

The Effects of Pumping Speed on the Operation of a Cold Cathode Ion Source

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ABSTRACT

A cold cathode ion source is a differentially pumped device with one end of the plasma chamber open to the vacuum environment of the coating system. Therefore, the operational parameters of the ion source and the quality of the films made using the ion source are affected by the parameters controlling the vacuum level. These include the pumping speed of the chamber, any leaks that may be present and the controlled flow of any gases into the chamber. The pumping speed of the chambers is the major factor not directly controllable that affects the quality of the films that can be made using the ion source. In this study we will present data on the operational parameters of a cold cathode ion source at different pumping speeds and the subsequent effect on the optical properties of TiO₂ films.

INTRODUCTION

The CC-105 broad beam cold cathode ion source has operational characteristics that have been well documented in the Operations Manual and in various publications [1-5]. All of the previous data taken at Denton Vacuum was done in an Integrity[®] 29 (I-29) in the Applications Laboratory. In this chamber the oxygen pumping speed was approximately 1500 l/sec. Installation of the CC-105 into equipment with lower or higher pumping speeds will result in functional changes in the operational characteristics. In order to understand these differences a study was conducted in a Denton Vacuum Integrity[®] 36 (I-36) chamber where the aperture of the pumping port into the plenum was partially blocked to simulate different pumping conditions. This study was done in two parts with the initial data being taken in a chamber with an O₂ pumping speed of 2350 l/sec utilizing a fully open aperture. The TiO₂ films were prepared in a different I-36 chamber with an O₂ pumping speed of 1800 l/sec utilizing a fully open aperture.

EXPERIMENTAL TECHNIQUE & DATA – PHASE I

The opening in the pumping port was adjusted by trial and error (using aluminum foil) to give varying pump speeds in

the initial set of tests. The pumping speed (S) was calculated using the following relationship:

$$S = \frac{0.0127 * F}{P}$$

where F is the flow in sccm and P is the pressure in Torr.

The opening in the pumping port was adjusted until the average calculated oxygen pumping speeds were approximately 480, 860, 1400 and 2350 (full open). Then data was taken for the V/I (voltage/current) characteristics and the total pressure measurement as a function of the drive current for starting pressures of 1x10⁻⁴, 2x10⁻⁴, 3x10⁻⁴

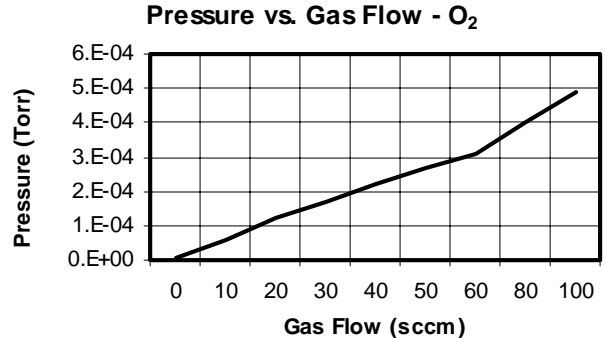


Figure 1a. Pressure vs. oxygen flow for a fully open aperture pumping port in an I-36 coating chamber.

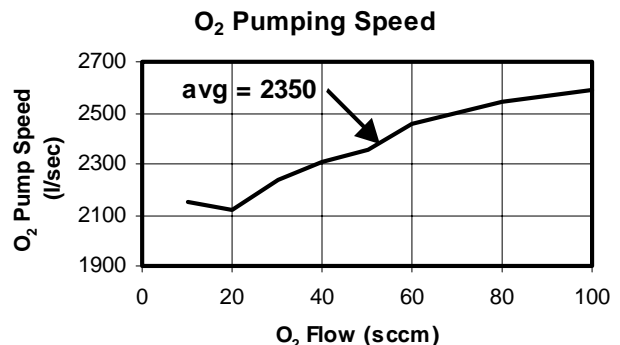


Figure 1b. Oxygen pumping speed for a fully open aperture.

and 4×10^{-4} Torr. The latter data was then compared for the effect of the pumping speed. An example of the flow rate pumping speed data is shown in Figures 1a and 1b respectively.

The voltage/current characteristics as a function of the drive current for the ion source operating at flows that give oxygen pressures of 1, 2, 3 and 4×10^{-4} Torr pressures is shown in Figure 2.

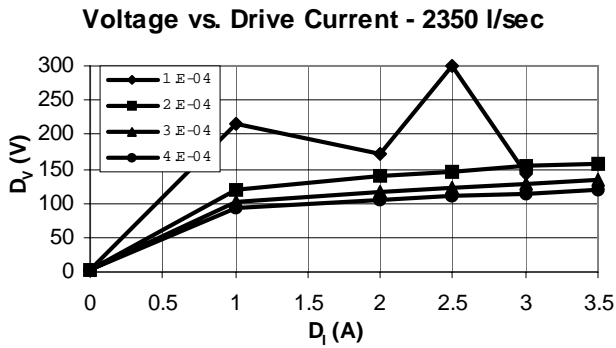


Figure 2. Drive voltage (D_V) vs. drive current (D_I) for the ion source operating at 4 different pressure levels.

The trends established in this set of data are consistent with what one would see for this ion source operating in any coating system. That is, the drive voltage required to sustain a plasma will increase as the drive current increases. However, the voltage increase does not follow a classical V/I curve. There will be an initial jump in voltage to ignite the plasma, and the increase will be slight thereafter. The required voltage increases as the pressure decreases, again by relatively small amounts until the pressure is too low to easily maintain the plasma. At that point, the voltage increases significantly and the required voltage can become erratic at some threshold level. In the above example, the lower pressure threshold for operating the source is about 1×10^{-4} Torr where the required voltage is about double the pressure for operating the ion source at the higher pressure levels.

The pressure remains constant at the initial setting before the ion source is turned on and after the ion source has been turned on but the drive current is 0 amp. As the drive current is turned higher the pressure increases. This is to be expected since the ionization process is splitting some of the oxygen molecules into oxygen atoms, forming more particles per unit volume. This pressure increase can occur when using a gas where the molecules are made up of 2 or more atoms. One would not expect to see a similar pressure increase for Ar since it is a monatomic molecule. The pressure increase for the 2350 l/sec pumping speed situation is shown in Figure 3.

The above trends exist at the lower pumping speeds. However, for any given pressure, the required voltages are

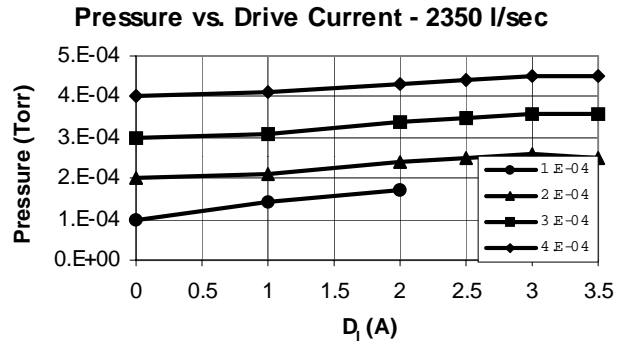


Figure 3. O_2 pressure vs. drive current for various starting pressure levels where the pumping speed is 2350 l/sec.

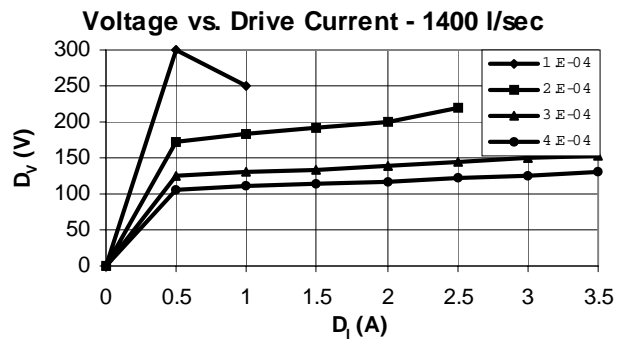


Figure 4. V/I characteristics for 1400 l/sec pumping speed.

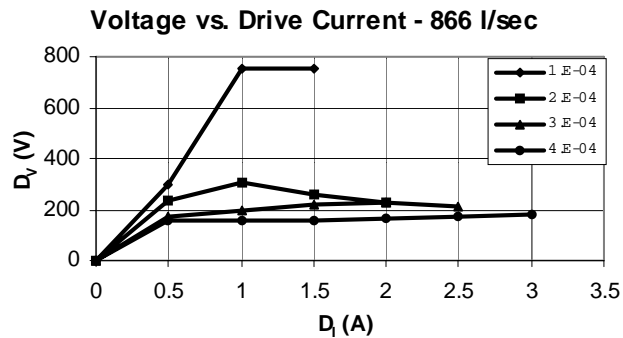


Figure 5. V/I characteristics for 866 l/sec pumping speed.

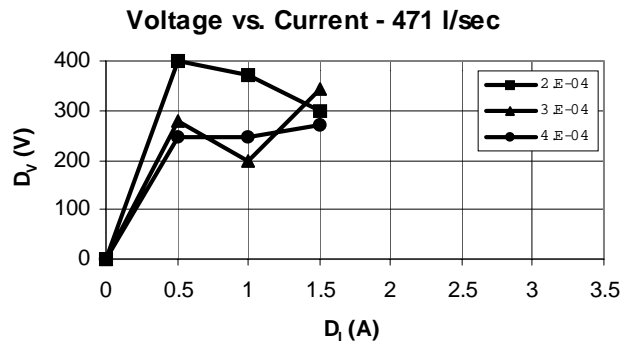


Figure 6. V/I characteristics for 471 l/sec pumping speed.

higher for lower pumping speeds. Figures 4, 5 and 6 show the voltage current pumping characteristics for pumping speeds of 1400, 866 and 471 l/sec respectively.

At 1400 l/sec the voltages required to maintain the drive current are only slightly higher for 3×10^{-4} and 4×10^{-4} Torr pressures. However the voltage for the 2×10^{-4} Torr curve is about 50 volts higher than for the 2350 l/sec oxygen pumping speed and the plasma cannot be sustained above 2.5 amps. The voltage increase for the 1×10^{-4} Torr pressure is about 100 volts higher and the drive current cannot be sustained above 1 amp. The voltages increase even more for the 866 l/sec and 471 l/sec pumping speed configurations. Figure 7 and Figure 8 show the drive voltage vs. drive current characteristics comparison for all 4 pumping speeds for starting pressures of 2×10^{-4} Torr and 3×10^{-4} Torr respectively.

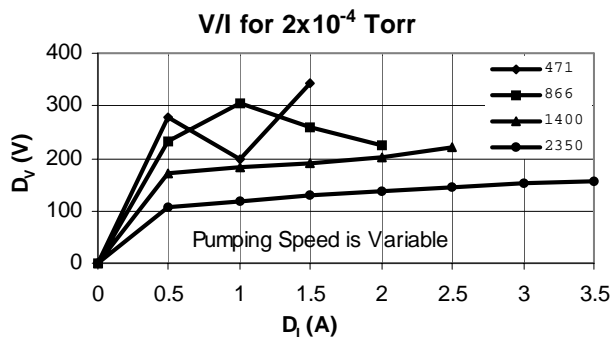


Figure 7. V/I characteristics for various pumping speeds for an initial pressure of 2×10^{-4} Torr.

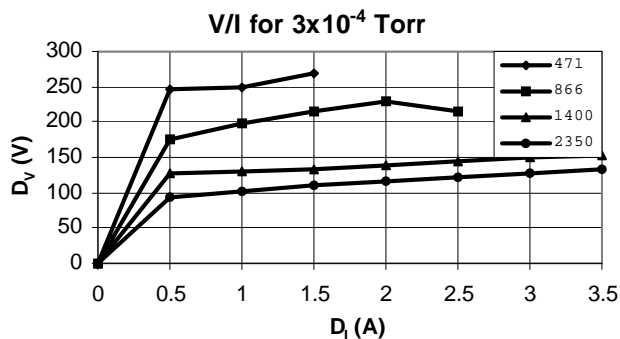


Figure 8. V/I characteristics for various pumping speeds for an initial pressure of 3×10^{-4} Torr.

It is of some interest to note that the level of pressure increase as a function of the drive current is also greater as the pumping speed decreases. This difference is not all that noticeable at the higher pumping speeds but becomes significant at the lower pumping speed (<500 l/sec).

There are some applications where higher ion energies are not desirable. Specifically where the purpose of the ion assist is to densify a coating but too much energy will break

the deposited molecules apart, adversely affecting the microstructure or causing absorption. We have conducted a study which shows that the ion energies are approximately half (ranging between $.4 \times$ to $.7 \times$ of the drive voltage [5]). Therefore establishing a lower drive voltage can be desirable. The increased drive voltage required to sustain a plasma at lower pumping speeds is not necessarily good. One way to offset the voltage increase is to increase the oxygen flow which gives a higher pressure and a lower voltage. The important factor is the characteristic of the films which can be made.

EXPERIMENTAL TECHNIQUE & DATA – PHASE II

A different I-36 coating chamber was used to make TiO_2 films using different pumping speeds. The purpose of this effort was to determine which changes in the process were necessary to make good films at different pumping speeds. Also, if good films could not be made, how bad were they. For this effort we constructed an aperture for the pump port of the chamber made of two semicircles which could be bolted together to give different pie shaped openings ranging from 0 degrees to 180 degrees (and 360 degrees if the constriction was left out all together). The full open aperture configuration gave an oxygen pumping speed of 1800 l/sec. Sectors of 70, 30 and 10 degrees open gave pumping speeds of 1200, 960 and 600 l/sec respectively (see Figure 9).

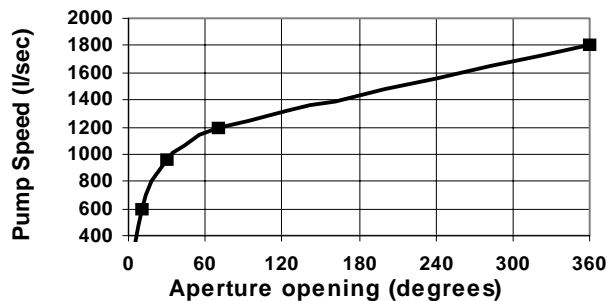


Figure 9. Oxygen pump speed as a function of pumping port sector opening.

The TiO_2 films were deposited to 3000 \AA at 3.5 \AA/sec using an ambient substrate temperature (typically starting at $50 \text{ }^\circ\text{C}$ and ending at approximately $85 \text{ }^\circ\text{C}$). The base pressure before introducing oxygen through the ion source was 7×10^{-6} Torr for the higher pumping speeds and was $<2 \times 10^{-5}$ Torr for the lower pumping speeds. All runs were done with a 2 ampere drive current (the drive voltage varied to maintain the current). The oxygen flow rate was used as a variable to control the optical properties of the films (refractive index and extinction coefficient). The optical properties and moisture stability of the films were determined from spectral data as published previously [2].

Films were deposited using all of the above pump speeds and flow rates of 13.3, 17.3, 21.3 and 25.3 sccm as needed to achieve non-absorbing thin film which was moisture stable and a film which was not moisture stable. The range of conditions ran and the refractive index of the films (@ 560 nm) are plotted in Figure 10.

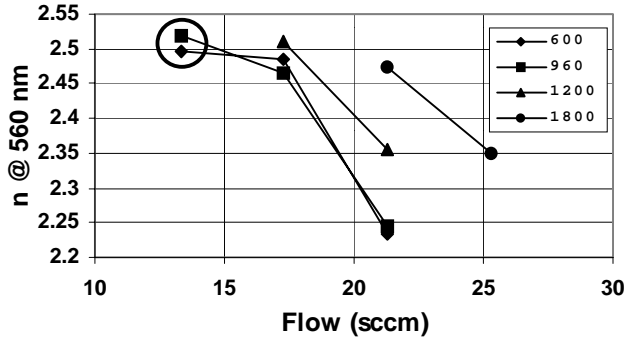


Figure 10. n vs. flow for TiO₂ films prepared at different pumping speeds. Circled values have k > .001 at 560 nm.

All of the above films with a refractive index > 2.46 are moisture stable. All of the films with a refractive index of < 2.45 are not moisture stable. Both of the films deposited at 13.3 sccm have k (extinction coefficients) > .001 at 560 nm. Also, the films deposited using a 13.3 sccm flow resulted in a deposition pressure which was too low to maintain the 2 ampere drive current. For these films the drive current was in the 1.4–1.5 ampere range, was erratic and the drive voltage was 800 volts. The drive voltage for all of the other films ranged from 220 volts to 300 volts. The films prepared using a flow of 17.3 sccm and higher are basically non-absorbing.

The above data is consistent with data we have reported previously. That is, the refractive index of the film increases as the oxygen pressure (flow) decreases. The interesting factor that comes out of this study is that the transition to higher index takes place at higher flow rates for the higher pumping speeds. This, of course, is not totally unexpected since we already know that the higher the pressure during deposition, the lower the film index, all other things being equal. However, what does change at different pumping speeds is the effect of the gettering action on the pressure during deposition. This effect is shown in Figures 11 (pressure) and Figure 12 (pressure change – gettering).

In Figure 11 the region to the left and below the dotted line show films which were absorbing. The region between the dotted and dashed line are films which are moisture stable. The region to the right and above the dashed line is films that are not moisture stable.

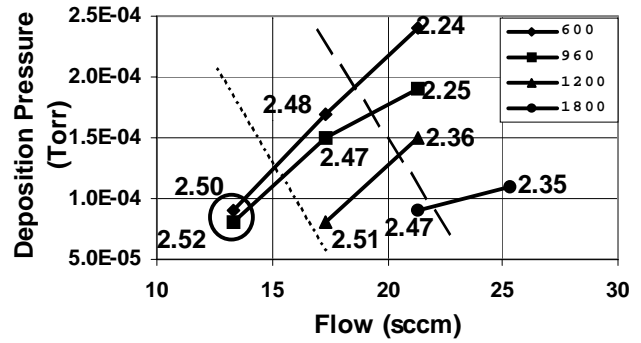


Figure 11. Pressure while depositing TiO₂. Refractive index at 560 nm shown with each data point.

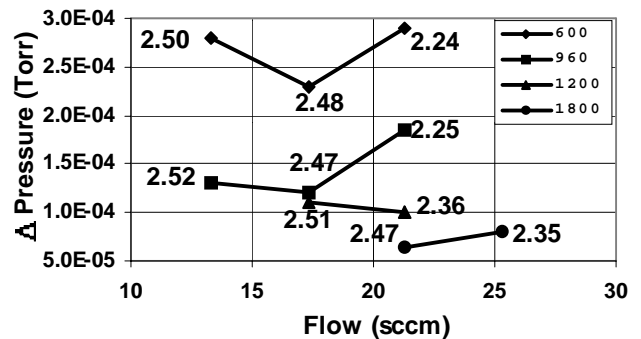


Figure 12. Oxygen pressure change (gettering) during TiO₂ deposition using various oxygen flow rates and chamber pumping speeds.

From Figure 12 we can see that at each pumping speed the change in pressure due to gettering is about the same (indicating that the same amount of oxygen is being used up) regardless of input flow. However, the change of pressure due to gettering increases as the pumping speed decreases.

All of the refractive index dispersion curves have about the same shape. This is shown in Figure 13. where curves for 8 of the films prepared for this study are plotted, two for each of the pumping speeds (1 which is moisture stable and 1 which is not).

CONCLUSIONS

Basically what we have learned from this exercise is that non-absorbing moisture stable optical films can be made with a cold cathode ion source in coating systems with a broad range of pumping speeds. It is much easier to make good films in systems with high pumping speeds. At the higher pumping speeds the pressure during film deposition

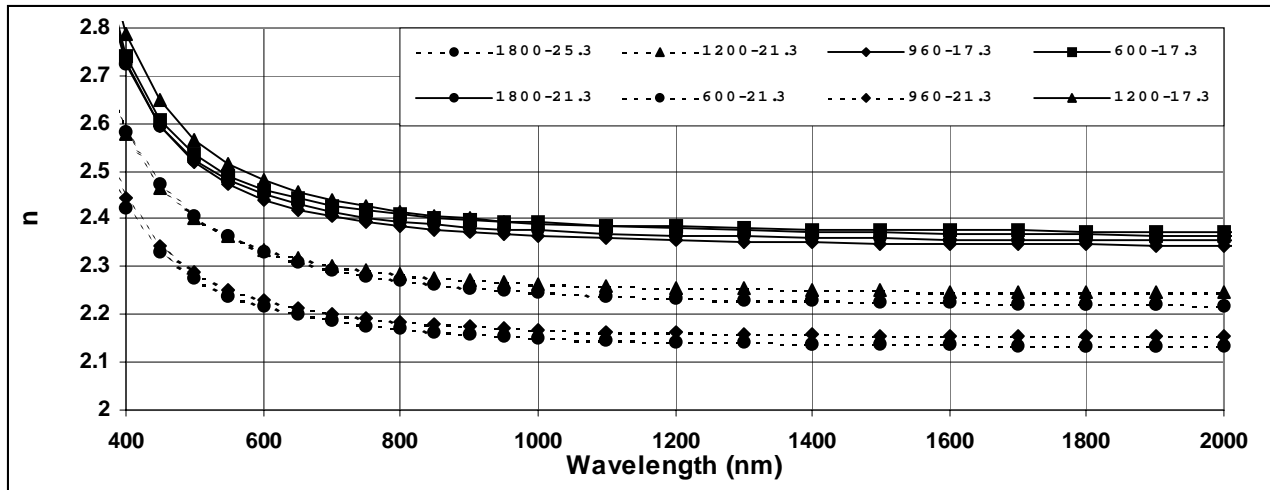


Figure 13. Refractive index of various films. First # is pumping speed (l/sec) and second # is O₂ flow (sccm).

may be surprisingly low (in the mid-10⁻⁵ Torr range for pumping speeds as high as 3600 l/sec). At lower pumping speeds it is necessary to have higher pressures during deposition in order to make good films. In the example provided, a pressure of approximately 2.5x10⁻⁴ Torr is needed to make good films (dense and moisture stable) for the 600 l/sec pumping speed.

It is obvious that when comparing IAD film deposition parameters from different reports, differences in pressures used to achieve similar results may be due to the pumping speeds of the respective systems. It is also obvious that when trying to duplicate results from a publication, it is necessary to alter deposition parameters to take into account possible differences in pumping speed.

This study was done in a 36 inch (900 mm) diameter system. It was prompted by reports of problems in establishing good processes in systems with relatively low pumping speeds. However, we have shown that the pumping speed itself is not a problem. Often the systems with lower pumping speeds are smaller in size. Possibly the smaller size is the real problem.

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