60th Annual Technical Conference Proceedings
Providence, Rhode Island, April 29-May 4, 2017
https://doi.org/10.14332/svc17.proc.42627

ISSN 0737-5921
www.svc.org

Comparison of Three Different Ion Sources and the Effects of Additional Neutralizer Current

Ronald R. Willey[1], R. Shakoury[2], Wayne G. Sainty[3], K. Patel[4]
[1]Willey Optical, Consultants, Charlevoix, MI
[2]Department of Physics, Imam Khomeini International University, Qazvin, Iran
[3]Saintech Ion Beam Systems, Tuncurry, Australia
[4]Luma Optics Pvt Ltd, Mumbai, India

ABSTRACT

The behavior of three significantly different geometries of industrial ion sources are compared. The gas flow needed for a given discharge voltage can be significantly reduced by additional neutralizer filament current beyond that needed to eliminate arcing/sparking. This sparking is due to excess charge build-up on substrates from the positive ions from the source. This reduced gas flow also reduces the process pressure and thereby reduces the competition of that gas for a position in the matrix of a film being deposited with the ion assisted deposition intended to produce increased film density and other beneficial effects.

INTRODUCTION

Three significantly different geometries of industrial ion sources have been tested, modeled, and compared in terms of drive/discharge voltage (Vd) and current (Ad), as a function of gas flow, and filament/neutralizer current (NC). The primary gas used for this testing was argon (Ar), but some testing was done with oxygen (O_2) and nitrogen (N).

A major observation related to the extensive work by Zhurin[1] was that the Vd versus gas flow (in SCCM) performance was a strong function of filament emission current. The gas flow (and thereby process pressure) needed for a given Vd and Ad can be significantly reduced by additional neutralizer filament current (NC) in excess of what is needed to eliminate sparking at the substrates.

The three ion sources tested here were the MK-II from Veeco [2], the ST55 from Saintech [3], and the Fafnir from Willey Optical[4].

Earlier work summarized by Willey [5,6] reported on the MK-II, the FAFNIR, and the EH400 and EH100 sources from Kaufman-Robinson. That report is augmented here and the behavior of increased NC is added.

The Vd is a function of: the geometry of the source, the SCCM of the gas, Ad, NC, and the pumping speed (PS) of the deposition chamber. The PS is usually not a continuous variable, and it is different in the three chambers used for the current tests. The report in Ref. 5, has more information on PS than in this current work. A new viewpoint is also added here of the Vd versus process/chamber pressure.

Mark-II Ion Source

The MK-II ion source [2] illustrated in Fig. 1 is probably the most commonly used gridless ion source in the world. As with all gridless ion sources studied here, there is a cathode filament/neutralizer opposite the anode of the source. This serves two purposes, one is to provide electrons to balance the charges of the positive ions that arrive at a substrate at some distance above the source, and the other purpose is to provide electrons in the active ion-forming region near the anode of the source. These latter electrons

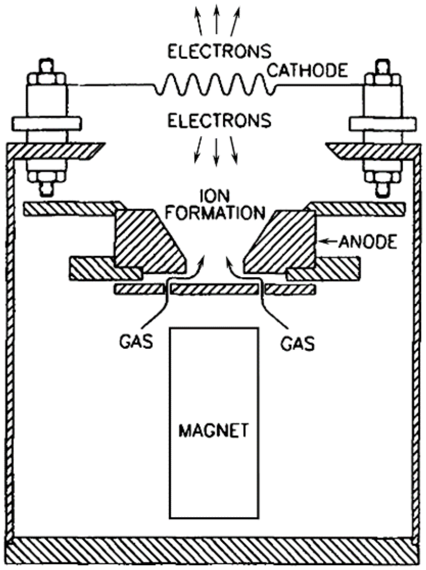

Figure 1. Configuration of the MK-II ion source

collide with neutral gas atoms entering the source from below to create ions. To increase the opportunities for these ionizing collisions, an axial magnetic field is applied to the ionization region to cause the electrons to gyrate in that field (Hall effect) and remain a longer time for interaction in the ionization region, creating more ions. These ions are then repelled by the positive field of the anode and form the broad beam which exits the ion source and is used for such purposes as ion etching and Ion Assisted Deposition (IAD).

The power supply/control system of the MK-II which was tested in this case can be set to provide a certain Vd, Ad, and %NC. The gas flow (in SCCM, controlled by the power supply) is primarily what determines the Vd, although the Ad and NC also have an effect on the Vd. The NC is determined by the filament current (FC). The FC, SCCM, and NC are also displayed on the power supply. The setting for the NC, in the case of the MK-II, is given as a percentage of the discharge or drive current, Ad.

The NC setting commonly used is 10%. The NC needs to be enough to counteract the positive ions reaching the substrates in a coating process. Insufficient NC will be witnessed as arcing or sparking on insulating surfaces in the chamber and on insulating substrates. Such sparks can cause damage to these surfaces. Additional NC is usually added until the arcing is stopped. An NC of 10% is typical.

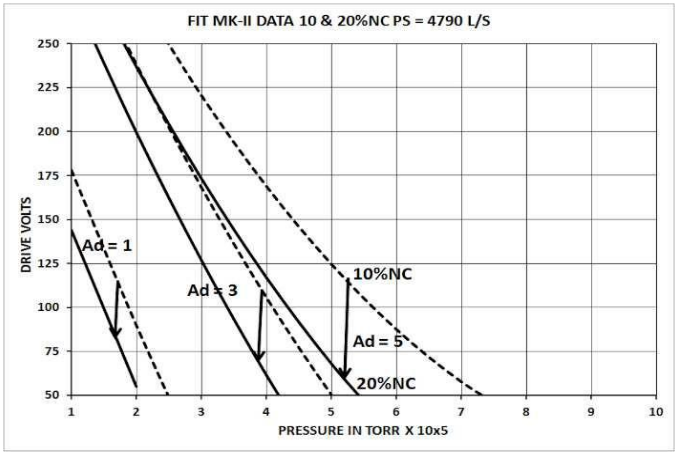

Figure 2. Drive volts versus pressure and drive current for a MK-II ion source in a chamber with a PS = 4790 L/S.

In accord with the findings of Zhurin [1], the MK-II was tested at a NC of 10% to eliminate arcing and also 20% to further reduce the Vd. In the figures, the dotted lines are with 10%NC and the solid lines at with 20%NC, showing the reductions of Vd, and the reduction is pressure is seen.

It has recently been found informative to plot Vd as a function of the chamber pressure in Torr. The SCCM is related to the pressure and PS by Eqn. 1.

$$\mathbf{SCCM = PS(L/S)*Pressure(Torr)/0.0127} \qquad \mathbf{(1)}$$

All of this is predicated upon all of the gas to the chamber entering through the ion source. It appears to be generally desirable to have a high PS to keep the chamber pressure low in order to minimize the competition of the gas with the depositing material which would reduce the film density and hardness.

Figure 2 shows the behavior of the MK-II in a chamber with a pumping speed of approximately 4790 liters/second (L/S). In a previous work [7], it was found that lower ion energies (in eV) were desirable to avoid disassociation of some compounds such as MgF_2, which would cause absorption. The eV is closely related to the Vd as shown by Zhurin in Ref. 1, Fig. 4.4. Therefore, it is desirable to keep the Vd and chamber pressure (as mentioned above) as low as practical, and the extra NC is very beneficial for this.

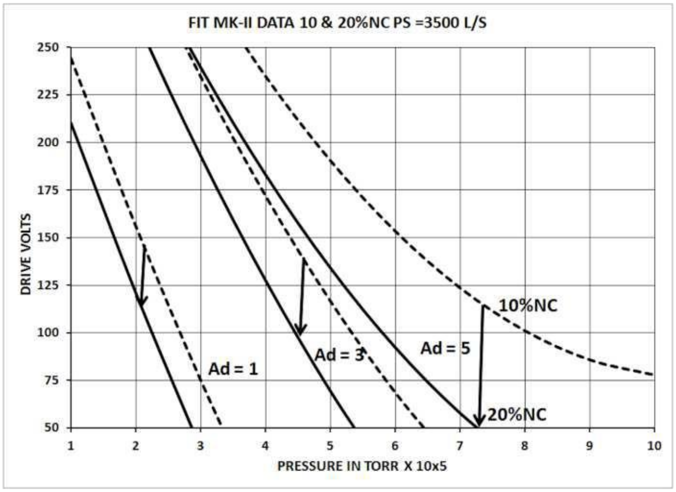

Figure 3. Drive volts versus pressure and drive current for a MK-II ion source in a chamber with a PS = 3500 L/S.

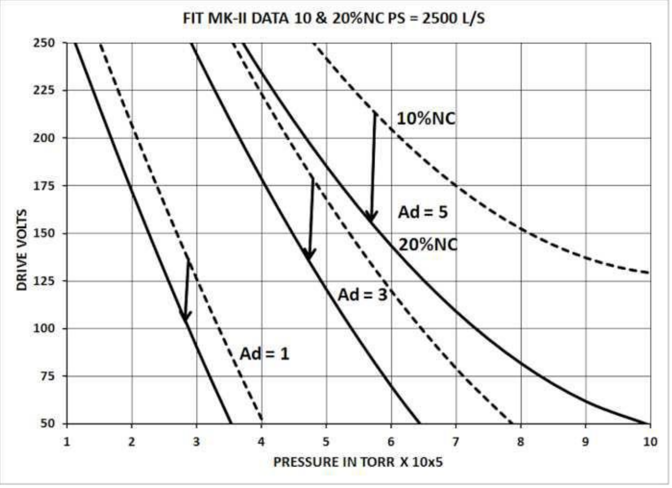

Figure 4. MK-II Vd versus pressure from Eqn. 1 fit to experimental data from a hypothetical chamber with a PS = 2500 L/S.

The plotted curves in Figs. 2-4 are generated with Eqn. 2 which is the result of the statistical fit of the measured data to a characteristic equation.

$$\mathbf{Vd = 448.5 - 0.05129*PS - 3.312*\%NC + 117.21*Ad - 104.6*Torr - 13.438*Ad^2 + 6.411*Ad*Torr + 3.643*Torr^2 - 0.09394*\%NC*Ad*Torr} \quad (2)$$

This data was taken in a system which could be operated at a PS of approximately 4790 L/S for argon and also 3500 L/S. Figure 3 is similar to Fig. 2 except for a PS of 3500 L/S. Figure 4 is not from actual measured data, but is generated using Eqn. 1 to extrapolate to probable values when operating in a chamber having a PS of 2500 L/S.

PS1500 Pasma Source (Fafnir)

The PS1500 Plasma Source otherwise referred to as Fafnir, as illustrated in Fig. 5, may be the least well known gridless ion source in the world. The power supply of the Fafnir is normally an MDX-5 sputtering power supply from Advanced Energy with reversed polarity from what is normally used for sputtering. Tests for this present work were done with an MDX-15; not because that power was needed, but because it was available. The filament and gas flows were controlled by a DynaVac [8] Ion Source Controller #408316.

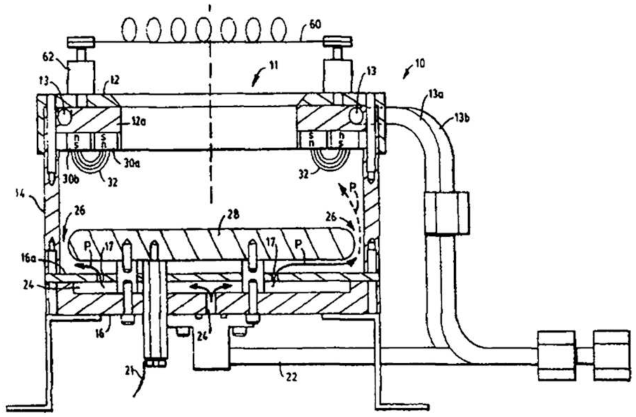

Figure 5. Configuration of the Fafnir Plasma Source.

The control approach with the Fafnir is different from that of the MK-II, in that the gas flow is manually controlled to give the desired Vd, and the filament current is manually controlled to a given ampere value (not a %NC). It was found that by adding about 1.2 amps of FC to that which would inhibit sparking, gave approximately the same result as using 20%NC with the MK-II. This is also consistent with Zhurin's [1] Fig. 4.9 on this same subject. It should be possible to simply repeat these same results with a Variac (variable transformer) for the filament control, and a common mass flow controller or even a needle valve could be adequate for the gas/voltage control.

Figure 6 shows the behavior of the Fafnir in a chamber with a pumping speed of approximately 1200 liters/second for argon (which is much lower PS than used for testing the other sources). The dotted lines are with the minimum FC for de-sparking and the solid lines show the characteristics when an additional 1.2 amps of FC is provided.

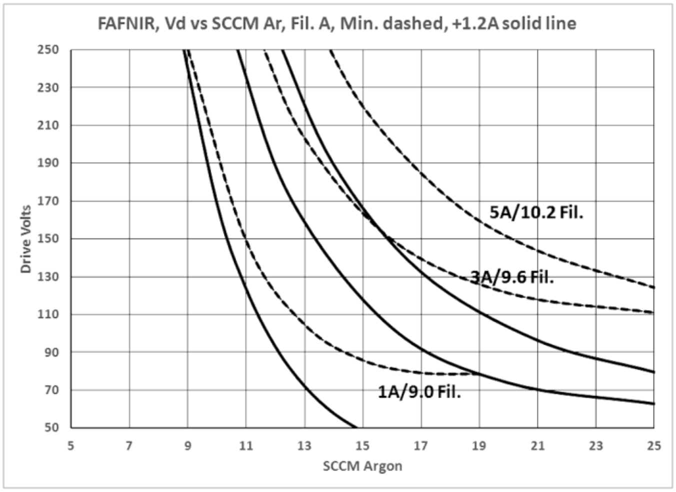

Figure 6. Vd versus gas flow and drive current for the Fafnir Plasma Source in a chamber of 1200 L/S pumping speed.

The plotted curves in Fig. 6 are generated with Eqn. 3 which is the result of the statistical fit of the measured data to a characteristic equation.

By applying Eqn. 1 to Eqn. 3, Eqn. 4 is produced.

$$\mathbf{Vd = 2124.15 - 11.31*Ad - 12545.2/SCCM - 337.97*FC + 2677.13*Ad/SCCM + 54424.4/(SCCM\,\hat{}\,2) + 614*FC/SCCM + 14.466*FC\hat{}2 - 182.46*Ad*FC/SCCM} \quad (3)$$

$$\mathbf{Vd = 2124.15 - 11.31*Ad - 159.32/(PS*Pressure) - 337.97*FC + 34.0*Ad/(PS*Pressure) + 8.778/((PS*Pressure)\hat{}2) + 7.8*FC/(PS*Pressure) + 14.47*FC\hat{}2 - 2.317*Ad*FC/(PS*Pressure)} \quad (4)$$

Figure 7 shows plots of Eqn. 4 for the Fafnir Vd as a function of pressure, drive current, and filament current. It can be seen that the addition of 1.2 amps of filament current reduces the Vd at a given gas flow, or the pressure is reduced for a given Vd and Ad. This figure can be compared with Fig. 4 for the MK-II.

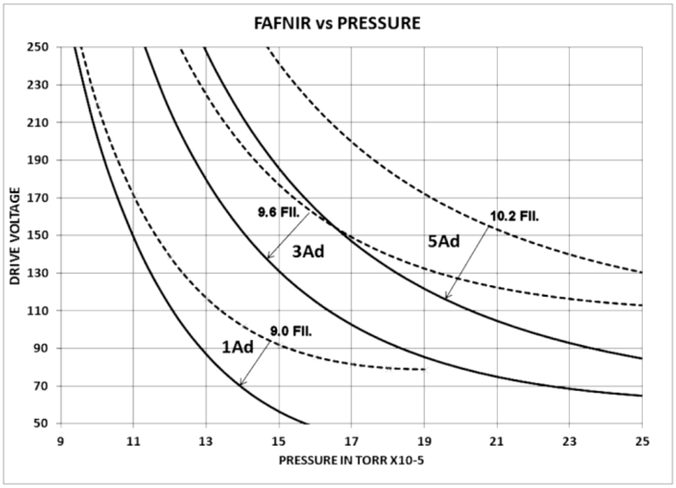

Figure 7. Vd versus Pressure, drive current and filament current for the Fafnir Plasma Source in a chamber of 1200 L/S pumping speed.

ST55 Ion System

The ST55 Ion System from Saintech in Australia is similar to the MK-II and Fafnir in many respects but differs in its geometrical details and its power supply. Figure 8 shows the geometry of the ST55 wherein there is also an axial magnetic field and a cathode filament opposite the anode and the gas flow enters into the ionization area from the sides. The significant differences between the ST55 and the other two sources are the power supply, the anode is TiN plated, and the anode is water cooled (although models of the MK-II and Fafnir have also been made with water cooled anodes).

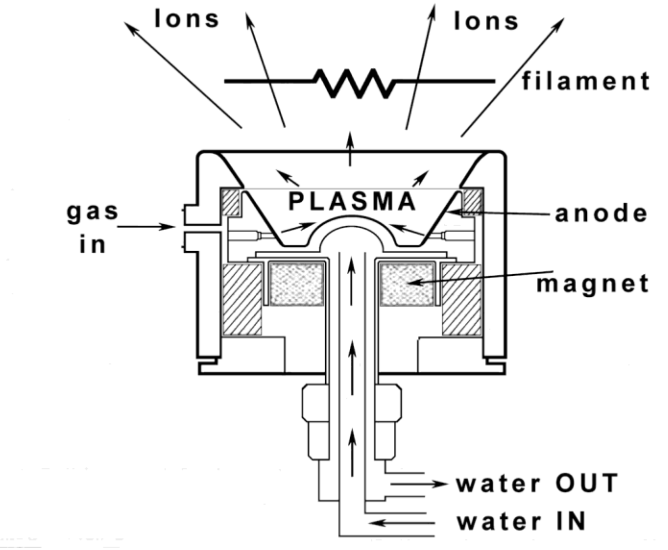

Figure 8. Configuration of the ST55 Ion Source.

The water cooling allows the source to operate at higher power and it protects the magnet from being heated to a temperature where it might degauss. In the case of the Fafnir, the magnets are not as near the anode, but they also need to be cooled to protect them from overheating. With both the Fafnir and the ST55, it is important to NOT turn off the cooling water until the ion source is cool, even though the ion process is completed. In the non-water-cooled version of the MK-II, it is advisable to allow the chamber and ion source to cool before venting, which causes some process delay.

The power supply for the ST55 is rectified AC power with selectable discrete RMS voltages of 90, 110, 140, 180, and 225 Volts. Figure 9 is taken from an oscilloscope trace of the anode voltage and anode current with time, at the power line frequency of 100 or 120 Hz. The anode current and filament current can be adjusted over continuous ranges.

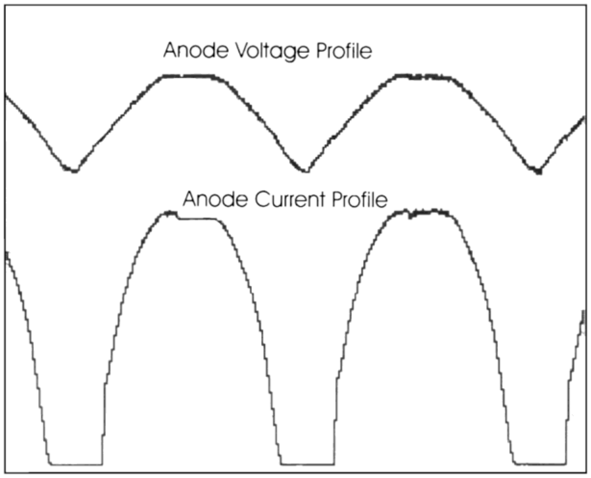

Figure 9. Oscilloscope trace of the anode voltage and anode current with time.

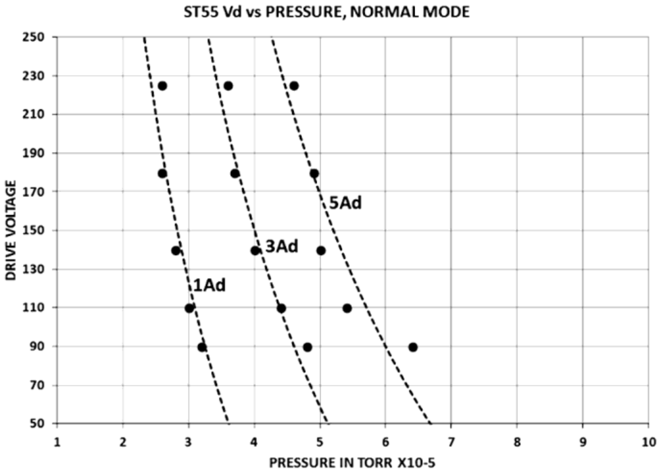

Figure 10. Vd versus pressure and drive current for the Saintech ST55 Ion Source. Dots are actual data points in Normal Mode in a chamber of 2000 L/S pumping speed.

Figure 10 shows the Vd versus pressure for the ST55 in a chamber of PS 2000 L/S to compare with Fig. 4 for the MK-II at 2500 L/S. Because the ST55 power supply has discrete voltage settings, the dots in Fig. 10 shows the actual measured data, and the dotted lines are from a data fit to the simple formula in Eqn. 5. Here, the

$$\mathbf{Vd = -278.44 + 915.14/Torr - 12.288*Ad + 341.14*Ad/Torr.} \quad \mathbf{(5)}$$

Vd is a function of Ad and the chamber pressure in 10^{-5} Torr. This performance compares favorably with the MK-II. A better fit to the measured points is expected from a more complex function, but Eqn. 5 is adequate for present purposes. Data is not available at this time for the ST55 to illustrate the effect of an additional 1.2 amps of filament current beyond that just adequate to eliminate sparking at each Vd and Ad.

CONCLUSIONS

Additional neutralizer current significantly reduces the process pressure for a given ion voltage and current. This should allow improved film density and hardness as compared with minimal neutralizer current in IAD processes. The different geometries of the ion sources tested have a significant effect on the voltage-pressure behavior of the individual source.

REFERENCES

[1] V.V. Zhurin, Industrial Ion Sources: Broadbeam Gridless Ion Source Technology, First Edition, Chap. 4 and Fig. 4.9, Wiley-VCH, Weinheim, Germany, 2012.

[2] Veeco Instruments Inc., http://www.veeco.com/products/mark-ii-gridless-ion-source

[3] Saintech Pty. Limited, Tuncurry, 2428 Australia. http://www.saintech.com/page/products.html#ST55

[4] Willey Optical, Consultants, Charlevoix, MI, USA, http://www.willeyoptical.com

[5] R.R. Willey, "Behavior of three types of plasma sources for optical coating," *Society of Vacuum Coaters Annual Technical Conference Proceedings*, **54,** pp. 323-327, 2011.

[6] R.R. Willey, *Practical Production of Optical Thin Films*, 3rd Ed., Sec. 3.8.5, Willey Optical, Consultants, 2015.

[7] R. Willey, K. Patel, and R. Kaneriya, "Improved Magnesium Fluoride Process by Ion-Assisted Deposition," *Society of Vacuum Coaters Annual Technical Conference Proceedings*, **53,** pp.313-319 2010.

[8] DynaVac, http://www.dynavac.com/

FOR FURTHER INFORMATION:

Ronald R. Willey,
Willey Optical, Consultants, Charlevoix, MI 49720,USA
ron@willeyoptical.com, (231) 237-9392