History

• 1985  Closed field magnetron (CFM) sputtering technology developed by Teer Coatings (UK) for tribological and wear resistant PVD coatings

• 1986  Teer Coatings Ltd. files for CFM patents and establishes both coating services and equipment manufacturing specifically for the hard coating and decorative market.

• 2001  AML Ltd. (UK) formed company and licenses CFM sputtering technology from Teer for development of technology into precision optical coating market

• 2003  AML Ltd. markets and delivers systems into the precision optical coating market worldwide

• 2008  AML Ltd. files for multiple patents for CFM technology into optical coating systems

• 2010  AML Ltd. sells company, IP and patents to Applied Multilayers LLC (AML) of Battle Ground, Washington, USA

• 2012  AML purchases IP and patents from Edwards Vacuum Ltd. for the small PlasmaCoat sputtering system

• 2014  Telemark acquires joint ownership of Applied Multilayers LLC
Products

- CFM Sputtering Systems
- Custom Systems (In-Line)
- Standard Systems (Batch)
- PECVD Reactors
### Patents Granted

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 9530629</td>
<td>Method for Depositing Multilayer Coatings</td>
</tr>
<tr>
<td>US 8206562</td>
<td>Application of a Material Layer to Display Devices</td>
</tr>
<tr>
<td>US 9562283</td>
<td>Coating of Optical Substrates using CFM</td>
</tr>
<tr>
<td>US 5427671</td>
<td>Ion Vapor Deposition Apparatus and Method</td>
</tr>
<tr>
<td>US 5660693</td>
<td>Ion Vapor Deposition Apparatus and Method</td>
</tr>
<tr>
<td>US 6090247</td>
<td>Apparatus for Coating Substrates</td>
</tr>
<tr>
<td>US 6090248</td>
<td>Apparatus for Coating Substrates</td>
</tr>
<tr>
<td>US 6159351</td>
<td>Magnetic Array for Magnetrons</td>
</tr>
<tr>
<td>US 6143143</td>
<td>Masking Means and Cleaning Techniques for Surfaces</td>
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### Patent Pending

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Description</th>
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<tbody>
<tr>
<td>US 12/224 354</td>
<td>Method/Apparatus for Forming a Coated Optical Lens</td>
</tr>
</tbody>
</table>
Technology

Closed Field Magnetron (CFM)

Plasma not shown complete for clarity

Cutaway of South Magnetron 1 showing plasma configuration

Trapped and enhanced plasma
Closed Field Magnetron Sputtering

Open Field  Closed Field

High Ion Current Density and Low Ion Energy

- High Density Films
- Smooth Surface Optical Coatings
- Stress Controlled Films
- Minimal Defect Density/Particles
- Low Temperature Process
- Small and Large Load Capacity
- Scalable Technology
Load Capacity

CFM has nearly 3X the Load Capacity vs. Evaporation Systems
<table>
<thead>
<tr>
<th>Coating System</th>
<th>CFM450/2</th>
<th>CFM650/4</th>
<th>CFM850/6</th>
<th>CFM1050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drum diameter</td>
<td>250mm</td>
<td>424mm</td>
<td>532mm</td>
<td>700mm</td>
</tr>
<tr>
<td>Linear magnetron length</td>
<td>410mm</td>
<td>610mm</td>
<td>1055mm</td>
<td>1255mm</td>
</tr>
<tr>
<td>Magnetron width (target size)</td>
<td>133mm</td>
<td>133mm</td>
<td>133mm</td>
<td>133mm</td>
</tr>
<tr>
<td>Magnetron positions</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>6 - 8</td>
</tr>
<tr>
<td>Available coating area (±1%)</td>
<td>1875 cm²</td>
<td>5040 cm²</td>
<td>11,130 cm²</td>
<td>17,920cm²</td>
</tr>
</tbody>
</table>
Systems

**CFM450 AR Coating system**
- 30 lens capacity (72mm dia)
- Two 400mm linear magnetrons
- 250mm drum diameter
- Diffusion pumped system
- Modem and Internet diagnostics
- In situ hydrophobic process
- AR coating cycle time typically 40 minutes
- Meissner trap option

**CFM650 AR Coating system**
- 60 lens capacity (72mm dia)
- Up to Four 600mm linear magnetrons
- 400mm drum diameter
- 2000 litre/sec Turbomolecular pumped system
- Modem and Internet diagnostics
- In situ hydrophobic process
- AR coating cycle time typically 40 minutes

**CFM850 AR Coating system**
- 120 lens capacity (72mm dia)
- Up to six 1m linear magnetrons
- 550mm drum diameter
- Two 2000 litre/sec Turbomolecular pumps
- Modem and Internet diagnostics
- In situ hydrophobic process
- AR coating cycle time typically 40 minutes
- Meissner trap option

**CFM1050 AR Coating system**
- 240 lens capacity (72mm dia)
- Up to eight 1.2m linear magnetrons
- 750mm drum diameter
- Four 2000 litre/sec Turbomolecular pumps
- Modem and Internet diagnostics
- In situ hydrophobic process
- AR coating cycle time typically 40 minutes
- Meissner trap option
CFM 450 Used to AR coating prescription lenses in Canada

CFM650 used to apply mirror coatings to sunwear lenses in Shenzhen, China
CFM450

Chamber diameter (internal) 450mm
Chamber height (internal) 640mm
Chamber diameter (external) 528mm
Chamber height (external) 685mm

Drum diameter 250mm
Linear magnetron length 410mm
Magnetron width (target size) 133mm

Magnetron positions:

Available coating area (±1%): 1875 cm²
CFM650/4

Chamber diameter (internal) 714mm
Chamber height (internal) 837mm
Chamber diameter (external) 724mm
Chamber height (external) 881mm

Drum diameter 424mm
Linear magnetron length 610mm
Magnetron width (target size) 133mm

Magnetron positions: 4
Available coating area (±1%): 5040 cm²
CFM850/6

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber diameter (internal)</td>
<td>760mm</td>
</tr>
<tr>
<td>Chamber height (internal)</td>
<td>1381mm</td>
</tr>
<tr>
<td>Chamber diameter (external)</td>
<td>780mm</td>
</tr>
<tr>
<td>Chamber height (external)</td>
<td>1451mm</td>
</tr>
<tr>
<td>Drum diameter</td>
<td>532mm</td>
</tr>
<tr>
<td>Linear magnetron length</td>
<td>1055mm</td>
</tr>
<tr>
<td>Magnetron width (target size)</td>
<td>133mm</td>
</tr>
<tr>
<td>Magnetron positions:</td>
<td>6</td>
</tr>
<tr>
<td>Available coating area (±1%)</td>
<td>11,130 cm²</td>
</tr>
</tbody>
</table>
### CFM 1050/8

<table>
<thead>
<tr>
<th>Specification</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber diameter (internal)</td>
<td>1640 mm</td>
</tr>
<tr>
<td>Chamber height (internal)</td>
<td>1620 mm</td>
</tr>
<tr>
<td>Chamber diameter (external)</td>
<td>1690 mm</td>
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<tr>
<td>Chamber height (external)</td>
<td>1670 mm</td>
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<tr>
<td>Drum diameter</td>
<td>700 mm</td>
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<tr>
<td>Linear magnetron length</td>
<td>1255 mm</td>
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<tr>
<td>Magnetron width (target size)</td>
<td>133 mm</td>
</tr>
<tr>
<td>Magnetron positions</td>
<td>8</td>
</tr>
<tr>
<td>Available coating area (±1%)</td>
<td>11,130 cm²</td>
</tr>
</tbody>
</table>
Plasma Express

Multilayer Express AR Coating system

- 6 lens capacity (72mm dia)
- Two 6 inch circular magnetrons
- 200mm drum diameter
- Load Lock for fast cycle time
- Turbomolecular pumped system
- Modem and Internet diagnostics
- In situ hydrophobic process
- AR coating cycle time typically 15 minutes
<table>
<thead>
<tr>
<th>Target Materials</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>AzO, IZO, CdTe, CdS</td>
<td>Thin film solar cells on glass or polymer sheets</td>
</tr>
<tr>
<td>SiO₂, Nb₂O₅, TiO₂, Ta₂O₅</td>
<td>AR, IR, UV coatings, telecommunications, imaging optics, edge/notch filters</td>
</tr>
<tr>
<td>GeC, DLC</td>
<td>Infrared coatings, hard carbon coatings</td>
</tr>
<tr>
<td>ITO, AZO</td>
<td>Touch panels, EMC coatings, cold mirrors, displays, electrochromics</td>
</tr>
<tr>
<td>Au, Ag, Al</td>
<td>Lamp reflectors for heat management and greater efficiencies</td>
</tr>
<tr>
<td>SiO₂, Nb</td>
<td>Eye glasses, colored sun glasses, AR coating on optical fibers</td>
</tr>
</tbody>
</table>
Film Characteristics

100nm thick aluminium alloy films produced with:
RMS roughness ~ 1.3nm
Grain size < 200nm

Data provided by Cambridge Display Technology
ITO – 3D Surface Roughness

Parameters calculated on the surface 5378 ITO 17min 28sec > Zoomed

Amplitude Parameters

- $Sp = 2.48$ nm
- $St = 4.4$ nm
- $Sq = 0.453$ nm
## Metal Oxides Stress Levels

<table>
<thead>
<tr>
<th>Dielectrics</th>
<th>Silica</th>
<th>- 150MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niobia</td>
<td></td>
<td>- 27MPa</td>
</tr>
<tr>
<td>TCO</td>
<td>ITO</td>
<td>- 50MPa</td>
</tr>
</tbody>
</table>

Method – Deflection of thin coated substrate

Error ±5%
UV/IR Blocker Spectral Transmission Before & After Steam Exposure
Surface Roughness Parameters – 1um Thick Nb2O5

Amplitude Parameters

St = 5.69 nm
Sq = 0.452 nm
Quantitative Metrology Analysis – 1um Nb2O5 Film
Cross Sectional Electron Micrograph – 1μm Thick Nb2O5
Niobia Spectral Transmission – Suprasil Substrate
CFM Summary

- CFM optimizes deposition energy and produces low stress, high ion current density with low ion energy, ultra-smooth and spectrally stable coatings.
- Process is room temperature - ideal for use on polymer substrates.
- High deposition rates as CFM is reactive sputtering.
- Simplified deposition control system – Time & Power.
- Does not require an expensive auxiliary plasma source or separation of reaction and deposition zones.
- Typical 3X load capacity over evaporator systems.
- CFM technology is readily scaleable in drum diameter and magnetron cathode length.
- CFM process can be implemented in batch, in-line or roll-to-roll formats.
- Only two moving parts in chamber - Substrate Drum & Shutter.
- Excellent economy of source materials.
PECVD Reactors
PECVD Applications: Diamond-like Carbon (DLC)
Boron Phosphide (BP)

- An extremely rugged and abrasion resistant AR coating for use on large area, outer surfaces of Ge optical components (domes)

- Environmental Specifications

  Passes MIL-C-675 tests for
  ✓ Adhesion
  ✓ Abrasion
  ✓ Humidity
  ✓ Salt Spray
  ✓ Salt Solubility