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OUTGASSING ANALYSIS DURING TRANSPORT FOR 14-m-LONG ARC-CELL VACUUM CHAMBERS OF THE TAIWAN PHOTON SOURCE

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Abstract

An outgassing analysis during transportation for the large, 14-m-long, ultra-high-vacuum aluminum arc-cell chambers of the Taiwan Photon Source (TPS) was performed using residual gas analysis (RGA). Each cell was baked to 150 °C in the laboratory to achieve ultra-high vacuum. Under pumping by primarily ion pumps (IP) and non-evaporable getter (NEG) pumps, the cells obtained pressures of 6.4×10^{-9} Pa on average, and the main residual gas was H_2. Here, vacuum pressure measurements and residual gas analyses were performed in situ while a cell chamber was being transported. It was found that the vibration of the arc-cell vacuum chamber caused the pressure to rise abruptly; in this case, the main outgassing gas was CH_4. Once the arc cell had been fully installed, the vacuum pressure gradually decreased to the original vacuum pressure because of the pumping effect of the ion gauges.

INTRODUCTION

Construction of the Taiwan Photon Source (TPS) began in 2010, and it is expected to begin operations in 2015. The TPS uses a medium-energy electron storage ring operating at 3 GeV. The vacuum chambers of the TPS storage ring are constructed of an aluminum (Al) alloy because of its high thermal conductivity, absence of magnetism, low residual radioactivity, and ease of machining [1]. The TPS contains 24 aluminum arc-cell vacuum chambers in the electron storage ring. Each arc-cell chamber is 14 m in length, including two straight chambers (S3 and S4) and two bending chambers (B1 and B2), as shown in Fig. 1. The straight chambers were constructed from extruded aluminum alloy and subjected to chemical cleaning in a sequential process [2]. The bending-chamber components were manufactured using computer numerical control (CNC) alcohol machining and cleaned with ozonated water [3-4]. Then, each chamber was assembled and jointed using tungsten inert gas (TIG) welding. A residual gas analyzer was installed in the arc-cell vacuum chamber to observe the outgassing of residual gases. According to previous research, [5] ozonated water effectively removes residual carbon from the surfaces of aluminum alloys, and the thermal outgassing rate of such alloys has been found to decrease to 6.7×10^{-12} $Pa\cdot m\cdot s^{-1}$ after baking. Each cell was assembled in the laboratory to create the closed vacuum vessel with two sector gate valves and then pumped by turbo pumps and dry pumps, followed by a 24-hour bakeout. After bakeout and 24 hours of pumping, pressures of less than 1.0×10^{-8} Pa were achieved at room temperature for all cells. Once the vacuum pressure of the 14-m-long aluminum vacuum chamber had achieved UHV levels, the four ion pumps were turned off to investigate the outgassing and to analyze the residual gas using the pressure build-up method. The TPS cell vacuum system is described in detail below.

For one cell aluminum vacuum chamber, which is 14 m in length, the components of the vacuum assembly include two sector gate valves (SGVs) (comb-type RF shield; VAT), two pumping gate valves, bellows, beam position monitors (BPMs), extractor ionization gauges (IGs) (IE514, with an IM 540 gauge controller; Oerlikon), non-evaporable getters (NEGs) (MK5-type SAES getters), ion pumps (IPs) (Starcell 200 $L\cdot s^{-1}$ for nitrogen; Agilent), crotch absorbers, photon stoppers, front-end valves, angle valves, a residual gas analyzer (RGA) (Transpector 2, H100M, used with the control software Tware 32; Inficon), turbomolecular pumps (TMPs) (V81M; Agilent, STP 451; Edwards), and dry pumps (Drytel 1025; Adixen). The vacuum components were assembled in a clean room (class 10,000) under controlled dust-level and humidity conditions to minimize the outgassing rate from the chamber's inner surfaces.

The RGA spectrum was continuously recorded during pumping. In all experiments in this study, the following species were recorded: m/z = 2, 4, 12, 13, 14, 15, 16, 18, 28, 32, 40, and 44, associated with H_2^+, He^+, C^+, CH^+, CH_2^+, CH_3^+, CH_4^+/O^+, H_2O^+, N_2^+/CO^+, O_2^+, Ar^+, and $CO2^+$, respectively. The current I that is reported here represents a RGA spectrum rather than a partial pressure. Although the partial pressure could not be calculated exactly, the predominant component of the residual gas could be inferred by referring to the manufacturer's instructions for the RGA.

This paper focuses on the types of gases produced with increasing vacuum pressure during the cell transportation. While the cell was transported, the ion pumps were turned off and the ion gauges and RGA spectrums were both recorded. It is observed what kinds of gases were responsible for the variation of vacuum pressure. After the arc cell had been fully installed, the variation of the vacuum pressure was continuously observed and the pumping mechanism was discussed.

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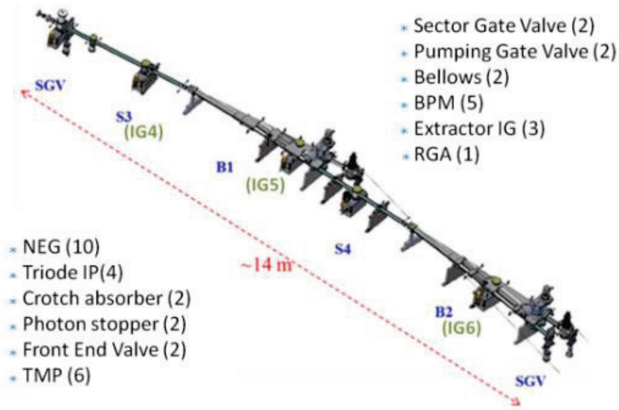

Figure 1: One 14-m-long aluminum arc cell of the TPS.

EXPERIMENTS

After assembly and bakeout, it was confirmed that all arc cells could achieve ultra-high-vacuum status; the lowest vacuum pressure that the arc cells could achieve in the assembling laboratory after bakeout was 6.4×10^{-9} Pa on average.

This paper was focused on the outgassing analysis of the 14 m long arc-cell vacuum chambers during transport. The speed of the transportation vehicle was less than 10 km/h. The transportation photos are shown in Figure 2. In our standard procedure, all flanges are tested for helium leakage prior to transport of an arc cell. The helium-leakage test for an arc cell is performed using the leak-detection mode of the RGA at a secondary electron multiplier voltage of 2500 V. After the arc cell passed the helium-leakage test, the four ion pumps were turned off. Since the ion pumps were switched off, the main pumping systems of arc cells included NEG pumps and extractor ion gauges. Next, the RGA spectrums were analyzed to find what types of gases produced during the transport process.

RESULTS AND DISCUSSION

The residual gas spectrum was recorded in prior to the transport time, shown in Figure 3. The residual gas inside the vacuum chamber of the cell includes H_2, CH_4, CO, and Ar.

As one arc cell transported from the assembly laboratory to the TPS tunnel, analyses of both the vacuum pressure and the residual gases were performed in situ, as shown in Figs. 4(a) and 4(b), respectively. The 14-m-long arc-cell vacuum chamber was mounted in custom-designed fixtures and suspended from a crane. Roughness of the road or speed bumps can lead to an abrupt increase in vacuum pressure. The residual gas that is primarily produced with such an increase in vacuum pressure is CH_4. This residual gas CH_4 may originate from the ion pumps, the stainless steel vacuum chamber, [6-7] or the NEG pumps [8].

The profiles of the vacuum pressure and the CH_4 signals over time were fitted to a first-order exponential decay equation to determine the time constants (τ), shown in table 1. The volume of a cell is approximately 0.5 m^3, based on an analysis tool (the SolidWorks software package). Therefore, the pumping speed (S) was estimated to be approximately 5×10^{-4} $m^3\cdot s^{-1}$. Previous investigations [9], [10] have demonstrated that the pumping speeds for ion gauges that are associated with N_2 are on the order of 1×10^{-5}-1×10^{-4} $m^3\cdot s^{-1}$, and the pumping speeds of all tested gauges have been observed to be higher for Ar than for N_2 [10]. In our case, the primary residual gases were H_2, CH_4, and Ar, and the average measured pumping speed was 6.9×10^{-4} $m^3\cdot s^{-1}$ for most of the cell extractor gauges associated with major inert gases in the 14 m-long cells [11]. When the 14-m-long arc-cell vacuum chamber was installed in the TPS tunnel and mounted using the vacuum chamber supports, the vacuum pressure gradually decreased to the original vacuum pressure without any pumping by the four ion pumps. It was concluded that the pumping effect was provided by the three ion gauges.

Figure 2: The RGA was installed during the cell transport.

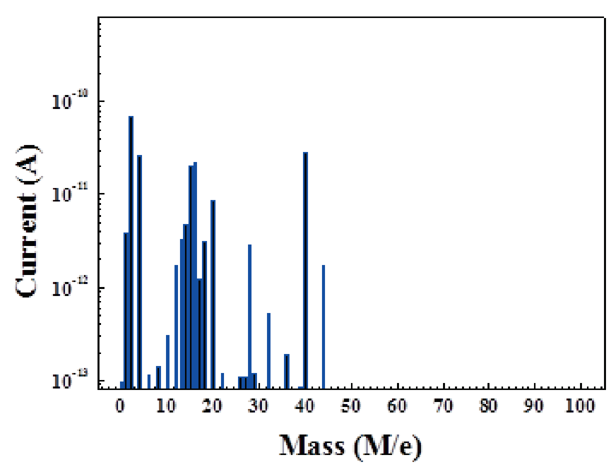

Figure 3: The RGA spectrum during the transport time.

Table 1: Estimated Time Constants for Mass 15, 16, Fitting by First-order Exponential Decay Equation.

	mass 15	mass 16
Time constant (τ)	929.56791	929.65288

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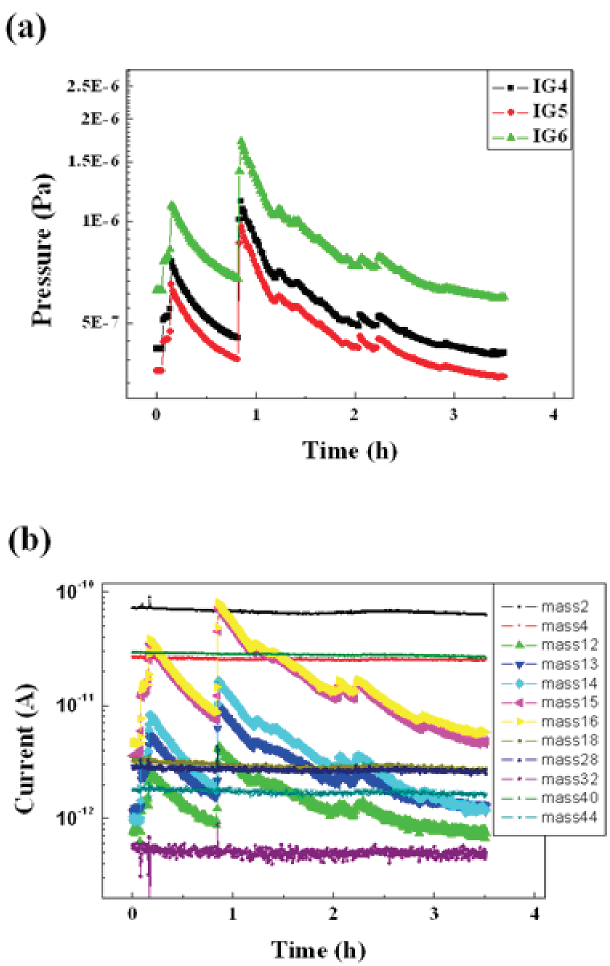

Figure 4: (a) The vacuum pressure and (b) the RGA performed as a cell was transported.

CONCLUSION

This paper primarily focused on the outgassing of a cell was recorded while the cell chamber was transported from our laboratory to the TPS tunnel. The outgassing analysis indicated that CH_4 was emitted as a result of the vibration of the arc cell. It was inferred that this outgassing of CH_4 may have originated in the ion pumps, the stainless steel vacuum chambers, or the NEG pumps. Following the final installation of the chamber, the vacuum pressure gradually decreased to the original vacuum pressure because of the pumping effect of the three ion gauges.

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