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High efficiency, Combined Triode Sputter Ion and NEG Pump for Extreme High Vacuum

K G Bhushan*, S M Rodrigues, D T Gaikwad and Pratap Reddy Kasina

Technical Physics Division,
Bhabha Atomic Research Centre, Trombay, Mumbai - 400085, INDIA

* email: bhushan@barc.gov.in

Abstract

We report on the development of a combined Triode Sputter Ion pump (TSIP) and Non-Evaporable Getter (NEG) pump for extreme high vacuum. The triode sputter ion pump incorporates a new type electrode consisting of a solid honeycomb anode, Titanium micro-cell pumping elements that have been developed after several rigorous ion trajectory simulations in combined electric and magnetic fields and enhanced high purity ceramic spacers. Pumping speed measurements conducted on the micro-cell electrode shows a 30% increase as compared with a conventional electrode. The micro-cell electrode also shows better pumping speed at higher pressures and also for inert gases. In addition, a novel NEG pump made from several individual pill-getters containing special stoichiometric ratios of Ti-V-Zr-Fe that has high pumping speeds specifically for Hydrogen, water vapor and CO_2 is also incorporated in the pump. The individual pill-getters are activated around 250^oC. It is demonstrated that the TSIP together with the NEG Pump reaches an ultimate pressure of $< 5 \times 10^{-11}$ mbar in a clean vacuum system within 72 hours as measured by a calibrated Extractor Gauge.

Key words: Triode Sputter Ion Pump, NEG Pump, Extreme High Vacuum

1. INTRODUCTION

Ion pumps are being routinely used for the production of clean ultrahigh vacuum environments in enclosed systems [1]. While most applications like high-energy particle accelerators, synchrotron radiation sources, surface analytical instrumentation systems, etc., require ultrahigh vacuum conditions, they also require good pumping characteristics for non-getterable gases (i.e., Ar, He, CH_4). Higher pumping speed for non-getterable gases and hydrogen is usually obtained by using a combination of pumps, like Triode Sputter Ion Pump (TSIP) and Titanium Sublimation Pump or Turbomolecular pump and Cryo-pump [2]. In the case of TSIP, attempts have been made to enhance the pumping speed for non-getterable gases by introducing a titanium sublimation filament inside the pump [3, 4], while in the case of diode sputter ion pumps, it has been attempted by replacing one electrode with Tantalum instead of Titanium [5]. Another important requirement for ion pump elements is that they should have very low leakage currents in order to maintain UHV conditions as well as to utilize the ion-pump current as a means of determining the pump pressure and hence the pressure of the system.

A few designs have been put forward for improving the pumping speed for non-getterable gases as well as for obtaining very low leakage currents. J. Knaster, et al., have reported an optimized annular Triode ion pump for the large hadron collider which allows the hadron beam to pass through ion pump [6]. Yusuke Suetsugu has presented a novel geometry for the ion pump element where the magnets are placed inside the penning cell [7, 8]. The earliest reported work on the geometrical structure of the ion pump element was by Pierini and Docino, which had a different cathode shape and a conventional honeycomb anode [9].

Non Evaporable Getters have been used to produce extreme high vacuum. Benvenuti and co-workers [10, 11] have demonstrated a Zr-V-Fe based NEG strip to achieve pressures below 10^{-13} Torr. Most of these studies have concentrated on thin film coatings of NEG materials that can be activated by passive heating such as during the baking procedure. Getter materials compacted in the form of small circular disks has not been largely used.

In this paper, we describe the design and performance of an ion pump with novel electrode geometry together with a Ti-V-Zr-Fe NEG in the form of a compacted circular disks developed in our laboratory specifically intended for large throughput requirement in ultrahigh vacuum applications. The combined ion and NEG pump after sufficient baking and activation cycles reaches an ultimate pressure of about 2.5×10^{-11} mbar as measured by a calibrated Extractor Gauge.

2.0 DESIGN OF THE ION PUMP ELEMENT

2.1 Background

The design of the ion-pump element closely follows the design of Pierini and Docino [9]. However, a few unique features have been incorporated in the design in order to handle large throughput requirements. The underlying principle of the pumping characteristics of a SIP relies on the sustainability of Penning discharge. Since the discovery of the Penning discharge in 1898, the properties of the discharge have been investigated. The first relevant theory was proposed by Redhead [12]. A better understanding of the discharge emerged after Helmer and Jespen performed experiments to investigate the theory proposed by Redhead [13]. Later, Dow studied the space-charge behaviour at various magnetic fields and observed a transition mode in the penning discharge before the high-pressure mode [14]. Schuurman, subsequently gave a general description of the discharge modes classified according to the applied magnetic field and residual pressure, while keeping the anode voltage constant [15].

2.2 Simulations

Electromagnetic field and trajectory simulations were performed using PC based electro-magnetic field simulation program SIMION [16] to understand the pumping characteristics of the Sputter Ion Pump and to enhance the production of sputtered material from the cathode. Simulations were performed in the penning geometry with radial symmetric electric field in order to ascertain the trajectories of residual gas ions. The main aim of these simulations was to ascertain the probability of an ion formed inside the penning cell hitting the cathode in order for sputtering to take place. A constant magnetic field required to sustain the discharge was also included in the simulations. Results were obtained for a wide variety of initial conditions starting from low electric field and high space-charge condition (which is the high-pressure mode of the discharge) to high electric field and low-space charge condition (which is the low-pressure mode).

Figs. 1a and 1b show the results of the simulations for the conventional sputter ion pump electrode and the modified novel geometry. It is clear that the modified geometry of the cathode has increased the penetration of the electrostatic field which in turn leads to, a) higher probability of extraction of ions from the high space-charge region of the penning cell and b) to keep the electron clouds bounded and bunched in their cycloidal orbits there by increasing the probability of ion production. It is also seen from the trajectory simulations that more ions collide with the cathode in the modified geometry than in the standard geometry, thereby enhancing the quantitative sputter yield from the electrode.

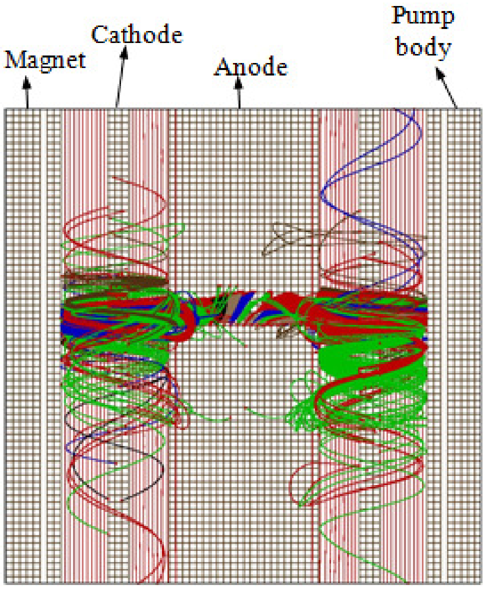

FIG. 1a Ion trajectories for various initial conditions of the conventional sputter ion pump electrode.

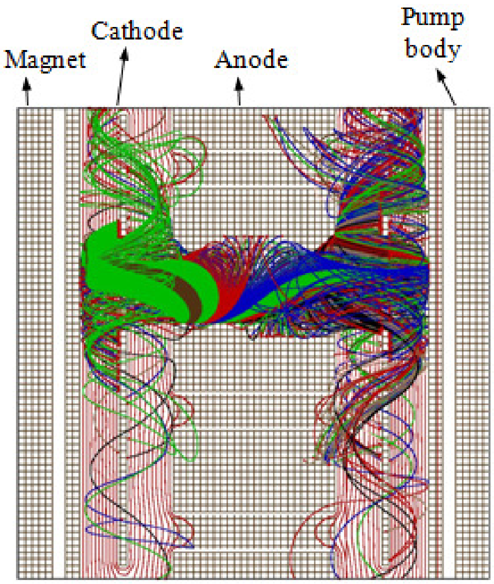

FIG. 1b Ion trajectories for various initial conditions for the modified ion pump electrode.

3.0 EXPERIMENT

3.1 Fabrication of the Ion pump electrode and NEG Pump

Fig. 2 shows the photograph of the new type of ion pump electrode developed in our laboratory. The cathode shape was fabricated by using CNC Wire EDM, from 2.5mm thick 99.9% pure titanium plates. The burrs and sharp edges were removed by treating in mild acid solution and polished by hand. The anode was machined from solid with array of penning cells in the form of honeycomb to minimize sharp edges which would otherwise occur if the anode were to be fabricated by spot welding individual thin-walled pipes. To reduce the leakage current special purpose UHV compatible high purity Alumina ceramic spacers were utilized to isolate the cathode from the anode. Resistivity and high voltage breakdown measurements with Megger instrument indicated a leakage current of less than 5 µA at 5000 Volts indicating an open circuit resistance in excess of 1 Gigaohms at atmospheric pressure. Four such identical electrode assemblies each containing 38 penning cells were fabricated and kept inside a standard 140 l/s ion pump body. The assemblies were thoroughly cleaned in mild alconox solution, followed by ultrasonic agitation in soap solution and then in clean hot de-ionized water and vacuum baked at 300°C prior to assembling inside the pump body.

FIG. 2 Modified Ion pump Element

3.2 Fabrication of the NEG Pump

The NEG pump was made by compacting fine powders of Ti-V-Zr-Fe in the specified stoichiometry ($Ti_{0.4}$-$V_{0.25}$-$Zr_{0.30}$-$Fe_{0.05}$) after optimizing for activation temperature. It was seen that in the compacted form, the NEG powders have high porosity that gives high pumping speed for Hydrogen, CH_4 and some pumping speed for H_2O and CO_2. Fig. 3 shows the arrangement used for holding the NEG pills along with a tungsten wire heater for activating the getter modules. The NEG pump with the getter modules mounted is located inside the centre of the sputter ion pump by suitable holding rods. Electrical connections are brought out on the neck of the ion pump through 4-pin electrical feedthrough which is also used for monitoring the temperature of the NEG modules. The NEG modules are activated by heating to a temperature 250 – 300°C for about 30 minutes.

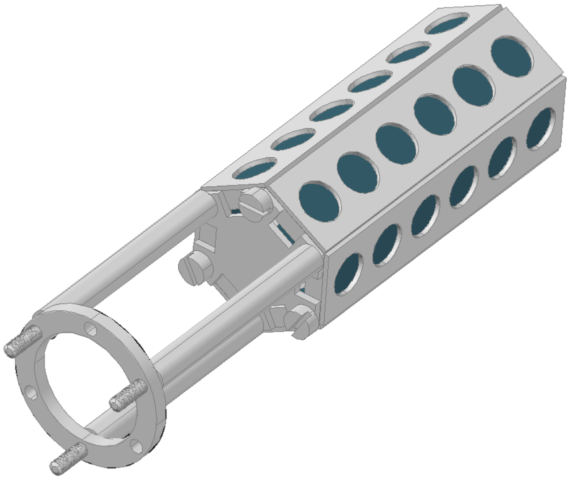

FIG. 3 NEG pump with the getter modules

4.0 RESULTS

4.1 Pumping speed measurement for the new ion pump electrode

Pumping speed measurements were conducted using the two-gauge, calibrated conductance method [17]. Gas for which the pumping speed had to be measured was introduced through a fine control leak valve in order to vary the base pressure in the system. At each measurement pressure, sufficient time was allowed for the system to stabilize at the equilibrium pumping speed. This equilibrium time constant varied from gas to gas and also with pressure. The effective pumping speed for the particular gas at a particular pressure was then calculated using the formula,

$$S = C_1\left(\frac{P_1}{P_2} - 1\right) \text{ lit s}^{-1}$$

where C_1 is the known conductance value of an orifice, P_1 and P_2 are the pressure readings in the main chamber and the gas inlet chamber respectively.

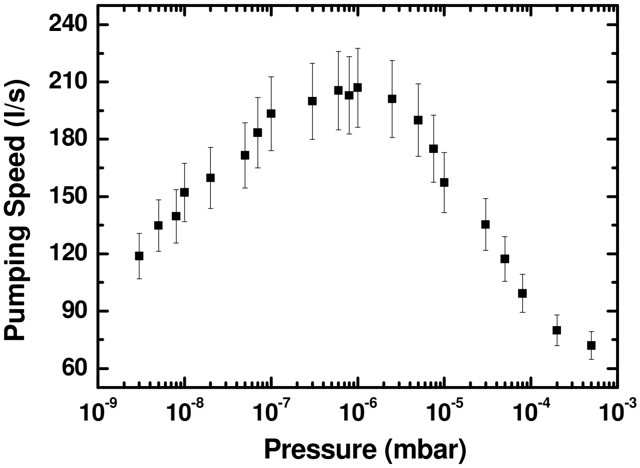

FIG. 4a. Pumping speed measurements for the ion pump containing modified SIP elements.

Fig. 4a shows the pumping speed measured for the new pumping element with Nitrogen. The modified element demonstrates a remarkable trend with increased pumping at high pressures indicating high throughput capacity. Results are compared with standard SIP element for nitrogen gas (Fig. 4b) showing a 30% increase in the pumping speed. The ratio between pumping speeds for argon and nitrogen for the new element is shown in Fig. 4c. The pump was was also tested by continuously pumping 10 mbar.l of argon at a pressure of 10^{-5} mbar for 24 hours. The element was found to be stable and in good condition. Negligible erosion had happened on the titanium cathode.

4.2 Pumping and activation measurements for NEG pump

The NEG modules were activated by resistive heating of a tungsten filament at about 350°C for 30 minutes. The heating was turned off and pressure drop was observed indicating the modules have been activated and pumping. The pumping speed of the NEG pump was measured for different gases separately in another experiment by introducing different gases through calibrated gas dosing valve (RVC300, with PVR116 Pfeiffer Vacuum, Germany). From these experiments it was calculated that each NEG module had about 100 mbar.l for H_2 and lesser pumping for other gases.

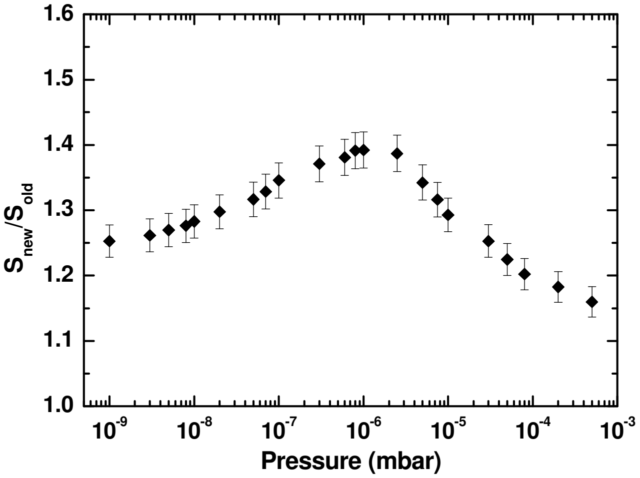

FIG. 4b Comparison of the pumping speeds of the standard SIP element with the new SIP element.

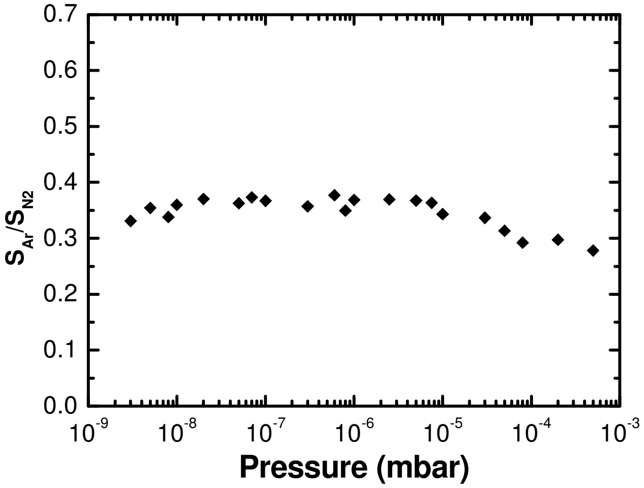

FIG. 4c Comparison of the pumping speeds of the modified SIP element for Argon and Nitrogen

4.3 Ultimate pressure measurement

The combined pump containing the modified ion pump electrodes and the NEG module was connected to an ion trap vacuum chamber and was tested for ultimate pressure. Fig. 5 shows the pump down curve for the entire system. Several baking and activation cycles were performed at 300°C. It can be seen that after about 150 hours of pumping and baking the base pressure in the ion trap vacuum chamber reached below 10-10 mbar and after about 250 hours reached ~ 2.5 x 10^{-11} mbar.

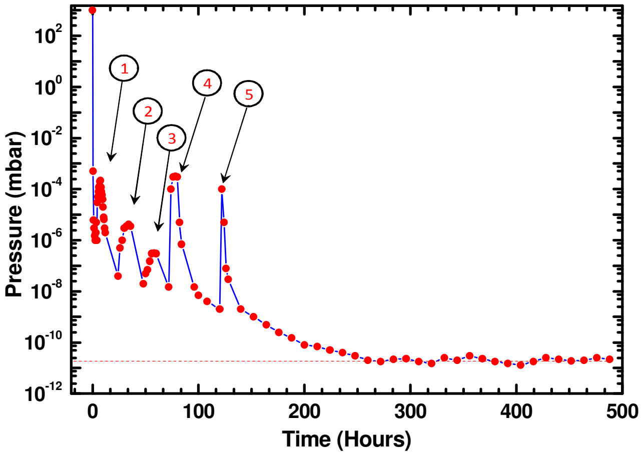

FIG. 5. Pumpdown sequence for the combined Ion and NEG pump. 1 – Baking cycle at 300°C, 2 – Second baking cycle at 250°C, 3 – Third baking cycle at 250°C, 4 – NEG activation at 300°C and fourth baking cycle, 5 – Fifth baking cycle at 200°C

5. CONCLUSION

We have developed a new combined pump incorporating a modified sputter-ion-pump element for high throughput and higher pumping speed and a NEG module pump. The new design was based on simulation studies of the electrode geometry in a Penning discharge environment. Simulations indicated a higher probability for producing sputtered titanium neutrals, which are responsible for the pumping action. This was later confirmed in the pressure measurement experiments. A pump containing four identical modified electrodes and NEG module has been tested successfully yielding a net pumping speed of about 200 lps which is about 30% higher than the conventional sputter ion pump electrode geometry. The combined pump also reached an ultimate pressure of about 2.5 x 10^{-11} mbar and is in operation continuously.

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