Behavior of Three Types of Plasma Sources for Optical Coating

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ABSTRACT

Typical plasma sources, as used in optical coating, bombard the surfaces of the substrates with electrons and ionized gasses such as argon, oxygen, and nitrogen. The energy of the ions in electron volts and the ion current depend primarily on the source geometry, gas flow, pumping speed of the chamber, and the current provided by the power supplies to the ion source and electron source. Three common types of such sources with differing geometries are compared over their practical ranges of operation in various optical coating production chambers. Some aspects of using plasma assisted deposition to influence coating properties such as density, absorption, microscopic structure, adhesion, hardness, etc., are touched upon. The probable benefits of the various source geometries for different applications are mentioned.

INTRODUCTION

The author has had the good fortune over the past few years to work with various clients to apply their plasma/ion sources to improve their optical coating processes. This has provided the opportunity to gather data on the performance of the three types of sources discussed here along with an additional source of different size but of the same type as one of the three. This now allows the comparison of these sources to assist in the selection for a given application and to help in setting up a process. All of these tests were in optical coating chambers of a “box” or drum like geometry.

The sources tested were the Kaufman and Robinson, Inc.[1] EH1000 (see Fig. 1) and EH400 units, the well known MK-II of Veeco/Commonwealth[2], and the DynaVac IS1000[3] (see Fig. 2) which is also here referred to as the FAFNIR. The data on theEH400 and EH1000 is augmented heavily from the KRI® manuals on those sources and that data was taken in a fashion similar to the author’s work.

Figure 1. KRI® EH1000 Plasma/Ion Source.

These sources have somewhat similar behavior to each other which is a function of chamber pumping speed (PS), gas flow(SCCM), and drive current (Ad, sometimes referred to as discharge current).

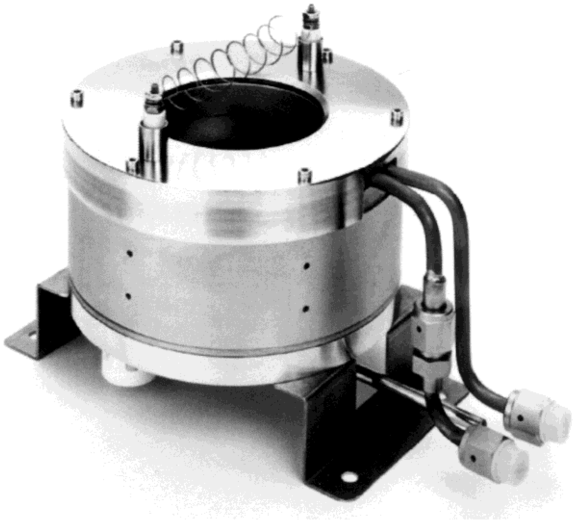

Figure 2. DynaVac IS1000/FAFNIR Plasma/Ion Source.

The first step in each case was to determine the effective pumping speed of the chamber. The source was then operated and data recorder over its range of current and gas flows within its power limitations. The data for each source was fit to equations giving the Drive Voltage (Vd, sometimes referred to as discharge voltage) results for given PS, SCCM, and Ad. The equations then allow plotting of these parameters for the comparison of the sources and estimating the behavior of each source in any given chamber and application.

This paper deals only with behavior using argon gas. Oxygen and nitrogen are also commonly used, and they have similar behavior except that the scale factor limits may change.

EXPERIMENTS

The pumping speed of each chamber is determined by admitting a given flow of argon gas and recording the pressure for several flow rates. This should produce plotted lines like one of those seen in Fig. 3.

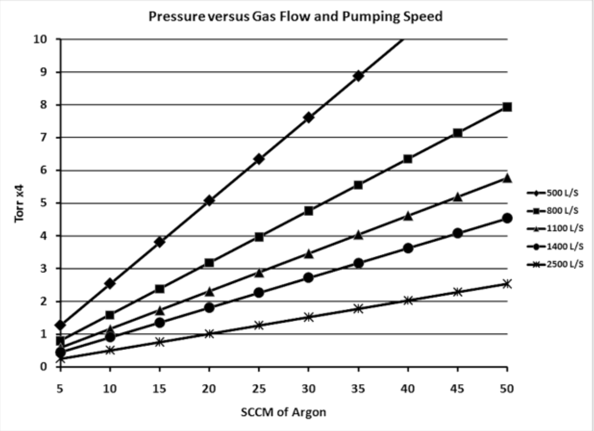

Figure 3. Chamber pressure in Torr ×10^{-4} versus argon gas flow for various chamber pumping speeds.

The pumping speed in liters per second (L/S) can then be calculated by:

PS = .0127*SCCM/pressure in Torr.

In some of the test cases, the pumping system has been throttled to allow testing the source at lower PS. In one case the position of the high vacuum valve was controlled to give a specific PS, while in another case, the pumping aperture was masked with heavy foil to produce the desired effect. In other cases, the results come from separate chambers with different PS.

The source being tested is then turned on and run through its range of operation in SCCM and Ad from 0.5 or 1 amp up to its limit, taking data at suitable intervals.

FITTING DATA TO EQUATIONS

The recorded data is then put into a spreadsheet and plotted as in Fig. 4. It has been found empirically that the data can all be fit, within the measurement error, to the formula:

Vd = Vbase +Smult/(SCCM –Soffset)

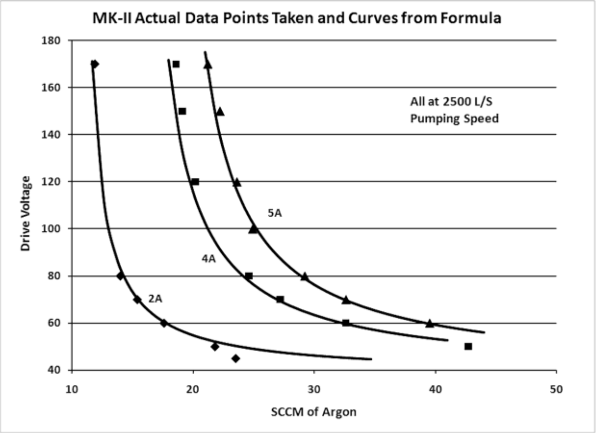

Figure 4. Curves fit to actual data points taken with MK-II source in a chamber with 2500 liters/second (L/S) pumping speed.

where Vbase is a constant voltage offset, Smult is a multiplier of the flow rate function, and Soffset is an offset of the flow rate. By plotting this function overlaid on the data points as in Fig. 4, the three variables can easily be adjusted manually for the best "eyeball" fit to the data. When the coefficients for all these formulae have been found, they are then processed by DOE software [4] to find the coefficients for the combined effects of all of the variables (on the one source) as shown in Tables 1 and 2. The curves in Fig. 4 are plotted from data after the DOE fitting process.

Table 1 shows that as many as 14 coefficients may be necessary to properly describe the behavior of each different source. The equations in Table 1 have three groups to define the Vbase, Smult, and

PLASMA SOURCE	Vd(PS,Ad,SCCM) Vd = Vbase + Smult/(SCCM-Soffset)
EH400	Vd = a +PS*b +(e+f*PS+(g+ h*PS)*Ad +(n*Ad+p*PS)*PS*PS)/(SCCM-(i +(k+m*PS)*Ad))
EH1000	Vd = a +PS*b +(e+f*PS+(g +h*PS)*Ad) /(SCCM-(i +(k+m*PS)*Ad))
MK-II	Vd = a +PS*b +(c +d*PS)*Ad +(e+f*PS+(g+ h*PS)*Ad) /(SCCM-(i +j*PS +(k+m*PS)*Ad))
DynaVac	Vd = a +PS*b +(e) /(SCCM-(i +j*PS)

Table 1. Equations fit to data for each of the Plasma/Ion Sources tested.

PLASMA	COEFFICIENTS						
SOURCE	a	b	c	d	e	f	g
EH400	34	0.00786	0	0	143.11	0.05862	13.688
EH1000	38	0.0025	0	0	-9.3	0.19288	105.7
MK-II	52.286	-0.00571	2.38	-0.00095	646.4	-0.2786	-83.29
DynaVac	60	-0.01333	0	0	800	0	0
	h	i	j	k	m	n	p
EH400	0.11857	2	0	1.333	0.0019	-9.17E-05	2.00E-08
EH1000	-0.03213	2	0	1.07421	0.0009796	0	0
MK-II	0.075714	-2.7	0.003421	0.7282	0.000641	0	0
DynaVac	0	1	0.00667	0	0	0	0

Table 2. Coefficients for the equations fit to data for each of the Plasma/Ion Sources tested.

Soffset for each source as a function of PS and Ad. Table 2 gives the coefficients “a” through “p” for each source.

These equations are somewhat extensive, but when entered into a spreadsheet, they can be easily used to generate plots for the behavior of any of these sources over any ranges supported by the measured data, and possibly predict the behavior somewhat outside of the range of the measured data.

COMPARITIVE BEHAVIOR

Figure 5 compares the four sources at the maximum current of 3.5 amps for the smaller EH400, all calculated for 1100 L/S. They all look similar, but the MK-II might be the choice here if the lowest gas flow (and thereby lowest chamber pressure) was desired at Vd such as 80-100 volts. This voltage generally is proportional to the electron volts (eV) of the ions where the eV peaks at about the Vd and has a broad distribution about Vd. Zhurin[5] gives more detail on variations in such profiles of eV as a function of Vd for given sources and conditions.

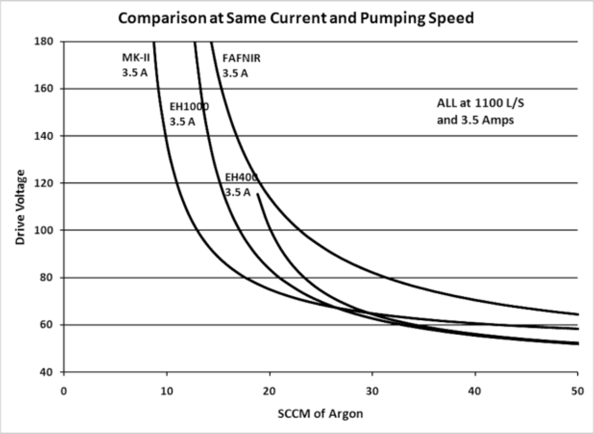

Figure 5. Comparison of the Drive Voltage behavior at 3.5 Drive Amps in a 1100 L/S chamber for each of the four sources tested.

Figure 6 compares of the Vd behavior of each source in an 1100 L/S chamber at the sources maximum current and maximum power for that source.

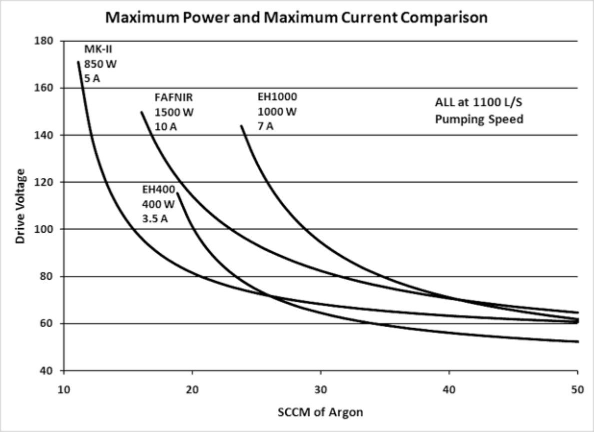

Figure 6. Comparison of the Drive Voltage behavior in a 1100 L/S chamber at the maximum current and up to the maximum power for each of the four sources tested.

If maximum current were desired, the FAFNIR would provide that, and the chamber pressure would be lower than the EH1000 source.

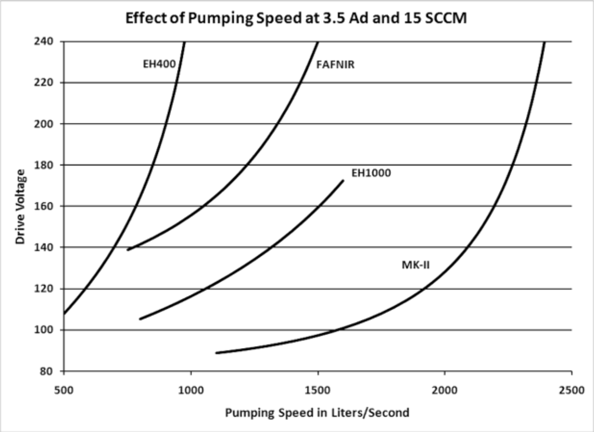

Figure 7. Comparison of the effect of pumping speed on Drive Voltage at 3.5 Amps and 15 SCCM on each of the four sources tested.

Figures 7, 8, and 9 compare the sources for effects of pumping speed under the same operating conditions of 3.5 Ad and SCCM. These plots are at 15, 20, and 25 SCCM respectively.

The MK-II seems to keep the Vd lowest at the higher PS.

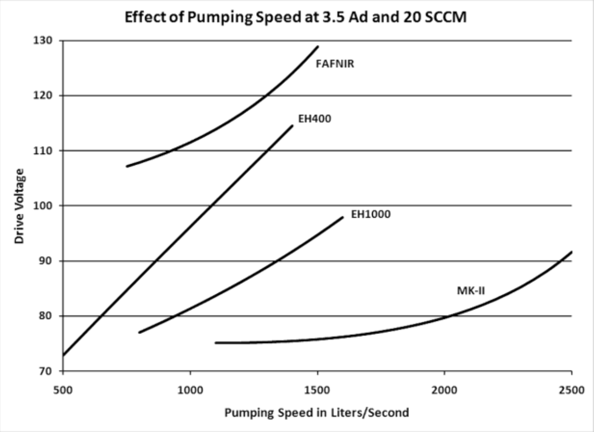

Figure 8. Comparison of the effect of pumping speed on Drive Voltage at 3.5 Amps and 20 SCCM on each of the four sources tested.

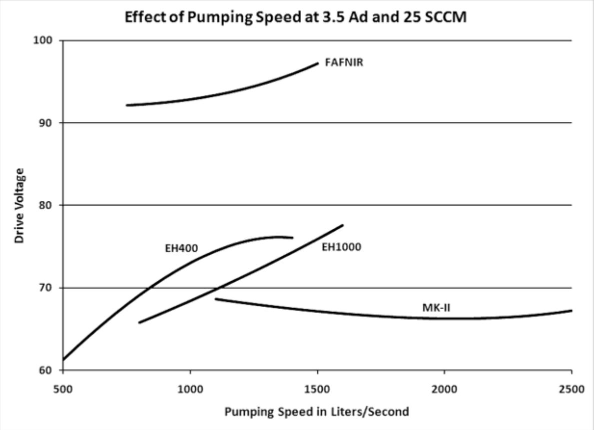

Figure 9. Comparison of the effect of pumping speed on Drive Voltage at 3.5 Amps and 25 SCCM on each of the four sources tested.

PLOTS FOR PREDICTION

Figures 10, 11, 12, and 13 are plots which allow the prediction of the Vd versus PS, SCCM, and Ad for each of the sources. The reader may also contact the author for a copy of an Excel spreadsheet which has implemented Tables 1 and 2, and will calculate any desired curve from these.

Each figure plots the behavior at the extremes of PS measured for that source. The lines which connect points of common SCCM on the maximum current curves would actually be concave as seen in Figs. 7, 8, and 9, but are added here to aid the eye in comparisons using these plots.

The FAFNIR data in the current work shows that there is little change in Vd with Ad. This is consistent with earlier work [6].

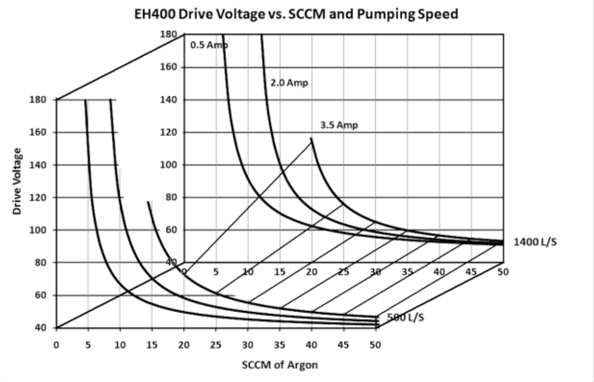

Figure 10. Plot of Drive Voltage results versus argon flow, Drive Amps, and pumping speed for the EH400 Plasma/Ion Source.

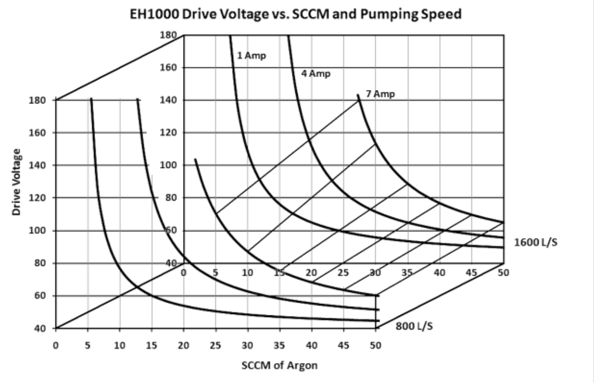

Figure 11. Plot of Drive Voltage results versus argon flow, Drive Amps, and pumping speed for the EH1100 Plasma/Ion Source.

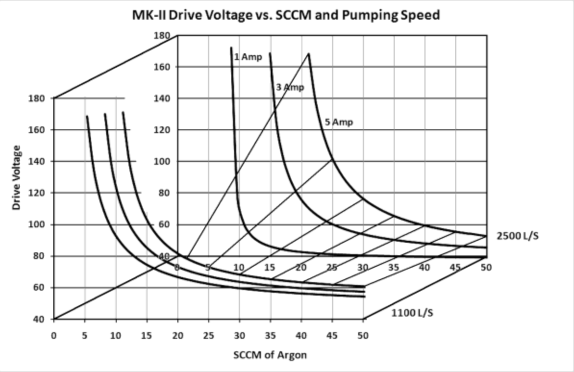

Figure 12. Plot of Drive Voltage results versus argon flow, Drive Amps, and pumping speed for the MK-II Plasma/Ion Source.

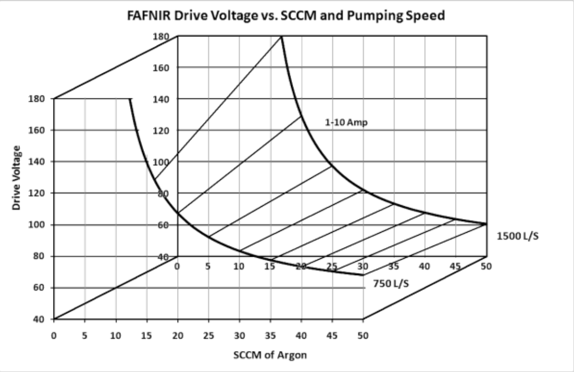

Figure 13. Plot of Drive Voltage results versus argon flow, Drive Amps, and pumping speed for the FAFNIR Plasma/Ion Source.

Ion/plasma sources such as used here can aid in producing optical thin films with less absorption, greater density, better microscopic structure, better adhesion, greater hardness, etc. Most of the cases on which the author has worked tend to benefit from to lowest practical chamber pressure, lowest ion voltages, and highest ion current. The lower chamber pressure is to minimize the competition of the gas with the depositing atoms, and the lower ion voltage is to minimize the dissociation of molecules in coatings such as MgF_2 and TiO_2. The higher ion current is desired because it will limit the speed of the deposition process to that wherein sufficient ions can be provided for the desired results.

If lower Vd is desired in a given case, the PS might be reduced by throttling as mentioned above, but PS can not be increased beyond the capability of the chamber. Note, however, that the pressure increases for a given SCCM when the PS is decreased. The process trade-offs of all of these factors need to be carefully considered.

SUMMARY

Information is provided here from experimentally derived data as to the behavior of three types of sources and two different model in one case. This information should be useful in the application of any of these given ion/plasma sources to specific processes and chambers.

REFERENCES

1. Kaufman and Robinson, Inc., 1306 Blue Spruce Drive, Suite A, Fort Collins, Colorado 80524
2. Veeco, Ion Sources, 2330 E. Prospect, Fort Collins, CO 80525
3. DynaVac, 110 Industrial Park Road, Hingham, MA 02043-4369
4. *DOE KISS 2007 Software*, SigmaZone.com and Air Academy Associates, LLC, 1650 Telstar Drive, Suite 110, Colorado Springs, Colorado 80920.
5. V. V. Zhurin, "Optimum Operation of Hall-Current Ion Sources," *Vacuum Technology & Coating*, 59-67(2008).
6. R. R. Willey, Practical Production of Optical Thin Films, p. 177, Willey Optical, Consultants (2008).