

By Andrew Shabalin, Mike Amann, Michael Kishinevsky, Ken Nauman,  
and Colin Quinn of Advanced Energy Industries, Inc.  
Eugene Anokin and Allen Bourez of HMT Technology Corporation

**INDUSTRIAL ION SOURCES AND THEIR APPLICATION FOR DLC COATING**

Advanced Energy—the leading supplier of plasma process power technology—now offers a new generation of ion-beam sources. This product line brings you industrial, low maintenance, high yield functions—with process performance, quality, and cost of ownership benefits that other technologies can't match.

This paper was presented at the SVC 42nd Annual Technical Conference and is reprinted by permission.

- No filaments or hollow cathodes
- No grids or ion optics
- Reactive gas compatible
- Industrial, low maintenance design
- Field proven dc power supply
- Easily retrofittable

Advanced Energy has recently introduced a new product line of anode layer ion sources for industrial applications. The platform is based on an extensive development effort that started in the Soviet Union back in the 1960s initially aimed at space propulsion.

What makes these sources very robust and suitable for a broad range of industrial applications is their ability to operate without external electron emitters. Thus, they can work in reactive gas environments. In particular, oxygen can be used as a working gas.

Two varieties of the sources are offered: linear and round (multi-cell). The linear source is suitable for inline coaters, and the round source is intended to process one substrate at a time.

With the round source, a protective DLC deposition process on hard disks has been developed. The key features of the process are the absence of particle contamination and virtually maintenance-free operation of the source.

without an electron emitter, have a simpler design, and exhibit less electrical noise due to the absence of isolating (ceramic) walls in the discharge area. Their lower energy efficiency is less of a problem on the Earth.

**INTRODUCTION**

Advanced Energy has recently introduced a new platform of gridless ion sources with anode layers. These sources are developed for industrial applications and based on the so-called closed drift thruster design, which was developed in Russia beginning in the 1960s.

There are two major categories of closed drift ion sources, or thrusters: ion sources with an extended acceleration zone (Figure 1) and ion sources with a short acceleration zone (Figure 2), also called ion sources with an anode layer<sup>III</sup>. Ion sources with an extended acceleration zone are better suited for space applications because they have higher energy efficiency which is a larger share of input power that is converted into ion energy; this is important for spacecraft. High efficiency also means lower cooling requirements. On the other hand, ion sources with an anode layer are better suited for industrial applications because they can work

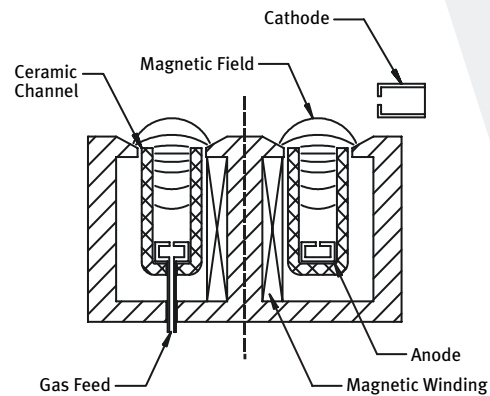


Figure 1. Ion source with extended acceleration zone

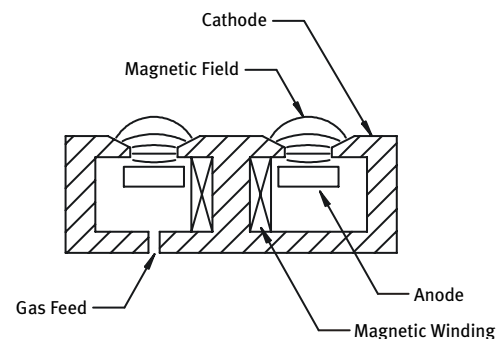
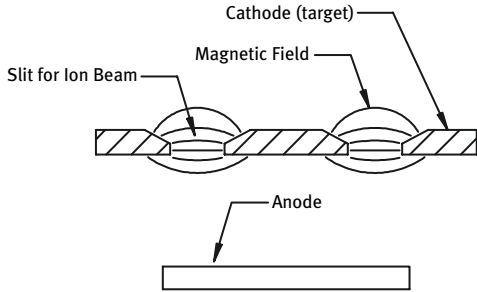


Figure 2. Ion source with short acceleration zone

## INDUSTRIAL ION SOURCES AND THEIR APPLICATION FOR DLC COATING

The ion source with an anode layer resembles a magnetron cathode (Figure 3), except that the main vacuum chamber is on the opposite side of the target, and the target has a slit to let the ion beam out.



**Figure 3. Anode layer ion source diagram**

The anode layer ion sources are very robust by nature—they don't have accelerating grids and don't need an electron emitter. They work in reactive gas environments because they have no parts that can burn off. AE ion sources can run in pure oxygen for a long time without any degradation or need for maintenance. At the same time, maintenance of gridless ion sources is much easier than that of gridded sources.

### PRODUCT DESCRIPTION

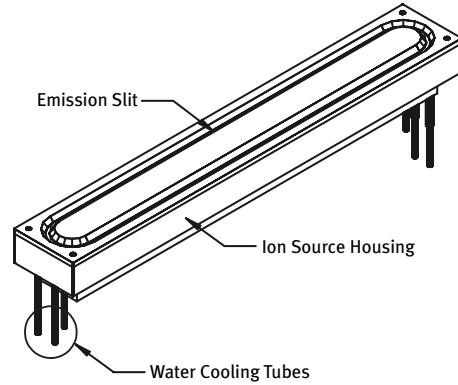
Advanced Energy makes two varieties of ion sources: linear and round (multi-cell). The linear source (Figure 4) has a racetrack shaped emission slit similar to a magnetron discharge zone. The metal housing is grounded, and the source can be installed inside the vacuum chamber or on a flange. Water cooling tubes are fed through two smaller flanges, and all water connections are at the atmosphere. The power supply is a modified Pinnacle™ II model which supplies the following:

- Maximum voltage 1500 V
- Maximum current 16 A
- Maximum power 12 kW

Electrical power is connected to the anode cooling tubes that are insulated from the chamber. Working gas can be fed through the hole in the flange directly to the ion source or by using a separate feedthrough and a flexible gas line. The source has a gas manifold that distributes gas evenly along the source. The AE linear source utilizes permanent magnets. Edges of the emission slit are made of soft iron, and the anode is made of nonmagnetic stainless steel. The flange-mounted ion source bolts to the flange via four holes in the corners.

There is no theoretical limit to the length of the source. Currently Advanced Energy makes 65 cm and 94 cm long models.

The linear source is intended for inline systems like glass coaters, web coaters, and inline disc production systems. The ion beam is uniform in the longitudinal direction, and the substrate continuously moves perpendicularly to the beam. In most applications, the beam profile in the direction of the substrate movement isn't very important, and linear current density (ion current per unit length of the beam) is used to characterize the source rather than current per unit area.



**Figure 4. Linear ion source**



**Figure 5. Round multi-cell ion source**

The round multi-cell source (Figure 5) is designed to process one substrate (e.g., magnetic disc) at a time. Each cell of the round source is an individual small anode layer ion source. Cells fill the entire source working aperture and share gas distribution and magnetic systems.

The multi-cell source is flange-mounted. Most parts of the source are at atmosphere and can be easily water-cooled without using vacuum feedthroughs. The magnetic system has an electromagnet that provides additional flexibility. The magnet coil is at atmosphere and is air-cooled. The ion source has two electrical connectors, one for high voltage (up to 1500 V) and the other for the magnet (up to 10 V, 2 A). It also has fittings for the gas and water.

## INDUSTRIAL ION SOURCES AND THEIR APPLICATION FOR DLC COATING

### EXPERIMENTAL RESULTS

#### Discharge and Beam Measurements

Volt-ampere characteristics of the 65 cm ion source for two different argon flows are summarized in Tables 1 and 2. Ion beam current data should be considered with some cushion because the ion source works at high gas pressure (usually 1 to 4 mTorr) and some ions in the beam are converted to fast neutrals due to charge exchange with background gas. From the process point of view, fast neutrals are as good as ions, however they don't contribute to the measured beam current. On the other hand, the slow ions that are produced at the same time from the background gas tend to drift away in all directions and produce an ion current signal outside the beam.

The linear ion source can work in two distinct modes: high-voltage and low-voltage, while the multi-cell source has only a high-voltage mode of operation. High-voltage mode (Table 1) could be achieved at low gas flow. In this mode, discharge voltage increases with increasing discharge current. By increasing gas flow, one can switch the ion source to the low-voltage mode with a much larger discharge current while discharge voltage remains almost constant (Table 2). We think that in high-voltage mode there is a circulating Hall current, where the electron space charge isn't compensated by ions. This current increases with increasing discharge voltage and causes more ionization and an increase in the discharge current. In a low-voltage mode, the electron space charge is compensated by ions, so the discharge current is not limited by space charge.

<b>Discharge Voltage, V</b>	<b>680</b>	<b>836</b>	<b>1140</b>	<b>1550</b>
<b>Discharge Current, A</b>	<b>0.06</b>	<b>0.08</b>	<b>0.12</b>	<b>0.16</b>
<b>Beam Current, A</b>	<b>0.029</b>	<b>0.044</b>	<b>0.076</b>	<b>0.12</b>

Table 1. Argon, 27.4 sccm

<b>Discharge Voltage, V</b>	<b>299</b>	<b>336</b>	<b>330</b>	<b>325</b>
<b>Discharge Current, A</b>	<b>0.63</b>	<b>4.26</b>	<b>7.16</b>	<b>9.82</b>
<b>Beam Current, A</b>	<b>0.211</b>	<b>1.78</b>	<b>3.28</b>	<b>5.12</b>

Table 2. Argon, 68.5 sccm

Figure 6 shows the linear current density profile (current per unit length) for the 65 cm linear ion source. The linear current was measured using a long narrow electrode, oriented perpendicularly to the beam, in the direction of substrate movement. The current peak at 7 cm is due to the round part of the racetrack. The same peak should be present at 73 cm also, but our probe didn't move that far.

Discharge current of the round (multi-cell) source and ion current density are shown in Figure 7. Data were taken for

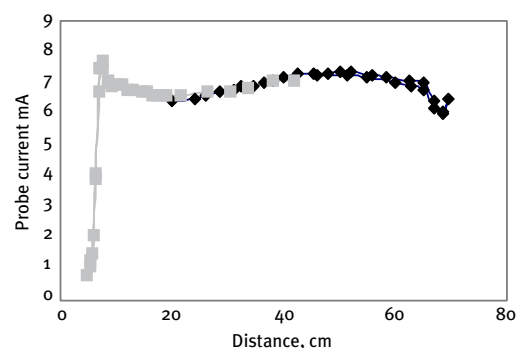


Figure 6. Linear current density for 65 cm ion source

an oxygen flow of 50 sccm. The total beam area is about 100 cm<sup>2</sup>, so total beam current is up to 35 mA. Again, because of charge-exchange between ions and background gas, some of the ions are converted into neutrals before they reach the Faraday cup used for this measurement.

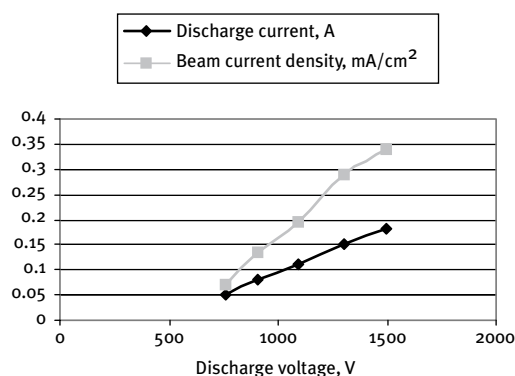


Figure 7. Volt-ampere characteristics of the multi-cell source

From the uniformity point of view, there is an optimal distance between the multi-cell ion source and the substrate. If the substrate is too close, the cell pattern becomes pronounced. If the substrate is too far away, the cell pattern smoothes out, but current density starts rolling off at the edges. The AE 12 cm multi-cell ion source has uniformity better than  $\pm 5\%$  on 95 mm diameter.

#### Experiments Modeling Applications

Using the linear ion source, we etched DLC films on silicon wafers with an argon beam. Our equipment didn't allow us to move the sample against the source, as in a production machine, so we installed a sample stationary, turned the ion source "on" for some period of time, and then measured the amount of removed material. The DLC thickness before and after etching was measured by optical methods and the width of etched strips was measured with a caliper. Then we calculated the etch rate as if the sample would move against the source.



## INDUSTRIAL ION SOURCES AND THEIR APPLICATION FOR DLC COATING

In a high-voltage mode, despite the higher ion energy, the total beam current was limited and the recalculated etch rate was 1.3 Å at the sample speed of 4 fpm (feet per minute). In a low-voltage mode at 10 A discharge current, the etch rate was up to 50 Å at 4 fpm.

In the same arrangement, we deposited DLC films with the linear source. We used ethylene, acetylene, and butane as precursor gases. In other runs we deposited DLC films, feeding argon into the source and butane into the vacuum chamber. The best film hardness was with ethylene at a deposition rate of up to 46 Å at the substrate speed of 4 fpm. The discharge voltage was approximately 1000 V and discharge current was 0.8 A. Using butane with the same discharge parameters produced a much softer film.

We used the round (multi-cell) ion source to etch SiO<sub>2</sub> on 4" silicon wafers with an argon beam. At a discharge voltage of 1400 V and discharge current of 0.21 A, the etch rate was 9.2 Å/s. Etching the surface of the plastic film (PTFE and polyimide) before the deposition of Ni significantly improved adhesion.

### DLC DEPOSITION ON HARD DISCS

With the multi-cell ion source, we developed a DLC deposition process for hard discs. In our laboratory, using butane as a working gas and 4" silicon wafers as a substrate, we deposited up to 1000 Å films in 40 seconds. That corresponds to a deposition rate of 25 Å/s at a discharge current of 0.25 A. Film thickness was measured by a spectrophotometer.

Film hardness was measured by scratching the DLC film on the silicon wafer with a sharp tungsten needle. This test is fast and simple, and even if it doesn't allow measuring the absolute value of hardness, it is very good for comparison of different films.

Working on butane, the hardest films were obtained at the maximum discharge voltage of 1500 V. This is consistent with results from others<sup>[1]</sup> that optimum carbon atom energy for DLC deposition should be between 100 and 150 eV. In our case, at a 1500 V discharge voltage, the average ion energy was about 700 eV. In the case of a butane ion, this energy is divided among four carbon atoms and ten hydrogen atoms, so each carbon atom would have about 140 eV. With acetylene at 1500 V, the film was softer than with butane at the same discharge voltage.



Printed in USA  
SL-WHITE12-270-01 1M 01/01

California	New Jersey	United Kingdom	Germany	Korea	Japan	Taiwan	China
T: 408.263.8784 F: 408.263.8992	T: 856.627.6100 F: 856.627.6159	T: 44.1869.320022 F: 44.1869.325004	T: 49.711.779270 F: 49.711.7778700	T: 82.31.705.2100 F: 82.31.705.2766	T: 81.3.32351511 F: 81.3.32353580	T: 886.2.82215599 F: 886.2.82215050	T: 86.755.3867986 F: 86.755.3867984

DLC films were deposited on thin-film magnetic hard discs in an industrial cluster system. Butane and ethylene were used as the working gases. We were able to consistently achieve deposition rates of 10 Å/s with uniformity better than ±5% with film thicknesses of 40 - 50 Å. The films were particle-free and passed the gliding and corrosion tests. Ion sources were working on the industrial system for many hours without any degradation of film quality or need for maintenance.

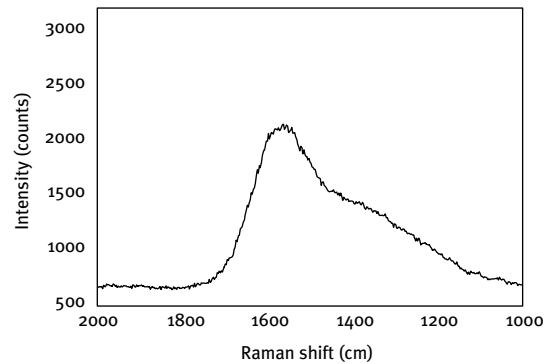


Figure 8. Raman spectrum with ethylene at discharge voltage of 1300 V

Figure 8 shows the Raman spectrum obtained with ethylene at a discharge voltage of 1300 V. This spectrum shows a G-peak at 1579.4 cm<sup>-1</sup>, D-peak at 1412.3 cm<sup>-1</sup>, D/G area ratio of 1.76, and widths of G and D peaks 143 and 351 cm<sup>-1</sup>. Films made with butane at 1500 V had a D/G area ratio of 1.14.

### CONCLUSION

A new family of rugged industrial ion sources has been introduced. The sources are of the anode-layer type and can operate without an electron emitter. Virtually maintenance-free operation makes this type of source attractive for a wide range of industrial applications. Particle-free, high-rate DLC deposition on hard discs had been demonstrated.

### REFERENCES

- 1 V.V. Zhurin, H.R. Kaufman and R.S. Robinson, "Physics of closed drift thrusters," *Plasma Sources Science & Technology*, 8, R1 (1999).
- 2 S. Sattel, T. Gießen, H. Roth, M. Scheib, R. Samlenski, R. Brenn, H. Ehrhardt and J. Robertson, "Temperature dependence of formation of highly tetrahedral a-C:H," *Diamond and Related Materials*, 5, 425 (1996).

Advanced Energy Industries, Inc.  
1625 Sharp Point Drive  
Fort Collins, Colorado 80525  
800.446.9167  
970.221.4670  
970.221.5583 (fax)  
support@aei.com  
www.advanced-energy.com