The PFC-330 in Chamber Water Vapor Cryopump

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ABSTRACT

To meet the demands for improved throughput and water vapor management in smaller batch and load locked vacuum PVD coating systems, IGC-Polycold Systems Inc. developed the PFC-330 ST fast cycle in chamber water vapor cryopumping system. The PFC-330 ST utilizes mixed zeotropic refrigerant technology to cool a tubular in chamber cryosurface. Water vapor can be pumped to a partial pressure of 1 x 10^{-9} torr with this unit and to 1 x 10^{-11} torr with the PFC-330 LT (low temperature) version. Water vapor pumping speeds potentially greater than 30,000 l/s can provide radically reduced pump down times and gains in product throughput. In the same process time intervals the PFC-330 can allow background water vapor pressure to be reduced by an order of magnitude or more. The PFC-330 series features ultra-fast regen capability to permit full or partial cryosurface regeneration in short substrate load and unload time intervals. Capital costs are readily recovered through enhanced system utilization. Integrated with the system pumping package, the PFC-330 allows for the use of smaller turbomolecular, cryo or diffusion pumps. In certain PVD coating systems the PFC-330 may be used with a small turbo pump to handle all high vacuum pumping requirements. The PFC-330 features an optional isolated control interface to permit automatic control by remote low voltage signal from system computer of PLC master controls.

INTRODUCTION

In most vacuum processes, water vapor is the predominant residual gas once the system has been rough pumped. Due to continual outgassing from chamber and substrate surfaces, water vapor typically comprises greater than 90% of the total residual gas load. To minimize total pump down time to base vacuum, it is therefore essential to have the highest possible pumping speed for water vapor.

The need for high pumping speed increases dramatically as the process driven base vacuum level becomes deeper. For example, a process requiring a 1xE^{-6} torr base vacuum will typically require a 10X increase in high vacuum pumping time compared to a process requiring a 1xE^{-5} torr base vacuum. When low base vacuum levels are required, the pump down time often constitutes a major portion of the overall process cycle. As 90% of this high vacuum pumping is typically water vapor, the need for high speed water vapor pumping is of paramount importance.

By a very large margin, the most effective method of achieving high water vapor pumping speed is through the use of an in chamber or in plenum cryosurface. The optimum cyrosurface is one composed of continuous tubing. Tubing, with its high surface area to volume ratio, permits the optimum combination of high pumping speed and ultrafast transient thermal response. Cooling occurs by passing a cryogenically cooled medium through the tubing. Tubing can be bent to form a cryosurface with almost any net shape, thereby allowing easy integration into almost any vacuum system. Such a cryosurface is referred to as a "cryocoil," while historically it was termed a Meissner coil. Historically liquid nitrogen was the usual cryocooling medium, but for the past twenty years the vacuum industry has moved to the economical use of closed loop cryogenic refrigeration systems that circulate a mixed zeotropic refrigerant through the coil. IGC-Polycold Systems Inc. has been the dominant manufacturer of such closed loop cryogenic refrigeration systems. IGC-Polycold manufactures a broad range of such high speed water vapor cryopumps, collectively designated the PFC series. These units have great cooling power and permit extremely fast cool down and warm up (regen) of the cryocoil. This combination of factors permits direct in chamber use, even in non-loadlocked batch vacuum chambers.

Optical coating, both precision optics and opthalmics, is a prime example of a process where the pump down cycle constitutes a significant portion of the overall process cycle with dramatic impact on throughput. Base vacuum levels are typically in the E^{-6} torr range and pump down to base vacuum can constitute a large portion of the total process cycle. In the semiconductor and the magnetic thin film head industries, base vacuum levels are often in the 1xE^{-8} torr range or deeper and total pump down time can be great relative to the actual deposition cycle. This latter situation generally dictates the need for load locks in addition to high speed water vapor pumping.

Many of the process chambers used in production of both precision optics and opthalmics, as well as in thin film head

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and semiconductor metallization, are relatively small. To meet the extreme need for high speed water vapor pumping in smaller batch and load locked evaporative, sputter and ion beam deposition systems for such applications, IGC-Polycold has developed the PFC-330 series. The PFC-330 compliments the larger models in IGC-Polycold's line of PFC fast cycle water vapor cyropumps, which are used in larger vacuum system applications.

FEATURES OF THE PFC-330

The PFC-330 ST is illustrated in Figure 1. This unit has been commercially available for 6 months. Identical in appearance is the PFC-330 LT, a lower temperature version for deep base vacuum requirements. The PFC-330 LT will make its commercial appearance in the coming months.

Figure 1. PFC-330 ST Wafer Vapor Cryopump.

These systems achieve fast thermal response by circulating refrigerant at high pressure and velocity. A single compressor is utilized to keep internal moving parts to a minimum, which in turn assures extremely high reliability. The fast thermal response translates into extremely fast cryocoil cool down time and extremely fast heat up for cryosurface regeneration. Regeneration of the coil occurs in under 3 minutes, while cool down to deep cryo-temperature is achieved in 4 minutes. It is this capability that permits placement of a cryosurface directly in the process chamber in the case of non-loadlocked batch coating systems. Regen is readily performed in the time interval intermediate to successive batch loads.

The PFC-330s feature full remote control capability. With an optional isolated electrical interface the unit may be controlled by low voltage AC or DC signal from a PLC or other computer control system. The PFC-330s are available in CE-Marked version for European application.

The PFC-330s utilize a proprietary non-flammable CFC-free refrigerant that meets all environmental regulations dictated under the Montreal Protocol through the year 2020.

The PFC-330 features a floor footprint of only 24" x 22", allowing easeful integration in clean room wafer fab environments. The refrigerant line is semi-flexible for easy installation and is available in a standard closed cell foam insulated version or in a vacuum jacket insulated version. The vacuum jacketed line has virtually no thermal loss, and this feature permits the PFC-330 to be placed at significant distance from the vacuum process system.

PERFORMANCE AND APPLICATION

Optimizing Pumping Speed

Net pumping speed in the high vacuum regime is characterized by the by the following relationship:

$$1/S_{net} = 1/C + 1/S_{pump}$$

where C is the geometrically dependent molecular conductance to the pump. To achieve high net speed, both the speed of the pump and the molecular conductance must be maximized. Conventional high vacuum pumps such as cryopumps and turbo pumps are limited in terms of their gross pumping speed, but they are also limited due to conductance restrictions inherent in their use. Both these types of pumps must be outside the vacuum chamber and in the case of cryopumps, definitely isolated by a high vacuum valve. The conductance of the pump orifice and the offset due to the pump orifice, high vacuum valves, etc., further restrict the attainable net pumping speed. If the pump port is remote from the chamber due to a plenum, deposition shields, etc., further reduction in net speed seen at the chamber results.

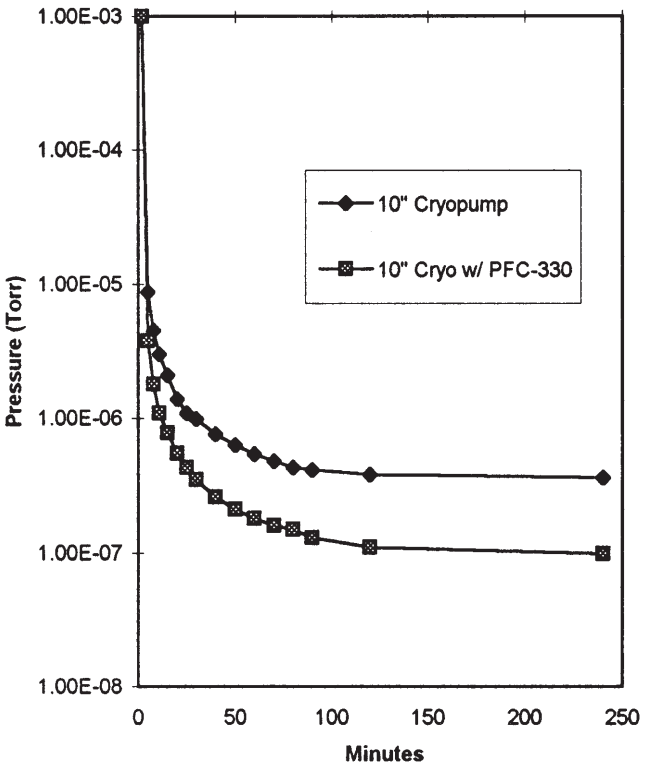

Figure 2. Comparative pump down curves for a sputter system.

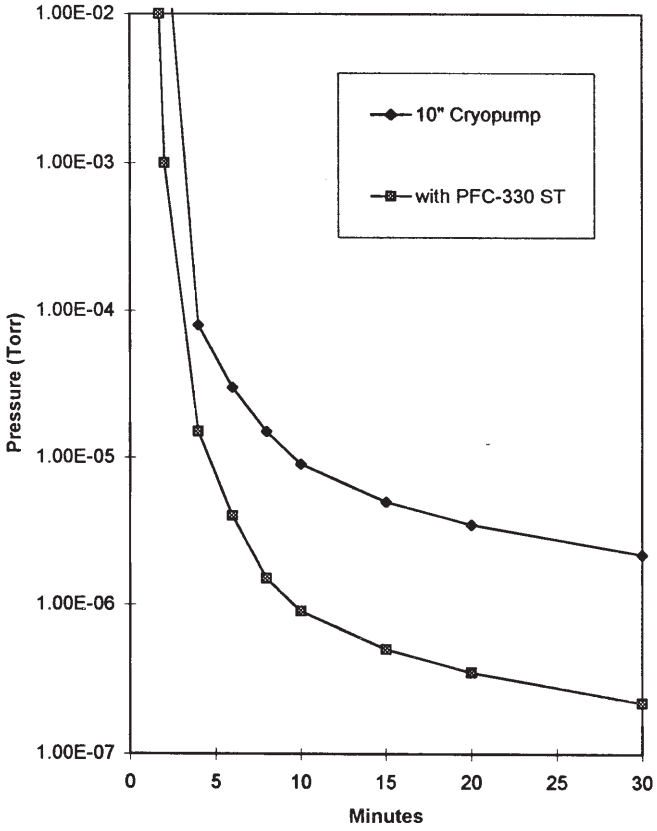

Figure 3. Comparative pump down curves for an opthalmic coating system.

The PFC-330 overcomes such conductance restrictions because the cryosurface may be situated directly in the chamber, or in some cases in the plenum in a position immediately adjacent to the process chamber. In addition, the comparatively great cooling power of the PFC-330 permits the use of a large total cryosurface. Pumping speed is directly proportional to total cryosurface area.

The result is pumping speeds for water vapor that are significantly greater than can be obtained by any other pumping method. Because water vapor is usually 90% of the battle, the overall pump down time for the system is greatly reduced. The high thermal load capability the PFC-330 also in many cases permits the use of an in chamber cryosurface in vacuum process where the deposition chamber must be at elevated temperatures. Optimally configured radiation shields can often be employed that mitigate the thermal load while still allowing great conductance of water vapor molecules to the cryocoil. In plenum placement is an alternative in the case of hot deposition processes.

The PFC-330 is typically paired with either turbo pumps or cryopumps, which must pump the smaller 10% (typical) dry gas load, as well as hold process pressure in the case of sputtering processes. As the PFC-330 selectively pumps water vapor with high speed at typical sputtering process pressures, background water vapor partial is kept much lower, and this has been observed to enhance thin film physical and mechanical properties in many applications.

The PFC-330 can be paired with a turbo pump, thereby eliminating the need for conventional cryopumps and their associated regen in many applications. Alternatively, when paired with a cryopump it can permit the downsizing of the cryopump as it need only handle the smaller dry gas load.

Regeneration

As indicated, the PFC-330 is capable of regenerating a typical cryocoil in less than 3 minutes, which allows in chamber placement in batch coaters. Regen typically is programmed to commence the instant the vacuum system is put into its vent cycle. Full regeneration is generally completed by the time the chamber door is opened. With a typically sized cryocoil a dwell period in standby mode of 5 minutes is required. This can be the time during which the chamber is unloaded, the new load is put in and the chamber is then rough pumped. The PFC-330 is put into cool down mode at a preselected time during the roughing cycle, typically when pressure reaches a few hundred microns. Cooling of the cryocoil to -120°C takes 4 minutes. High speed pumping of water vapor begins almost instantly as the cryocoil temperature is always below the equilibrium water vapor pressure in the chamber in any real instant of time. With cryocoils in the process chamber of load locked systems, regen need only take place infrequently, perhaps once a week during routine maintenance, etc.

Pumping Performance

The water vapor pumping speed for typical PFC-330 applications is 20,000 l/s net. Significantly greater pumping speeds can be realized in given applications by using larger cryocoils with some attendant sacrifice in cool down speed.

Figure 2 illustrates comparative pump down curves for a sputter deposition chamber utilized in thin film head production using an 10" cryopump with and without a PFC-330 ST unit. The time to reach a base vacuum of $1xE^{-7}$ torr after chamber opening was reduced from over 24 hours down to approximately 2 hours. Process throughput was increased dramatically. Figure 3 shows pump down curves for a batch optical coating chamber pumped to $1xE^{-6}$ torr with the PFC-330 and a 10" cryopump and with cryopump alone. Here pump down time to base vacuum was reduced from over 30 minutes to approximately 9 minutes. The overall process cycle was reduced by 30%.

To date, the PFC-330 ST has been commercially utilized on precision optical coating systems, opthalmic lens coating systems, thin film head sputter deposition and ion beam deposition systems, semiconductor thin film metallization systems, evaporative systems for growing compound semiconductor devices and crystals for laser telecommunications applications, and a number of other similar applications.