Comparison of Two Ion/Plasma Sources for Optical Coating

By **Ron Willey**, Willey Optical Consultants

Morton[1] reported on the effects of chamber pumping speed on the characteristics of the Denton CC-105 ion/plasma source. This source is in the class of what is generally referred to as a broad beam source. That is as opposed to a Kaufman-type source with grids, which tends to have a narrower beam divergence angle. Such sources are used for ion-assisted deposition (IAD) substrate cleaning before deposition, in lieu of glow discharge, and some plasma-enhanced chemical vapor deposition processes. The principal variables affecting the performance of some of the common ion/plasma sources used in optical coatings are chamber pumping speeds, gas flows, and drive currents. The first two parameters result in a given chamber pressure, which is important to most deposition processes. The mean free path and other deposition factors depend on the chamber pressure, and low pressure generally is the most desirable. Morton's work reported the drive voltages as a function of pressure and the drive current to the source for various chamber pumping speeds. The gas used through the source was oxygen. It was stated by Morton and also reported by Willey[2] and others that low ion voltages (resulting from low drive voltages) are desirable to avoid disassociation damage to the materials being deposited. Willey found for example that drive voltages above 300 V caused absorption in TiO_2 films. Therefore, the most desirable characteristics of an ion/plasma source are low drive voltages at low chamber pressures.

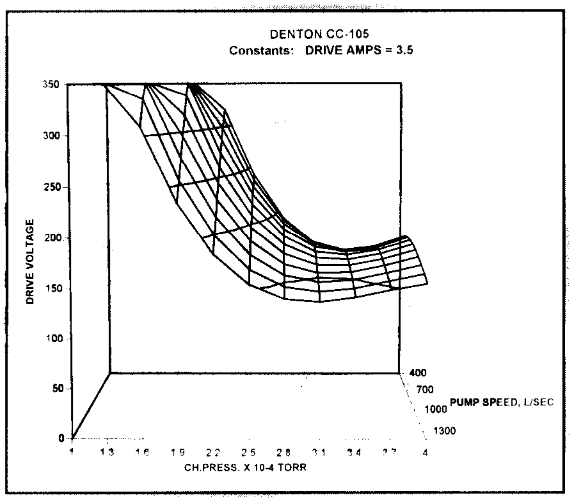


Figure 1. Drive voltage versus chamber pressure and pumping speed for the CC-105 source at 3.5 drive amps.

We had performed extensive characterization of the DynaVac PS1500 ion/plasma source in the past year for ranges similar to those of Morton's work. The relevant data from Morton's work was processed along with our own results using DOE software[3,4]. This allowed us to plot the results in a format for an "apples-to-apples" comparison as seen in the figures presented here.

When the drive voltages versus pressure and chamber pumping speed are compared over the ranges common to the testing of the two sources, **Figures 1** and **2** are produced. The common ranges are: from 1 to 4 × 10^{-4} Torr pressure, from 400 to 1,400 liters/second pumping speed and up to 3.5 drive amps. This is all using pure oxygen for the gas. High pumping speed has the advantage of reducing the drive voltage and chamber pressure. Morton's work extended to a pumping speed of 2,350 liters/second; whereas, our test work with the PS1500 to date has only been done in a chamber with up to 1,400 liters/second pumping speed. The comparison was limited to this pumping speed and to 3.5 drive amps because that was the limit of Morton's work. The PS1500 will normally operate at drive currents up to 10 drive amps and/or drive power limits of 1,500 watts continuously. **Figure 3** also shows the CC-105 over the more extended pumping speed range to 2,350 liters/second reported by Morton. **Figure 4** shows the PS1500 when operated at its extended range of 10 amps of drive current in a 1,400 liters/second chamber.

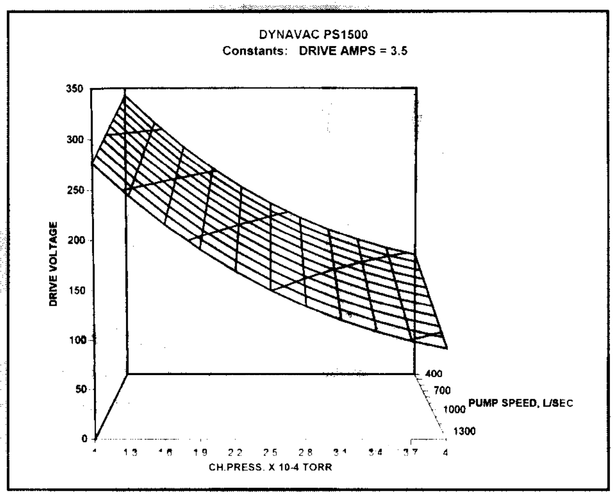


Figure 2. Drive voltage versus chamber pressure and pumping speed for the PS1500 source at 3.5 drive amps.

With both sources, there is not a strong influence of the

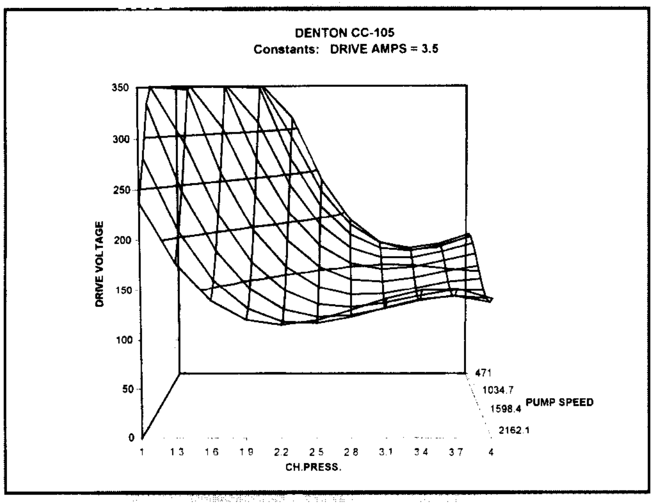


Figure 3. Drive voltage versus chamber pressure and pumping speed for the CC-105 source over the full range of pumping speeds reported and at maximum drive amps (3.5).

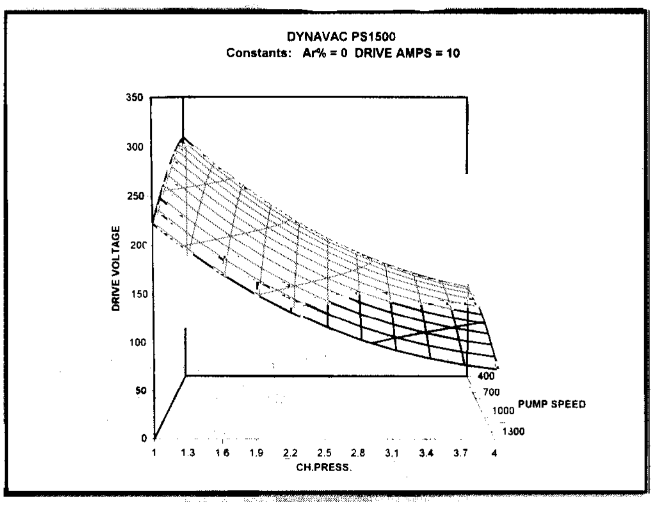


Figure 4. Drive voltage versus chamber pressure and pumping speed for the PS1500 source over the full range of pumping speeds tested and at maximum drive amps (10.0).

drive current on the drive voltage output. **Figures 5** and **6** show the comparison over the common range of testing from 1 to 4 drive amps and 400 to 1,400 liters/sec. **Figure 7** shows the CC-105 over the full range of measured pumping speeds to 2,350 liters/second. **Figure 8** shows the PS1500 over its full range of drive current to 10 amps.

The integrated ion current output of the PS1500 was measured at 11% of the drive current. It was not possible to measure any additional neutrals that might be coming to the surface because the ion probe used would only register charged particles. An ion current of 160 micro amps per square cm was measured at 10 drive amps with the probe at 57 cm from the source. The angular distribution of the beam output is seen in **Figure 9**. This is broader and flatter than most ion sources and is well suited to the large "box coaters" used in the optical coating industry because it can cover large substrate areas.

It can be seen from **Figures 1** and **2** that the PS1500 achieves lower drive voltages at lower pressures for the same pumping speeds. Greater pumping speeds benefit both sources proportionately. The PS1500 achieves less than 100 V at 3.5 A with the 1,400 liters/sec system. At 300 V, the pressure is $< 1.0 \times 10^{-4}$ Torr. The high drive currents of the PS1500 (10A) and thereby high ion currents (1.1 amps) provide the ability to deposit films at proportionately higher rates than sources of lesser power for the same ion-to-adatom or ion-to-molecule arrival ratios.

The ion-to-molecule arrival rate is a significant factor in IAD. Netterfield et al.[5] discuss this in detail with respect to CeO_2 in particular, but the work has general applicability. They speak of the critical arrival rate (CAR) that is required to produce stable films (i.e., fully densified, maximum index, no humidity shift, etc.). Let us digress briefly to give an example of the calculation of the adatom-to-ion arrival rate. Consider SiO_2 at a deposition rate of 5 A/sec or 0.5 nm/sec or 5×10^{-8} cm/sec. SiO_2 has a density of 2.2 gm/cm^3 and a molecular weight of 60. Therefore, a cm^3 would contain 2.2/60 moles times (Avogadro's number) 6.02×10^{23} molecules/mole = 0.22×10^{23} molecules. Therefore, a 5 A/sec rate would have 0.22×10^{23} times 5×10^{-8} cm./sec = 11×10^{14} molecules/sec (molecule arrival rate). If the measured

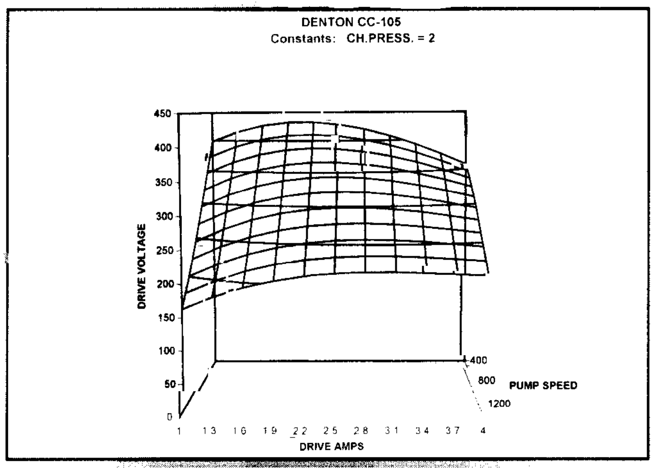


Figure 5. Influence of the drive current on the drive voltage output for the CC-105 source over the common range of testing from 1 to 4 drive amps and 400 to 1,400 liters/sec at a chamber pressure of 2 x 10^{-4} Torr.

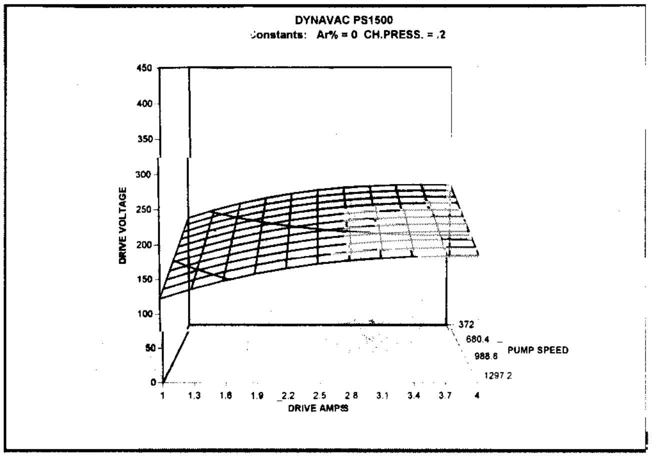
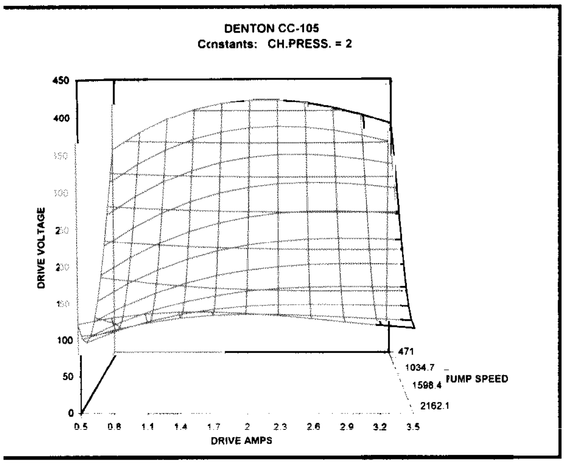


Figure 6. Influence of the drive current on the drive voltage output for the PS1500 source over the common range of testing from 1 to 4 drive amps and 400 to 1,400 liters/sec at a chamber pressure of 2 x 10^{-4} Torr.



igure 7. Influence of the drive current (to the maximum of 3.5 mps) on the drive voltage output for the CC-105 source over he full range of pumping speeds to 2,350 liters/second reported t a chamber pressure of 2 x 10^{-4} Torr.

on current on the depositing surface is 175 × 10^{-6} amperes coulombs/sec), this times 0.625 × 10^{19} charges/ coulomb, vould give 10.95 × 10^{14} ions/sec (ion arrival rate). This mplies a molecule-to-ion arrival rate of 11 × 10^{14}/10.95 × 0^{14} or about a 1:1 arrival rate.

It can be seen that a lower material deposition rate would e required if an IAD source is operated at maximum ion urrent and the CAR was not satisfied. This is at the root of he drive for higher power ion sources to provide robust ndustrial processes where rates are important to the ecoomics of the results.

From **Figures 1** through **8** here and Morton's report[1], it is pparent that high pumping speeds are preferred for most AD processes because of the lower drive voltages and ower operating pressures.

eferences

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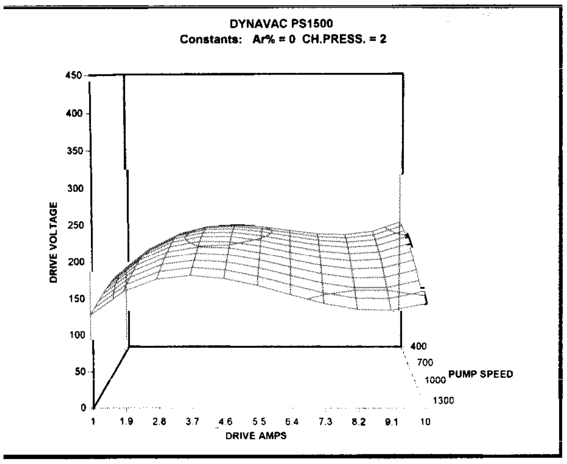

igure 8. Influence of the drive current (to the maximum of 0.0 amps) on the drive voltage output for the PS1500 source ver the maximum range of testing from 400 to 1,400 liters/sec t a chamber pressure of 2 x 10^{-4} Torr.

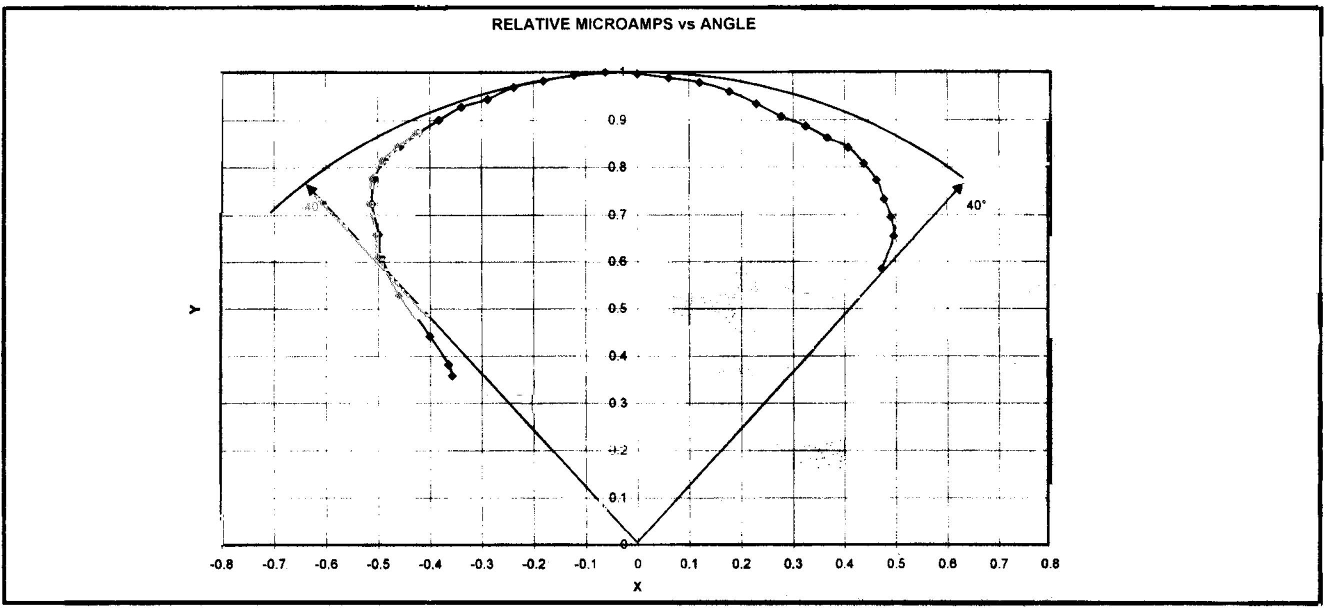

Figure 9. The broad angular distribution of the ion beam output for the PS1500 source.

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3. S. R. Schmidt and R. G. Launsby, Understanding Industrial Designed Experiments, Sec. 3.8, Air Academy Press, Colorado Springs, 1994.

4. U.S. Department of Energy, DOE KISS, Ver. 97 for Windows, Air Academy Associates (and Digital Computations, Inc.), Colorado Springs (1997).

5. R. P. Netterfield, W. G. Sainty, P. J. Martin, and S. H. Sie: "Properties of CeO2 thin films prepared by oxygen-ion-assisted deposition," *Appl. Opt.* **24**, 2267-2272 (1985).

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