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Characterization of the CEBAF 100 kV DC GaAs photoelectron gun vacuum system

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Abstract

A vacuum system with pressure in the low ultra-high vacuum (UHV) range is essential for long photocathode lifetimes in DC high voltage GaAs photoguns. A discrepancy between predicted and measured base pressure in the CEBAF photoguns motivated this study of outgassing rates of three 304 stainless steel chambers with different pretreatments and pump speed measurements of non-evaporable getter (NEG) pumps. Outgassing rates were measured using two independent techniques. Lower outgassing rates were achieved by electropolishing and vacuum firing the chamber. The second part of the paper describes NEG pump speed measurements as a function of pressure through the lower part of the UHV range. Measured NEG pump speed is high at pressures above 5×10^{-11} Torr, but may decrease at lower pressures depending on the interpretation of the data. The final section investigates the pump speed of a locally produced NEG coating applied to the vacuum chamber walls. These studies represent the first detailed vacuum measurements of CEBAF photogun vacuum chambers.

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Keywords: Polarized electron source; Photoinjector; Electron gun; Non-evaporable getter (NEG); Pump speed; Outgassing

1. Introduction

Electron beams with polarization up to 85% are used to probe nuclear structure at three independent experimental halls at the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (Jefferson Lab). The electron beams for each hall originate from the same gallium arsenide (GaAs) photocathode that sits in a 100 kV DC high voltage photogun [1]. Residual gasses in the gun chamber are ionized and degrade photoelectron yield (quantum efficiency, QE) when ions are accelerated into the photocathode, damaging the crystal structure or sputtering away the chemicals used to create the negative electron affinity condition.

Photocathode operational lifetime falls as average beam current extracted from the photocathode rises. At lower currents ($<100\,\mu$A), the photogun can operate uninterrupted for months before the QE and laser power are insufficient to provide the required beam. At high currents, the gun can provide uninterrupted beam for one to two weeks before the focused laser beam must be moved to a new location on the photocathode where the QE is still high. After exhausting the usable laser spot locations, the photocathode must be heated and reactivated in situ. This process restores photocathode QE and beam delivery can resume.

There are two identical photoguns at the CEBAF injector, with one providing beam to the accelerator and the other serving as a spare. The single-chamber design (Fig. 1a) requires venting to atmospheric pressure to replace the photocathode. After venting, the photogun must be baked to achieve a suitable vacuum condition by

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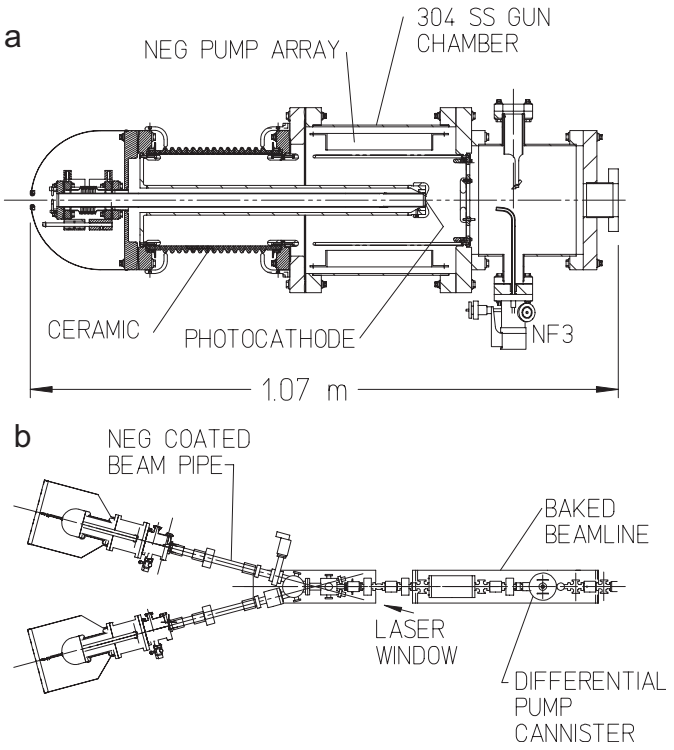

Fig. 1. (a) The CEBAF 100 kV DC high voltage GaAs polarized photogun and (b) the CEBAF 100 kV photoinjector.

removing adsorbed water vapor and activating the NEG pumps. Bakeouts are conducted using a thermally insulated oven and forced hot air to achieve a bake temperature of 250 °C with a typical duration of 30 h. Two types of bakes are performed: an initial bake with an inexpensive sacrificial photocathode following extensive vacuum work where the NEG modules have been exposed to atmosphere, and routine bakes following venting to dry nitrogen and installation of high polarization photocathode material. During the initial bake, maximum pressure, deduced from ion pump current, is $\sim 5 \times 10^{-6}$ Torr and QE of the sacrificial GaAs wafer is typically less than optimal. Routine changes of photocathode material take place by venting with dry nitrogen and using a glove bag with a dry nitrogen purge around the opened flange to prevent water vapor from entering the vacuum chamber. During bakeout, following a routine photocathode change, maximum pressure is typically 5×10^{-9} Torr and QE is high (up to 1% QE at the bandgap of 780 nm for high polarization superlattice material [2]).

Following a routine bakeout, the photocathode is activated to a negative electron affinity condition using Cs and an oxidant, NF_3 [3]. Activation occurs within the chamber, and the deposition of the chemicals introduces temporary vacuum excursions in the gun. The vacuum recovers within an hour following cathode activation and beam delivery takes place with the gun at base pressure.

The photoguns are connected to the accelerator using large bore (6.35 cm diameter) beampipes coated with NEG material (Fig. 1b). A 15° bend eliminates line of sight between the photogun and the accelerator beamline, and provides means to illuminate the photocathode at normal incidence, which is desirable for high polarization guns. The first 3 m of beamline downstream of the guns was baked to ~220 °C and a differential pump station isolates the baked beamline from the unbaked portion of the accelerator. These features of the injector ensure that the dominant gas load at the photoguns originates from the gun chamber outgassing rather than from the accelerator.

Ten NEG modules [4] surround the cathode/anode gap in the gun vacuum chamber providing extensive pumping of hydrogen gas, which is the dominant gas species in steel UHV systems [5]. A differential ion (DI) pump [6] located downstream of the anode pumps gasses that are poorly pumped by the NEG pumps, such as noble gasses and methane. There are also two GP100 NEG pumps [7] on ports downstream of the anode plate. An extractor gauge [8] and residual gas analyzer (RGA) [9] can be used to monitor pressure within the photogun. These hot filament gauges produce light and gas when energized, so they cannot be left powered during photogun operation since the light could be a source of uncontrolled and unpolarized photoemission and optimal vacuum conditions are achieved with the gauges off. Consequently, pressure is measured only during long accelerator maintenance periods. The best recorded pressures for the gun are shown in Fig. 2, as well as pressure values from test chambers also using NEG and DI pumps. The measured pressure in all chambers is significantly higher than predicted values, assuming typical outgassing rate for 304 SS of 1×10^{-12} Torr L/(s cm^2) and the vendor's stated NEG and DI pump speeds. These observations provided motivation for the outgassing and NEG pump speed studies presented here.

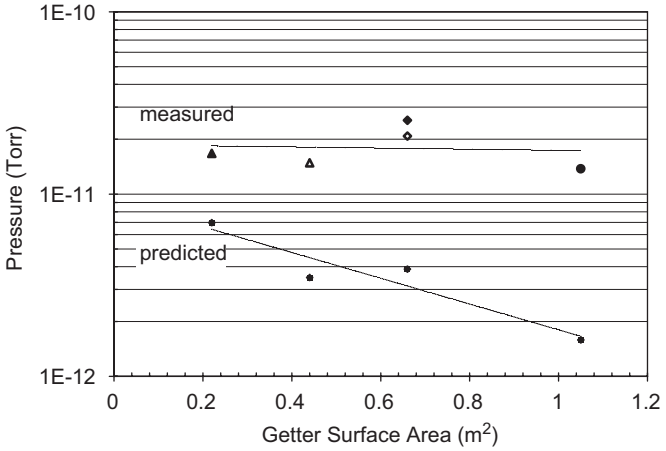

Fig. 2. Measured versus predicted pressure inside CEBAF photoguns and test stands. Closed and open triangles represent best pressure achieved in test stands with two and four fully activated SAES WP950 getter modules. Closed and open diamonds represent CEBAF photogun vacuum chambers, each with ten WP950 modules passively activated. Circle represents a new load-locked vacuum chamber with six fully activated SAES WP1250 modules. Lower data set represents values predicted from calculations based on chamber surface area, assuming an outgassing rate of 1×10^{-12} Torr L/s cm^2 and using manufacturers quoted pump speed.

Section 2 describes outgassing rate measurements for one of the original CEBAF photogun vacuum chambers, a new chamber constructed for these tests, and a chamber designed for a new load-locked gun. Section 3 describes NEG pump speed measurements of commercial pumps and in-house fabricated coatings.

2. Outgassing measurements

2.1. Introduction

The lowest pressure that can be achieved in any vacuum system depends on the amount of gas introduced into the system and the ability of the pumps to remove this gas. In a photogun, with no process gasses being introduced during beam delivery and virtually no gas coming from the beamline, the primary source of gas into the vacuum chamber is the outgassing of the chamber walls. Two methods [10], called throughput and accumulation, were used to study the outgassing rate from gun chambers constructed of the 304 stainless steel (SS).

2.2. Throughput method

The throughput method requires a test chamber and a pumping chamber separated by an orifice of known conductance. Gas from the test chamber is pumped only through the conductance-limited orifice. The outgassing rate, Q, can be determined using the equation $Q = C\Delta P/A$ where C is the conductance of the orifice, ΔP is the pressure difference across the orifice, and A the surface area of the test chamber.

The throughput method has the advantage that measurements can be made quickly. However, the method requires an accurate absolute pressure measurement. The Leybold extractor gauges used in these experiments were calibrated at the factory and assigned a calibration coefficient. Measured pressures in systems where hydrogen is the predominant gas must be scaled by a factor of 2.7 to account for the different ionization cross-section compared to nitrogen gas [11,12]. As with all hot-filament gauges, the gauge itself affects the vacuum within the test chamber, releasing gas at low pressures and pumping at higher pressures [13]. The conductance of the orifice was calculated from dimensions rather than modeled, because for this near-ideal thin flat orifice, the conductance calculation is typically quite accurate [14]. Uncertainty in the outgassing rate, dominated by uncertainty in pressure measurement, is estimated to be less than 0.2×10^{-12} Torr L/(s cm^2).

2.3. Accumulation measurement

For the accumulation method, the test chamber is isolated from all pumping and the pressure rise due to outgassing is monitored as a function of time, using a spinning rotor gauge (SRG) [15]. This direct reading gauge does not disturb the vacuum in the test chamber, unlike the hot-filament gauges. The outgassing rate, Q, can be calculated using the expression $Q = (\Delta P/\Delta t)(V/A)$ where ΔP is the change in pressure measured over time interval Δt, V is the volume of the test chamber, and A is the surface area of the chamber.

The disadvantage of the accumulation measurement is the long time required for accurate measurements. Accumulation times of $\sim$100 h are used to ensure that room temperature fluctuations are not influencing data. At the end of the accumulation period, the accumulated gas was analyzed by an RGA: over 95% of the accumulated gas is hydrogen, with CO and CO_2 seen as less prevalent gasses. This gas composition analysis was used to determine the correct accommodation coefficient in the SRG and the extractor gauge scaling factor.

2.4. Experimental setup

The outgassing test stand (see Fig. 3) consists of the three regions: the bake chamber, the test chamber and a pumping chamber, all separated by all-metal bakeable right-angle valves. The valve to the bake chamber is open during test chamber bakeout, to reduce the pressure in the test chamber to base pressure before starting the accumulation measurement, and when the accumulated gas is analyzed in the RGA. The bake chamber contains a 30 L/s ion pump and a NEG cartridge pump [16]. The test chamber, described below, has an extractor gauge and a spinning rotor gauge mounted on side ports. A 2 mm orifice with conductance of 0.8 L/s separates the chamber from an all-metal valve, a 30 L/s ion pump and an extractor gauge.

We studied three 304 SS chambers, one of which was electropolished and vacuum fired prior to baking. The two untreated chambers (called old 304 and new 304) are

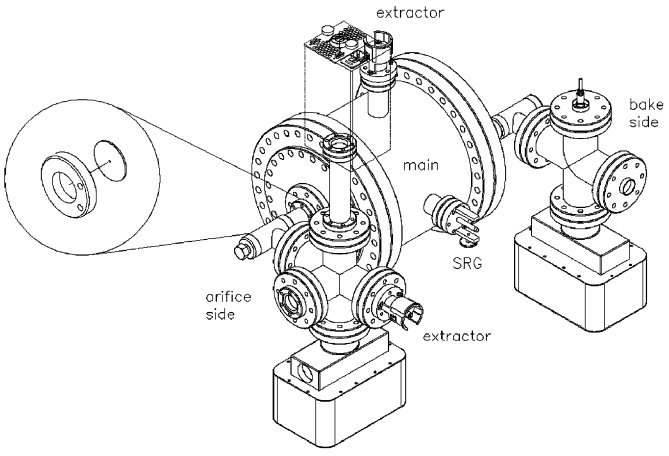

Fig. 3. Diagram of test stand used to measure outgassing rate of test chambers. The main chamber contains a spinning rotor gauge. The bake side of the chamber (right) contains an ion pump, NEG pump and RGA behind an all-metal right-angle valve. A conductance limiting orifice (shown in inset) separates the test chamber from an ion pump and an extractor gauge behind another all-metal right-angle valve.

standard CEBAF gun chambers, each with a volume of ~17 L and surface area of ~4000 cm^2. The new 304 chamber was manufactured for these tests, and the old 304 chamber was the original CEBAF gun chamber which had been baked at least 12 times before beginning these measurements. The electropolished chamber (labeled EP 304) was manufactured per AVS recommendations [17] and was larger with a volume of ~28 L and a surface area of 6500 cm^2, designed for a new load-locked gun. Chamber pretreatment and baking are summarized in Table 1.

All chambers have 25.4 cm diameter cylindrical bodies with 33.7 cm diameter ConFlat end flanges, 4.2 mm wall thickness and were manufactured to ultrahigh vacuum standards [18]. Metal was lubricated during machining using sulfur and silicone-free lubricants. Chambers were ultrasonically degreased in an alkaline cleaner [19], acetone and methanol, then rinsed in hot de-ionized water and blown dry with nitrogen gas. Parts were handled with clean-room vinyl gloves and all seals were made with ConFlat flanges and silver plated copper gaskets. The chambers were assembled and roughed down to 1×10^{-4} Torr using a Drytel [20] molecular drag pump. The ion pumps were turned on and the chamber was pumped overnight and then leak checked using the RGA. Following the bakeout, the chamber was again leak checked with the RGA and the filaments of the extractor gauges were degassed using the manufacturer's degas cycle (40 mA, 470 eV electron bombardment for 30 min) and allowed to stabilize for at least 12 h before any measurements were made.

2.5. Outgassing results and conclusions

The lowest measured outgassing rates for each chamber are listed in Table 1, which indicate reasonable (<30%) agreement between the two outgassing measurement techniques. The EP304 chamber provided the lowest outgassing rate of 8.9×10^{-13} Torr L/(s cm^2), though all chambers had outgassing rates near 1×10^{-12} Torr L/(s cm^2), which is a widely accepted value for untreated 304 SS baked at 250 °C [21]. Both new vacuum chambers exhibited considerably higher outgassing rates when first tested and required repeated bakeout to obtain the minimum values. Fig. 4 shows the outgassing rates as a function of the number of bakes (each 30 h at either 150 or 250 °C) for both the EP 304 and new 304 chambers. The data point shown along with the new 304 data at 13 bakes is the outgassing rate for the old 304 chamber. The electropolished chamber achieved an outgassing rate lower than the best measured outgassing from untreated 304 SS after only three bakes, making the electropolishing an expedient method of achieving a low outgassing rate compared to repeated bakes. Work to reduce the outgassing load from 304 SS chambers by coating the inner surface with NEG material will be discussed in Section 3.6.

3. Pump speed measurements

3.1. Introduction

The next course of study toward explaining the discrepancy between measured and calculated gun pressure was to measure hydrogen pump speed of NEG pumps as a function of pressure. We measured the hydrogen pump speeds after various activation protocols for commercial NEG pumps and pump speed after baking for an in-house NEG coated chamber. In all cases, two independent measurement techniques were used: a throughput method using hydrogen gas introduced through an orifice of known conductance and an ultimate pressure measurement.

Pump speed, S, is defined by $S = Q/P$ where Q represents the flow of gas into the system and P is pressure. For these pump speed measurements, three sources of hydrogen gas enter the test chambers as described in

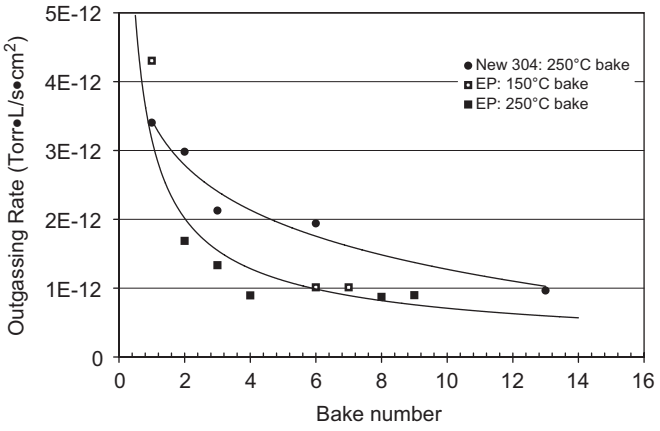

Fig. 4. Outgassing rate versus number of bakes (30 h, 150 or 250 °C) for new 304 and EP 304 chambers. The data point shown along with the new 304 data at 13 bakes is the outgassing rate for the old 304 chamber.

Table 1
Chamber preprocessing and baking parameters

Chamber	Preprocessing				In situ bake parameters		Outgassing rate (Torr L/(s cm^2))	
	t (h)	T (°C)	EP	Surface roughness (μm)	t (h)	T (°C)	Throughput	Accumulation
Old 304			No	3.7	400	250	9.7×10^{-13}	1×10^{-12}
New 304			No	3.7	180	250	1.9×10^{-12}	2.5×10^{-12}
EP 304	4	900	Yes	2.1	30 then 90	150 then 250		8.9×10^{-13}

Bake times given are the accumulated time from repeated bake cycles. Throughput data was not available for the EP 304 chamber.

Eq. (1). The first quantity in the numerator represents the controlled flow of hydrogen gas through an orifice, where C is the conductance of the orifice, P_{orf} and P_{main} represent pressure at the input and main chamber sides of the orifice, respectively, and the prime designation represents initial pressure before opening the valve to the hydrogen gas reservoir. The term Q_{wall} represents the flow of hydrogen gas into the chamber due to outgassing, which was measured as described in Section 2. The term Q_{gauge} represents the measured outgassing contribution from the extractor gauge [22]. This equation differs from that given in Ref. [23] by the inclusion of terms for gauge and wall outgassing, which are necessary when making pump speed measurements near the base pressure of the chamber.

$$S=\frac{C*\left\lfloor\left(P_{\mathrm{orf}}-P'_{\mathrm{orf}}\right)-\left(P_{\mathrm{main}}-P'_{\mathrm{main}}\right)\right\rfloor+Q_{\mathrm{wall}}+Q_{\mathrm{gauge}}}{P_{\mathrm{main}}}. \tag{1}$$

3.2. Throughput method

The throughput method of measuring pump speed introduces a conductance limited flow of hydrogen into the test chamber containing NEG material. Pump speed is calculated using Eq. (1), measuring the hydrogen partial pressure on either side of the orifice using residual gas analyzers. The benefit of this method is that the pump speed can be quickly measured over several orders of magnitude in pressure. Measurement accuracy is better at higher pressure as outgassing from the walls and gauges contributions are small and the uncertainties have less impact.

The pressure on the orifice side was raised in steps with approximately two measurements per decade. The pressure was allowed to equilibrate across the orifice for ~15 min per step, and measurements agree whether pressure was being raised or lowered in the chamber. During each series of measurements, the RGA's electron multiplier gain and voltage were cross-calibrated to the RGA's Faraday cup for hydrogen, which was internally calibrated with a current source within the device.

3.3. Ultimate pressure method

To measure pump speed at the lowest possible pressure in the chamber, a modification of the AVS recommended flowmeter method [23] was adopted, and is referred to here as the ultimate pressure method. At the ultimate pressure, the only source of gas into the chamber was the previously measured outgassing rate from the chamber walls. A Leybold extractor gauge was used for pressure measurement. Gauge outgassing was measured to be 4.4×10^{-10} Torr L/s, about 10% of the contribution from wall outgassing and consistent with values found in literature [22]. All extractor gauge readings were multiplied by a factor of 2.7 to account for the sensitivity of the gauge to hydrogen [11], and extractor gauge readings were measured with the RGA off to eliminate the gas load seen from the filament of the RGA. The ultimate pressure was measured with an all-metal right-angle valve open to a chamber containing an ion pump to avoid accumulation of gasses not pumped by the NEG pumps. Care was taken to ensure that the pressure measurement was stable following chamber bakeout or NEG pump activation. The extractor gauge was degassed by electron bombardment (30 min at 40 mA, 470 eV) the chamber was allowed to come to equilibrium for 7 days before measuring ultimate pressure. All measurements were made at room temperature, nominally 22 °C.

3.4. Experimental setup

The test stand that was used for outgassing studies was modified by inserting a fixture to hold commercial NEG modules near the chamber walls (Fig. 5). Either two or four SAES WP950 NEG modules were installed, with the modules electrically isolated using Macor ceramic stand-offs and connected to an electrical vacuum feed-through for activation via resistive heating of the substrate. A manual variable leak valve was added behind the orifice to introduce hydrogen gas. RGAs on either side of the orifice were used to determine the hydrogen flow rate across the orifice.

After installing the NEG pumps within the test chamber, the entire apparatus was baked for 30 h at 250 °C, which partially activated the NEG pumps and will be referred to as passive activation. An overboard differential ion pump, not shown in Fig. 5, provided primary pumping during the bakeout, while the ion pumps within the bake oven were also energized throughout the bake but provided little pumping at high temperatures. The valve to the overboard pump was closed once the system cooled to room temperature.

To achieve full activation of the NEG modules, 33 A of current was passed through the substrate heating the NEG

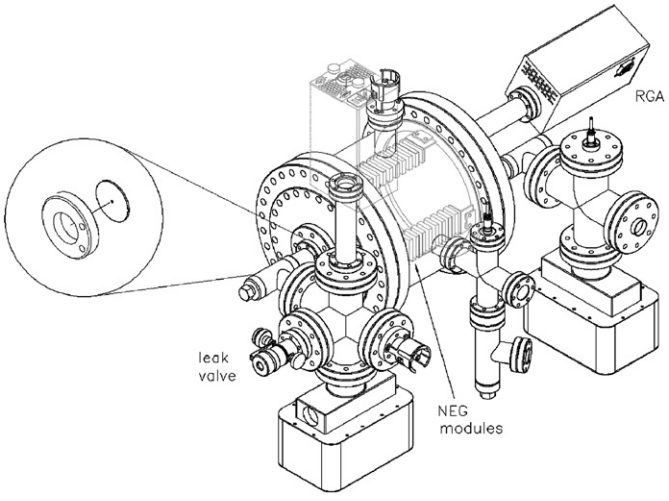

Fig. 5. Diagram of test stand used for NEG pump speed measurements. A hydrogen leak valve was added to the left side, either two or four NEG modules were installed, and an RGA was added to the main chamber.

modules to 400 °C for 90 min. Pumping during activation was provided by an ion pump and SAES GP100 cartridge NEG pump in the bake chamber, separated from the main chamber by a right-angle valve, and hydrogen partial pressure in the main chamber measured by the RGA reached a maximum pressure no more than 1×10^{-5} Torr. The extractor gauge was again degassed following NEG activation, and the system was allowed to equilibrate for one week before recording ultimate pressure.

3.5. Results: activation protocol

Throughput and ultimate pressure pump speed measurements for passive and full activation of one SAES WP950 NEG module are shown in Fig. 6. The benefit associated with full activation is evident at pressures greater than 3×10^{-11} Torr, with pump speed more than twice that obtained via passive activation during bakeout: 1200 L/s compared to 500 L/s. The hydrogen pump speed for a fully activated module claimed by the vendor is 430 L/s, which appears to be a conservative estimate. These measurements were made with four NEG modules installed in the chamber.

Fig. 6 also shows reduced pump speed at low pressure. The data follow the characteristic trend described by Eq. (2) [14,24], where pump speed drops to zero as a vacuum system reaches base pressure, P_o. Literature does not describe a mechanism that predicts reduced pumping speed at low pressures for NEG pumps. Reproducible pump speed measurement in successive trials indicates that the NEG modules in these tests were not saturated [25,26]. The low measured pump speeds near the system base pressure may be an artifact of the measurement technique, and the quantity being measured may be net gas removed from the system rather than pump speed, defined as the volumetric displacement $\Delta V/\Delta t$ [26]. Pump speed measurements are typically made at least an order of magnitude above base pressure of the chamber. At base pressure, the outgassing rate is in equilibrium with the pump speed with no net gas removed from the system, which may account for the apparent reduction of the pump speed.

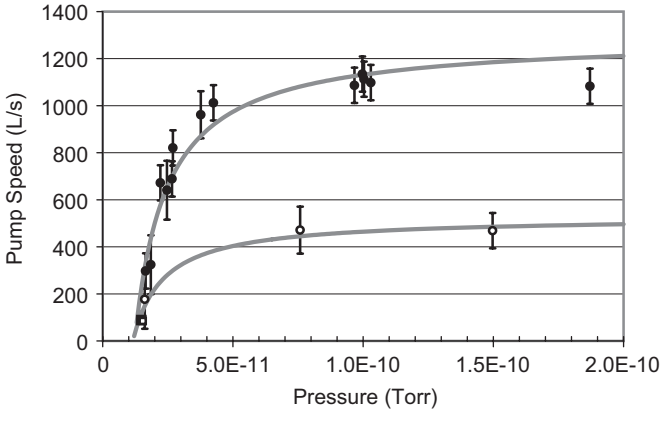

Fig. 6. Pump speed measurements versus pressure for a single SAES WP950 getter module. Data for full activation through resistive heating (closed circles for throughput method, closed square for ultimate pressure method) and passive activation via chamber bake (open circles for throughput method, open square for ultimate pressure method) are shown, with data fitted using Eq. (2).

$$S = S_{\max}\left(1 + \frac{P_o}{P}\right) \tag{2}$$

Another notable feature of Fig. 6 is that both NEG activation protocols produced nearly the same base pressure: $\sim 1.2 \times 10^{-11}$ Torr. Constant pump speed and outgassing throughout the pressure range implies pressure should be 1.3×10^{-12} Torr for fully activated NEG modules, and 3×10^{-12} Torr for passive activation, nearly an order of magnitude lower than the measured. One explanation is that the pressure measurements were not reliable below 5×10^{-11} Torr. Residual gas analyzers can be accurate to partial pressures of 1×10^{-13} Torr and extractor gauge X-ray limits are $\leqslant 1 \times 10^{-12}$ Torr. However, pressure measurements below 5×10^{-11} Torr are difficult and factors such as gauge calibration, proximity to the chamber walls, orientation and prior history can affect the accuracy of measurements [27], leading to artificially high pressure measurements and corresponding artificially low pump speed measurements.

Error analysis, again dominated by pressure measurement but also including errors in the conductance of the orifice, and uncertainty in the outgassing rate are shown by error bars in Fig. 6.

To determine if the NEG substrate material provided an additional outgassing component unaccounted for in calculations, pump speed measurements were made using two rather than four NEG modules installed in the chamber. As before, NEG modules provided ~1200 L/s pump speed when fully activated using resistive heating, and ~500 L/s for the passive activation during the chamber bakeout. Again, the base pressure in the chamber was nearly the same with two strips installed as with four at $\sim 1.2(\pm 0.2) \times 10^{-11}$ Torr, indicating possible gauge limitations. This test did not indicate the presence of an additional outgassing component, however, future tests might benefit from comparing conditions with wider pump module disparity, e.g., one versus five modules.

3.6. NEG coated chamber

Previous studies [28] have found that coating beampipes with getter material, commonly a combination of Ti, Zr, and V, is beneficial in providing distributed pumping within vacuum structures that are otherwise limited in their pumping capacity by conduction. The photoguns at Jefferson Lab are connected to the accelerator by a 1 m long pipe with 6.35 cm diameter. Significantly improved gun performance was noted when this vacuum pipe was coated with NEG material [29]. In an effort to reduce hydrogen outgassing from the surface and add more pumping to the system, an in-house system was developed

to coat a gun chamber with a NEG coating and measure the pump speed provided by this coating.

The EP 304 chamber was sputter coated with a Ti/V/Zr NEG coating by first installing an array of twisted Ti, Zr, and V wires (each 1 mm diameter) under tension in the center of the chamber. The chamber was baked at 150 °C for 48 h prior to starting the sputtering process. An argon glow discharge, with 25 mTorr argon and +550 V on the wires, was used to clean the chamber walls for 2 h [30]. After cleaning, the polarity of the voltage applied to the wires was reversed and the argon partial pressure was increased to 80 mTorr to start the sputter coating process [31]. Chamber temperature was held at 90 °C during the coating process. After 100 h, a coating with density $\pm 0.012\ \mathrm{g/cm^2}$ was produced.

The pump speed of the coating was measured using the same experimental setup as before, but since it is difficult to know the outgassing rate of the coated chamber, only the throughput technique was used. Pump speed of the entire coating (see Fig. 7) is up to 220 L/s at higher pressures, giving a modest pump speed per unit area of ± 0.02 L/s cm^2. Electron diffraction spectroscopy (EDS) analysis shows that the getter composition achieved is approximately 25% titanium, 50% vanadium and 25% zirconium (see Fig. 8). Surface profile analysis using scanning electron microscopy (SEM) indicates that the NEG surface has the desired textured and porous surface. Magnetron sputtering techniques, which coat more quickly and tend to have higher pump speed per unit area, are widely used commercially [32] and by other groups [33]. Similarly, the sputtering yield could be improved using krypton gas rather than argon [34], and both improvements may be implemented in the future if our needs merit the added complexity and cost.

4. Conclusion

We have undertaken an extensive investigation to determine the cause for the discrepancy between predicted and measured base pressure in the CEBAF photoguns. The outgassing rate of the chambers, at 8.9×10^{-13} Torr L/(s cm^2) for the EP304 chamber and 1×10^{-12} Torr L/(s cm^2) for the new 304 chamber, agrees with values found in literature. Electropolishing and vacuum firing the 304 stainless steel led to a lower ultimate outgassing rate and achieved this rate in fewer bake cycles.

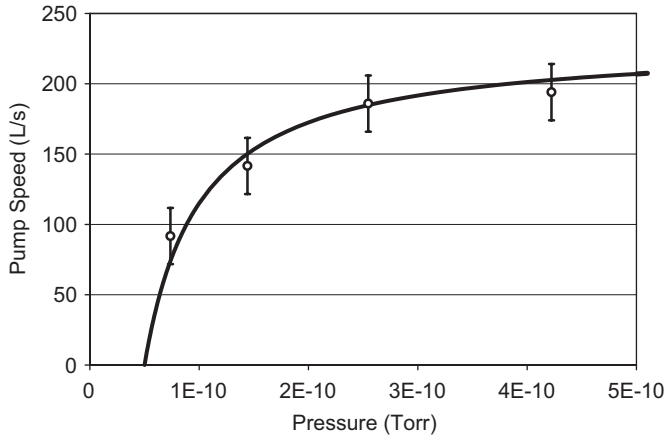

Fig. 7. Pump speed measurement of NEG coating, throughput analysis only.

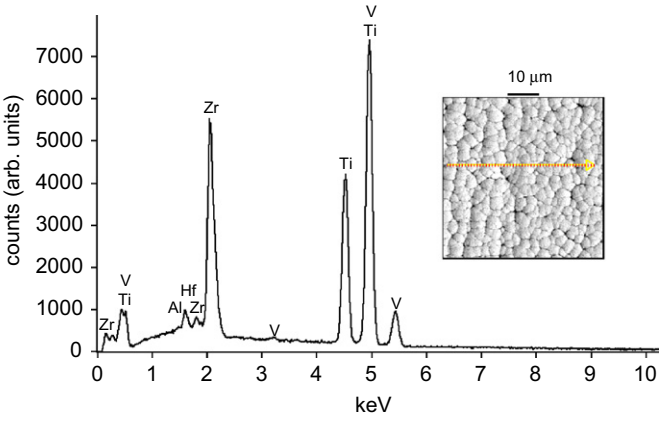

Fig. 8. EDS analysis of NEG coating composition showing 25% Ti, 50% V, 25% Zr. Inset figure is SEM image of surface morphology.

SAES WP950 NEG modules provide excellent pump speed at pressures greater than 5×10^{-11} Torr, and the full resistive heating activation provides more than twice the pump speed obtained through passive activation during a 250 °C bake (1150 versus 500 L/s per module). At pressures lower than 5×10^{-11} Torr, the measured pump speed decreases. At this time, we cannot determine if this is an actual decrease in pump speed, inability to accurately measure pressures below 1×10^{-11} Torr, or complications in measuring pump speed near the base pressure of the chamber. In-house fabricated NEG coatings add modest pumping capacity.

As a result of these vacuum studies, the high voltage chamber for a new CEBAF load locked 100 kV DC photoemission gun has been electropolished, vacuum fired, and NEG coated. Fully activated SAES getter modules and an ion pump provide pumping for the system. Initial testing has found a remarkably high photocathode charge lifetime during testing at average beam currents from 1 to 10 mA [35]. This new load-locked gun will be installed in CEBAF in 2007.

Future work will strive to achieve accurate pressure measurement, continue investigation of lower outgassing materials including 304 L or 316 LN [36], or steel/titanium alloys [37], and continued improvement of the procedure for activating the commercial NEG cartridges and applying the NEG films.

Acknowledgments

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