard and extended cathodes with a novel planetary scanning substrate carrier. Film uniformities and run-to-run repeatabilities are greatly improved using this technique. A new software enhancement that allows flexible programming of the pallet scan speed can be utilized to further improve the uniformity over the pallet. These techniques have allowed us to improve dielectric film uniformities from typical values of ± 12 to 15% to less than ± 2% over the pallet for a variety of reactive and non- reactive depositions.

References

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2. “Technique for Sputtering Energy Conserving Coatings,” S.A. Spura, R. P. Fontana, S. Hurwitt, A. Aronson, P.J. Walsh, W.E. Thouret, and L. Thorington, Annual Technical Conference Proceedings of Society of Vacuum Coaters, Chicago, IL (1980).

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