# Rapid Cycle, Small Batch Titanium Nitride Coater

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## INTRODUCTION

Cylindrical magnetron sputtering is an efficient and economical way to coat three-dimensional objects. A single, continuous target surrounds the substrates and produces a coating flux that arrives from all directions simultaneously. [1, 2] The targets are cylinders that slide into place without the need for clamping or bonding. For some materials, such as Ti, Zr, Al, Cu, stainless steel and others, targets can be fabricated from rolled sheets extremely inexpensively. The only coating losses are at the ends of the cathode, resulting in very efficient use of material and reducing the need for chamber cleaning.

The Cyclone™ Coating System, recently introduced by Ion Tech, incorporates the advantages of cylindrical magnetron sputtering in a complete system. The Cyclone™, which is shown in the photograph in Figure 1, uses an Isoflux Cylindrical Magnetron as the coating chamber itself. This simplified design minimizes the pumped volume, eliminates the need for water-to-vacuum seals, and significantly reduces system maintenance. In addition to these overall advantages, some of the unique features of the Cyclone™ make it particularly well suited for decorative and wear-resistant coatings of materials like titanium nitride (TiN), chromium nitride (CrN) and zirconium nitride (ZrN). This article describes those features and gives typical coating conditions for the deposition of TiN for cutting tool applications as an example.

## SYSTEM OPERATION

The Cyclone™ is offered as either a manual or fully automated system. In the automated version, the System Manager Software provides a graphical interface with animated movements, giving a visual representation of all components and controls as well as their status. Simple commands allow the creation of full recipes. Figure 2 shows the touch-screen display that is normally selected during a run, in which the machine layout is represented.

The Cyclone™ is pumped with an 1100 l/s turbomolecular pump and is offered with an optional 1600 l/s turbo pump. A moveable cylindrical shutter can be positioned between the target and the substrates for target preconditioning and part precleaning. One of the most important features is a unique flanged substrate holder, illustrated in Figure 3. By combining

Figure 1. Photograph of the Cyclone™ automated coating system.

this fixture with the axial magnetic field of the magnetron, a plasma trap is produced (effectively a post magnetron) that surrounds the parts. This trap, which is made possible because of the Cyclone™ design, allows high substrate bias current densities during etching and throughout the deposition process.

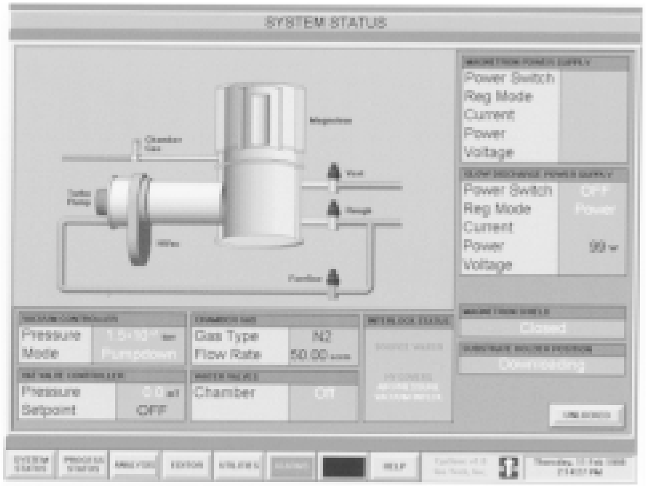


Figure 2. Touch-screen display showing operating parameters and the system layout.

A 500 W dc magnetron power supply and Sparc-le™ pulse network [3] are used for etching and substrate bias. We have found that pulsed power is far more effective for substrate cleaning than straight dc. Our conclusion is that surface oxides are more readily removed using pulsed power.

By heavily pumping the system, the instability that normally requires residual gas analyzers or optical emission monitors for process control is eliminated. [4] The Cyclone™ deposits TiN using $N_2$ flow control together with downstream pressure control and rapid pumping to produce a stable process. Evidence of this stability is the fact that any desired partial pressure of $N_2$ can be maintained by adjusting the flow alone. This makes the process extremely reliable, reproducible and robust with respect to drift and calibration.

The complete TiN coating process for the automated Cyclone™ consists of five distinct steps, which are performed in sequence with a single operator command:

1) Pumpdown

2) Target preconditioning and substrate cleaning and preheating

3) Ti interlayer deposition

4) TiN deposition

5) Cooling and venting

Table I summarizes the process parameters for steps 2, 3, and 4. A more detailed description of a complete TiN coating run follows.

**Pumpdown**

Depending on the number of parts and the condition of the fixture, pumpdown from atmosphere takes between 5 and 10 minutes to reach 5 x $10^{-6}$ Torr with the 1100 l/s pump. This time is typical after several days of operation. A clean, dry and empty system will reach the same pressure in less than three minutes.

**Target Conditioning and Substrate Cleaning & Heating**

Target conditioning and substrate etching take place with the cylindrical shutter separating the parts from the target. A pressure of 10 mTorr is established at an Ar flow of 100 sccm and the Ti target is pre-sputtered at 1 kW. Simultaneously the parts are biased at 200 W with the Sparc-le™ in the asymmetric pulse mode, resulting in a voltage of 385 V and current of 510 mA. The combined target and substrate powers preheat the substrates. This step lasts for 10 minutes, after which time the substrates reach the desired temperature of 350° C.

**Bias Sputter Deposition**

The target power is then raised to 4 kW and the pressure is reduced to 3 mTorr. The Sparc-le™ is changed to the straight dc mode and the substrate bias is adjusted to 330 V. The shutter is opened and pure Ti is deposited under these conditions for 2 minutes. This results in a 0.3 µm thick interlayer. The bias power supply voltage is then reduced to 150 V and the $N_2$

Table I. Typical parameter values during a TiN deposition run.

| Process Step | Pressure | Flows | Shutter | Bias Power | Target Power | Time |
|---|---|---|---|---|---|---|
| Substrate Etch/ Target Preclean/ Substrate Heat | 10 mTorr | Ar – 100 sccm | Closed | 385 V<br>510 mA | 360 V<br>2.8 A | 10 min |
| Ti Interlayer Deposition [0.3 µm] | 3.0 mTorr | Ar – 100 sccm | Open | 330 V<br>280 mA | 450 V<br>9.0 A | 2 min |
| TiN Deposition [3.0 µm] | 3.0 mTorr | Ar – 100 sccm<br>$N_2$ – 37 sccm | Open | 150 V<br>240 mA<br>[2 mA $cm^{-2}$] | 515 V<br>8.0 A | 30 min |

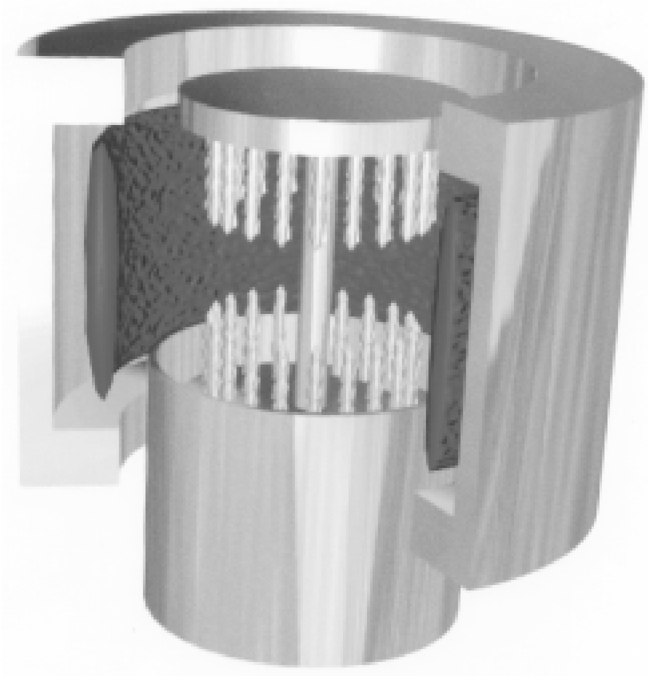

Figure 3. Illustration of the coating chamber during a run, showing the cylindrical shutter partially open. The spool-shaped substrate holder and the axial field of the cathode together produce an extremely effective plasma trap for etching and bias sputtering.

flow is established at 37 sccm for the TiN deposition step.

During coating, the bias current for a typical batch of parts is between 200 and 300 mA, depending on the size and number. Probe measurements have shown that these conditions produce a substrate current density of 2 mA $cm^{-2}$. The deposition rate is 0.10 µm $m^{-1}$. This combination of target and bias powers maintains the equilibrium temperature of 350° C throughout the coating run, which lasts for 30 minutes (for a 3 µm thickness of TiN).

It is important to note that all of the parts are exposed to identical conditions throughout the run, in contrast to some larger systems, which move parts through variable plasma and coating fluxes. Furthermore, excellent uniformity can be achieved by simply rotating each part about its own axis, greatly simplifying tooling and fixturing.

### Cooling and Venting

After the coating is complete, the chamber is vented with $N_2$ and the parts are allowed to cool for approximately 10 minutes.

## MACHINE THROUGHPUT

The total cycle time for depositing 3 µm of TiN is approximately 70 minutes from chamber close to open. Using a 19-cm ID cathode, thirty-six 6 mm drills can be coated per run. The Cyclone™ can also accommodate a 34-cm ID cathode, which would have a capacity of approximately one hundred 6 mm drills per cycle. In contrast, conventional coaters typically process a few hundred parts per hour. For example, a large box coater may do one to two thousand 6 mm drills in a four-to-six-hour cycle. However, since the cost of the Cyclone™ is less than one-fourth the cost of such machines, the throughput per capital dollar is similar. This fact, along with very low operating and consumable costs and simple maintenance, make the total cost per coated part extremely competitive.

## CONCLUSION

The desirability of rapid-cycle small batch coaters for depositing decorative and wear resistant coatings is becoming evident in the industry. The most lucrative segment of the functional coating market is associated with the rapid turnaround of parts. Furthermore, smaller machines allow redundancy, incremental capital investment and streamlined product flow. The Cyclone™ offers these advantages for a total cost per coated part that compares favorably to larger, more complex equipment. Finally, exclusive features and automation assure an extremely robust process and excellent coatings every time, so that downtime and rework are minimized.

## REFERENCES


1. J. A. Thornton and A. S. Penfold, Thin Film Processes, edited by Vossen and Kern, p. 75, Academic Press, New York, 1978.

2. D. E. Siegfried, D. Cook and D. Glocker, 39th Annual Technical Conference Proceedings of the Society of Vacuum Coaters, p. 97, 1996.

3. Sparc-le is a trademark of Advanced Energy Incorporated, Ft. Collins, Colorado.

4. A. S. Penfold, 29th Annual Technical Conference Proceedings of the Society of Vacuum Coaters, p. 381, 1986.