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# Suppression of Ag deposition by Ar gas in mtorr range and its implication to mitigation of impurity deposition on first mirrors

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ABSTRACT

We observe that Ar gas confined in a tube maintained at a pressure higher than 10 mtorr by a baffled duct is very effective in minimizing the deposition of incoming Ag particles onto the surface of quartz crystal microbalance (QCM) in the tube. Ar gas is introduced into the tube and the gas flow to the main chamber is minimized by a baffled duct. In this way, the tube pressure of 10 mTorr or higher is achieved. The pressure is found to be enough to suppress the deposition of nearly 97% Ag particles onto the QCM in the tube. The suppression of the Ag deposition is successfully explained by reduced mean-free path at the high pressure in the tube. We propose that the present approach can be very promising in the mitigation of impurity particles on first mirrors in thermonuclear reactors.

## 1. Introduction

Noble gases such as He and Ar are chemically inert under an ambient condition and are often considered as spherical balls which undergo elastic collisions in gas phase. Such properties can be utilized in studying fundamental properties associated with gas-phase collision such as collisional cross-section and mean free path [1–3]. There are number of other applications that can utilize such properties of inert gases. One example can be found from a controlled growth of porous thin films since a collimated beam of inert gases at a certain angle with the substrate surface may deflect metal or oxide particles impinging onto the substrate in a perpendicular geometry under a proper condition [4,5]. Another application exploiting such properties of inert gases is found in the protection of optic mirrors from detrimental effects of impurity deposition [6,7].

For example, various kinds of optical diagnostic systems are used in International Thermonuclear Experimental Reactor (ITER) for reliable measurements of various parameters of a burning plasma in a reactive condition. They are necessary for the protection and control of such plasma systems [8–10]. However, the harsh environment inside the thermonuclear reactor can potentially generate reactive species which can put irrecoverable damages to the plasma-viewing optics of optical diagnostic systems such as first mirrors [7,11,12]. The first mirrors are the front-end elements of the plasma-viewing optical systems and are very susceptible to erosion and deposition of energetic atoms or reactive species from the plasma. The first mirrors made of refractory metals such as Mo may undergo erosion by the bombardment of energetic atoms [9]. Also, the energetic particles such as impurities, wall conditioning materials and the sputtered first wall materials may be deposited on the first mirrors. Such processes can degrade the optical properties of the mirror surface such as optical reflectivity and make the whole optical systems unsuitable for the relevant diagnostics [10,13–15]. Once being damaged, the recovery of the first mirrors may require costly and time-consuming cleaning operations of the mirrors using various techniques [15–20]. Thus, protection of the first mirrors from the impurities from the beginning would be the best solution if possible. For such a purpose, techniques employing the use of baffles and gas feeding in the vicinity of mirrors have attracted a great attention as a promising way to mitigate the impurity deposition [6,7,17].

In our earlier experiments, we determined the collisional cross-sections between a beam of noble gases (such as Ne, Ar and Xe) and a beam of Au atoms [1]. We observed that collisions between the

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two beams crossing each other at a perpendicular geometry could effectively deflect the trajectory of Au atoms away from a straight line. This results in a suppression of the Au deposition rate onto the surface of QCM positioned in the initial beam path of the Au atoms. The Au deposition rate was found to decrease linearly down to 50% as the noble gas flux was increased. Here, the collisional cross-section was found to increase in the order of Ne < Ar < Xe, which was explained from the van der Waals radii of noble gases.

With an application to the protection of the first mirrors from impurities in mind, a high cut-off ratio (e.g. > 0.9) of scattered impurities to those incoming would be desirable for a reliable protection of the mirror systems with a long-term stability. For the purpose, we designed a new experimental setup in which a high pressure (10 mtorr or higher) of noble gas was maintained along the beam path of impurities toward QCM, while the main chamber was maintained at an operating pressure in a high-vacuum (HV) range of $<10^{-4}$ torr. A high cut-off efficiency may be achieved at the pressure of 10 mTorr or higher since a travel length of 10–100 cm for any particles in a typical vacuum system is much longer than the mean free path of gas molecules (~5 mm) at the pressure; several tens of collisions along the beam path would deflect the beam away from a straight line regardless of the initial energy of the beam. But, no experimental study has been performed to confirm such characteristics under a realistic condition. It is a question whether such a condition of the high pressure difference can be maintained under a realistic experimental condition. It is also a question whether the high mitigation efficiency close to 100% can be obtained by this approach.

In this study, we performed an experiment under which a high pressure (>10 mTorr) was maintained at a low Ar flow rate into the tube where the surface under protection was positioned, while the main chamber pressure remained in a HV range. Ar was chosen since the higher collisional cross-section of Ar than that of He would give a better chance of observing the scattering of the impurity particles. Ag was chosen as a model impurity considering that the chemical inertness of Ag would allow a precise determination of Ag mass increase by QCM. A nearly 100% efficiency in protection of the surface has been realized at the tube pressure of a few tens mTorr.

## 2. Experimental details

All experiments were performed in a HV system with a turbomolecular pump (Seiko Seiki STP-H1000C, 1000 L/s) which could be pumped down to $10^{-7}$ Torr as schematically described in Fig. 1. The Ag beam was generated from a DC magnetron sputter gun with Ag target, which was attached to the chamber at a line-of-sight geometry to the tube (see Fig. 1). The sputter gun was operated by directly injecting Ar gas (>99.99%) onto the Ag target (>99.99%) while the applied DC power was controlled at 50–100 W. This approach allowed the main chamber pressure ($P_{chamber}$) maintained below ~$1 \times 10^{-6}$ Torr when the sputter gun was running. The Ag flux measured by a quartz crystal microbalance (QCM) (Inficon, SQM-160) at the distance of 50 cm from the target was in the range of 0.1–0.3 Å/s. Ar gas was introduced to the tube region (see Fig. 1) through a 20 μm pinhole to fill the tube with Ar for the purpose of suppressing the Ag deposition onto the QCM. In this way, the Ar flow rate into the tube was controlled in the range of $10^{15}$–$10^{18}$ Ar/s by adjusting the inlet Ar pressure between 0 and 1200 Torr. The tube was connected to the main chamber through a baffled duct with its inner diameter (I.D.) of 28 mm. Cone-shaped baffles with a hole (I.D. = 15 mm, O.D. = 28 mm, angle = 45°) were positioned inside the 180 mm-long tube for the purpose of suppressing the gas conductance into the chamber. Up to 8 pieces of baffles were stacked in the tube with an equal spacing of about 10 mm in the tube in the present study. This resulted in a high ratio (>100) of pressures between the tube and the main chamber; the tube pressure ($P_{tube}$) of 10 mTorr or higher was achieved while $P_{chamber}$ was around ~$10^{-5}$ Torr.

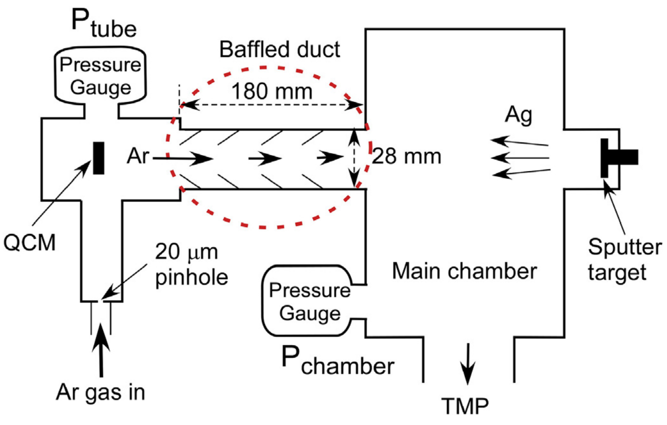

**Fig. 1.** Schematic diagram employed in this study for the evaluation on mitigation of impurity (Ag in this study) deposition on QCM by trapped inert gases such as Ar.

The pressure difference between the tube and the main chamber was systematically monitored while the Ar flow rate and the number of the cone-shaped baffles were varied. Also, the Ag deposition rate on the QCM was monitored to evaluate the effect of Ar gas confined in the tube on the mitigation of Ag deposition on the QCM.

## 3. Results and discussion

Fig. 2 shows changes in $P_{tube}$ and $P_{chamber}$ when the Ar flow rate into the tube is increased upto $3 \times 10^{18}$ Ar/s. We find that both pressures are raised in proportion to the Ar flow rate up to ~$1 \times 10^{18}$ Ar/s. Interestingly, the rise in $P_{chamber}$ (Fig. 2)(b) follows the same pattern regardless of the number of baffles used. However, $P_{tube}$ (Fig. 2)(a) increases in proportion to the number of baffles due to a reduced conductance (L/s) of the baffled duct; the Ar flow rate required to maintain the same $P_{tube}$ (e.g., 10 mtorr) decreases with increasing number of baffles. This results in a high pressure ratio between the tube and the chamber. As the Ar flow rate is raised above $1.5 \times 10^{18}$ Ar/s, both $P_{chamber}$ and $P_{tube}$ show changes in slope; the $P_{chamber}$ ($P_{tube}$) increases more (less) suggesting that the conductance through the baffled duct increases with increasing Ar flow rates.

Fig. 3 shows the ratio of $P_{tube}$ to $P_{chamber}$ with increasing Ar flow rates in (a) as well as against $P_{tube}$ in (b). The ratio is higher at lower Ar flow rates and decreases as the Ar flow rate increases. In addition, we find that an even higher ratio is achieved with increasing number of baffles. A high ratio of 200–300 is obtained when 8 pieces of baffles are introduced into the baffled duct. At the same Ar flow rates (e.g., $1 \times 10^{18}$ Ar/s), the ratio increases when the number of baffles increases. This effect is even more pronounced in Fig. 3(b). As the $P_{tube}$ increases, the ratio decreases. At the $P_{tube}$ of ~10 mTorr, the ratio seems to increase quite in proportion to the number of baffles. Due to reduced conductance with increasing number of baffles, lower Ar flow rates are sufficient to maintain such a high tube pressure. The $P_{tube}$ of ~10 mTorr or higher ensures a reduced mean free path ($\lambda$) for any molecules (or particles) inside the tube; the mean free path of ~5 mm or less can be estimated when the tube pressure is higher than 10 mTorr. The reduced mean free path would be beneficial in eliminating any impurity particles (Ag particles in our case) from being deposited on the QCM inside the tube