Monday Afternoon, November 6, 2023

Vacuum Technology Division
Room C120-122 - Session VT-MoA

Leaks, Flows, and Material Outgassing

Moderators: Giulia Lanza, SLAC National Accelerator Laboratory, **Chandra Romel**, Consultant

1:40pm **VT-MoA-1 Cesium Intercalation of Graphene: A 2D Protective Layer on Alkali Antimonide Photocathode*, Mengjia Gaowei,*** Brookhaven National Laboratory **INVITED**

Alkali antimonide photocathodes have wide applications in free-electron lasers and electron cooling. The short lifetime of alkali antimonide photocathodes necessitates frequent replacement of the photocathodes during a beam operation. Furthermore, exposure to mediocre vacuum causes loss of photocathode quantum efficiency due to the chemical reaction with residual gas molecules. Theoretical analyses have shown that covering an alkali antimonide photocathode with a monolayer graphene or hexagonal boron nitride protects it in a coarse vacuum environment due to the inhibition of chemical reactions with residual gas molecules. Alkali antimonide photocathodes require an ultra-high vacuum environment, and depositing a monolayer 2D material on it poses a serious challenge. In the present work, we have incorporated a novel method known as intercalation, in which alkali atoms pass through the defects of a graphene thin film to create a photocathode material underneath. Initially, Sb was deposited on a Si substrate, and a monolayer graphene was transferred on top of the Sb film. Heat cleaning around 550–600 °C effectively removed the Sb oxides, leaving metallic Sb underneath the graphene layer. Depositing Cs on top of a monolayer graphene enabled the intercalation process. Atomic force microscopy, Raman spectroscopy, x-ray photoelectron spectroscopy, low energy electron microscopy, and x-ray diffraction measurements were performed to evaluate photocathode formation underneath the monolayer graphene. Our analysis shows that Cs penetrated the graphene and reacted with Sb and formed Cs_3Sb.

2:20pm **VT-MoA-3 On Ground and In-Orbit Decontamination Strategies for Space Hardware*, Delphine Faye,*** Centre National d'Etudes Spatiales, France **INVITED**

Lessons learnt from the past have led to anticipating space equipment failures that may be caused by the presence of chemical contaminants resulting mainly from outgassing of polymer materials under vacuum[1].

Nowadays, when on-board instruments are becoming more and more sophisticated, when constraints are becoming more and more stringent in terms of quality and reliability for an extended mission duration, controlling both molecular and particulate contamination levels is a necessity and must be applied throughout the various phases of development and operation of a spacecraft. In order to maintain optimum performance of all equipment until the end of the mission, it is of paramount importance to mitigate the risks of degradation. This requires basic precautions not only in design and manufacturing but also and above all in integration and testing where a clean environment is highly recommended[2].

However, if there are very strict rules for selecting space materials, if thermal pre-treatments under ultra-high vacuum are performed at different stages of assembly, a residual outgassing potential of some materials often remains to be considered. As a result, undesirable matter may be deposited on sensitive surfaces and evolve depending on in-orbit environmental conditions. Thus decontamination strategies must be foreseen whether on ground or in orbit, at the very beginning of life or when anomaly occurs. To do this, there are conventional cleaning processes but interesting alternatives are also being studied e.g. for cleaning especially with non-contact techniques or for trapping contaminants under vacuum[3].

After a brief reminder of contamination issues for space sub-systems, this talk will present feedback from several use cases on specific projects. Different methodologies and associated techniques will be described as preventive or corrective actions as well as recent Research and Technologies developments[4].

references

1.A.C. Tribble, "fundamentals of contamination control", SPIE Press, 2000

2.ECSS-Q-70-01C, "Space Product Assurance, Cleanliness and contamination control", 2008

3.ECSS-Q-70-54C, "Space Product Assurance, Ultracleaning of flight hardware", 2017

4.D. Cheung, D. Faye, "Evaluation of decontamination processes adapted to large optical components" International Symposium on Contamination Control 2018, The Hague, Netherlands, 23-26/09/18

3:00pm **VT-MoA-5 Helium Permeation Through Zerodur Glass*, Sefer Avdiaj,*** University of Prishtina, Albania

In the pursuit of a new optical pressure standard [1], Ultra-Low Expansion (ULE) glass cavities were proposed as a means of measuring helium refractivity. However, the utilization of ULE glass gave rise to certain complications, with the pumping effect on helium being a significant issue [2]. As a solution, Zerodur glass was suggested as an alternative material for the cavity. To estimate the flow of helium gas through Zerodur glass, knowledge of the permeation constant K and the diffusion constant D is necessary. These parameters are related through the solubility S of helium in glass, as $K = S \cdot D$. In this research work, we experimentally measured the permeation of helium gas in Zerodur over a temperature range of 27 – 120 °C. Our results indicate that Zerodur has potential as a material for the new quantum standard of pressure.

3:20pm **VT-MoA-6 Improvement and Verification of Modified Knudsen Equation to Calculate the Gas Flow Rate through a Cylindrical Tube in Various Flow Regimes*, Hajime Yoshida,*** AIST, NMIJ, Japan

Calculating the gas flow rate through a cylindrical tube of known geometry might seem to be a simple problem but is actually rather complicated. This is because the characteristics of the gas flow depend on pressure, gas species, temperature, tube diameter, and tube length. There are at least six flow regimes to explain the characteristics of the gas flow, such as molecular flow, viscous laminar flow, turbulent flow, critical flow, subcritical flow, and their intermediates including slip flow.

In recent, we have developed the modified Knudsen equation which is applicable to the whole flow regime for arbitrary length of the tubes [1,2]. This equation has two advantages; one is that this equation is used without considering Knudsen number, Reynolds number, Mach number and the length-to-diameter ratio of tube, and the other is that it can be solved in straight forward without an iterative procedure although the other equations sometimes need it. This equation is especially useful when one does not know which flow regime the gas flow is in.

The solution of the modified Knudsen equation agreed with typical previous studies within 20 % - 30 %, but more study was still needed to confirm if this equation would be truly used for "whole" flow range. 70 literatures reported so far were compared with the modified Knudsen equation. The results reveal the conditions that the relatively large differences between them were observed. The author improved the modified Knudsen equation so that the agreements became within 20 % by introducing the effective length of turbulent flow. On the other hand, it was also found that significant differences around 50 % were observed at the high Reynolds number flow of short tubes. The improvement of modified Knudsen equation and comparison of the calculations of improved modified Knudsen equation with 70 literatures will be presented.

[1] H. Yoshida, Y. Takei and K. Arai, Vacuum and Surface Science 63 (2020) 373.

[2] H. Yoshida, M. Hirata, T. Hara, Y. Higuchi, Packag Technol Sci. 34 (2021) 557.

4:00pm **VT-MoA-8 Dirty Vacuums - To Contamination and Beyond*, Rod Boswell,*** *C. Charles, M. Davoodianidalik, J. Richmond, M. Shadwell,* Australian National University, Australia

With the recent global interest in space centred around the moon and Mars there is a real need for environmental test facilities that closely mimic lunar and Martian conditions. The challenges centre around two phenomena: vacuum and dust and both challenge mechanical sliding and rotating mechanisms, thermal control, space suits, interaction with charged particle and photon radiation.

Our group and Boswell Technologies has embarked on a number of projects aimed at investigating the basic physics and engineering problems posed by these environmental conditions and also to make available large dirty vacuum systems for research and industry to test systems in a dirty aggressive environment. In particular the lunar regolith comprises sharp edged dust with dimensions down to micrometres what can wreak havoc with moving systems especially human space suits where the dust apparently "burrows" into the material spurning all attempts to remove it. It is considered that photo-electrons generated by Lyman Alpha from the sun results in charged dust levitating from the surface and coating everything.

We have constructed a 3 metre diameter concrete dome and successfully vacuum tested it down to conditions close to that found on Mars. The design was inspired by habitats fabricated for those who, believing the arrival of imminent Armageddon, desired to protect themselves in these structures buried in the Australian sub-soil…….. Smaller vacuum systems of a few hundred litres are being used to approach lunar conditions with pressures around 10^{-6}Torr. For both chambers care needed to be taken with the structural integrity, dust and vacuum pumps and the onerous conditions of Work Health and Safety…….

A Lyman Alpha source has been developed and tested using rf energised hydrogen plasmas and magnesium fluoride windows. Initial tests have demonstrated the generation of photo-electrons by VUV radiation and absolute calibrations are being carried out with a commercially available VUV spectrometer and a VUV Deuterium source.

4:20pm **VT-MoA-9 Outgassing Studies of A36 Mild Steel***, James Fedchak, E. Newsome, D. Barker, S. Eckel, J. Scherschligt,* NIST-Gaithersburg

We present our most recent outgassing results for A36 mild steel. Mild or low-carbon steel is commonly used for structural applications and for piping. Modern secondary refining processes reduce the hydrogen content in mild steel, thus making these steels excellent candidates as low-outgassing materials for the construction of ultra-high vacuum chambers. Indeed, results from a 2016 paper by Park et al.[1] show H_2 outgassing rates for three Korean mild steels to be much lower than those from untreated stainless steel. Stainless steels such as 316L or 304L are commonly used for vacuum chamber construction, but for ultra-high vacuum or extreme-high vacuum applications, these steels must typically be heat-treated by vacuum-firing (nominally a 950 °C bake under vacuum for several hours) or subjected to a medium heat treatment (>400 °C bake in vacuum or air for several days) to achieve the required H_2 outgassing rate. However, untreated mild steel has the potential to achieve similar outgassing rates as heat-treated stainless steel. This could significantly impact the construction of future gravity wave detectors and other large vacuum systems because of the potential to reduce the cost compared to vacuum systems constructed of stainless steel which is both more expensive and must be heat-treated. We present results for both H_2 and H_2O outgassing. The former is measured after most of the water has been removed from the vacuum system by low-temperature bake (150 °C or less) with the system under vacuum. The water outgassing rate is measured during the system pump down prior to the baking the system to remove water, and is critical to many large vacuum system users as this affects the time and cost of commissioning.

[1] C. Park, T. Ha, and B. Cho, J. Vac. Sci. Technol. A Vacuum, Surfaces, Film. **34**, 021601 (2016).

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