Analysis on the Sensitivity of the ASDEX Type Ionization Gauge in Mixed Radiator Gases of Divertor Simulators*)

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The sensitivity of the ASDEX type ionization gauge (AIG) in the mixture of argon and hydrogen gas, which is a candidate of radiator gas in the radiative divertor, is studied. In a small vacuum chamber, the sensitivity of the AIG is calibrated against capacitance-manometers, which have constant sensitivity for all gas species. Increase of the output signal AIG was observed in the mixture of 25% Ar and 75% H_2, although the actual sensitivity of the gauge against gas pressure is degraded. In the gas pressure larger than 0.8 Pa, the degradation of the sensitivity will be the main concern of the measurements. The results indicated that the molecular ions produced by the collision between the metastable argon atom and hydrogen molecule is the main cause of the change of the sensitivity. The change of sensitivity is analyzed by varying the collision energy of the electrons and the ionization cross-section of the ArH molecular ion is evaluated.

Keywords: divertor, gas measurement, ionization gauge, mixture gas, asdex gauge

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1. Introduction

Reduction of the heat load on divertor plate is one of the crucial issues in fusion research. In the concept of the radiative divertor, the heat load is mitigated by strong radiation of light enhanced by an injection of neutral, cooling gas into the divertor plasma. Although the injection of a cooling gas is effective for the heat-mitigation, proper control of the gas amount is necessary since the gas may harm the core plasma heating. In addition, the choice of gas species is important for the successful operations of radiative divertor. It is known that the power of radiative loss from a cooling gas varies with the gas species. In example, neon has low radiative power in the plasma of low electron temperature while argon has several orders higher radiative power in the plasma.

Linear plasma machines that have open magnetic field have been good devices to study interactions between hot plasma and radiator gases. In example, the large tandem mirror device, GAMMA 10/PDX has been utilized as divertor simulator and cooling experiments of plasma by using many species of gases are performed [1].

The flexibility of linear divertor simulator is quite advantageous for studies of cooling gases and even it will be possible to explore a new, challenging recipes of cooling gas such as mixture of multiple gases. For such study of cooling gases, however, a reliable method to measure the gas pressure in the divertor region is required. The ASDEX type ionization gauge (AIG) is a diagnostic system that is capable of measuring gas pressure of 10^{-2}~10^{1} Pa that is a range of typical divertor simulators. However, only a little is revealed about the characteristics of the AIG in such a mixed gas environment. Therefore, in this research, the sensitivity of the AIG in the mixture gas is measured and analyzed. In the experiment, the AIG test stand of a small vacuum vessel is used for the absolute calibration of the gauge sensitivity. In discussion, the change observed in the sensitivity of the AIG is discussed by considering metastable atoms and molecular ions.

2. ASDEX Type Ionization-Gauge

As shown in Fig. 1 (a), the AIG is consisted of filament, control grid, acceleration grid and ion collector plate aligned linearly [2]. The filament and the grids are aligned in the straight line. The linear geometry enables the AIG to be operated in a magnetic field without losing a linear dependence of its sensitivity on gas pressures.

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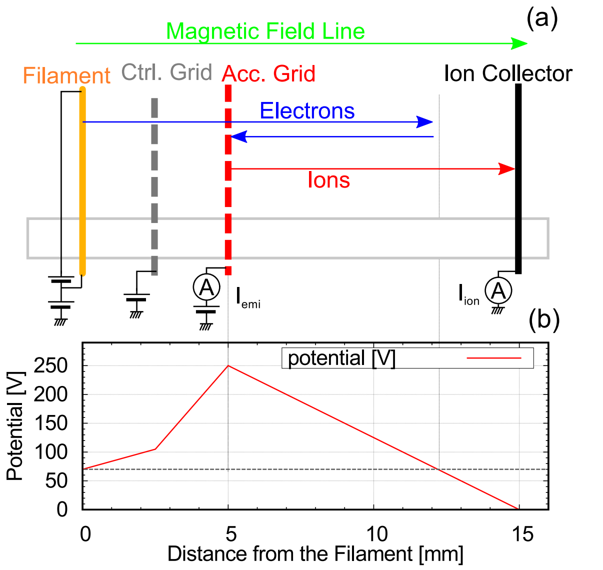

Fig. 1 (a) A schematic diagram of the AIG geometry with electrical circuits. (b) The spatial profile of the electrostatic potential applied to the filament and the grids.

The filament is made of tungsten and has thickness of 0.4 - 0.6 mm, which is much thicker than general ionization gauge such as the Bayard-Alpert gauge (BA gauge). The thick filament allows the AIG to endure the electromagnetic forces in experiments. The thermal electrons emitted from the filament is used for ionization of gas atoms or molecules. The electrons are accelerated the electric field applied for the filament and the grids. The number of thermal electron is monitored at the acceleration grid as the emission current I_{emi}.

When a gas atom is ionized by the thermal electrons, the ion is detected at the ion collector current I_{ion}, which is the measure of the amount of gas particle existing around the AIG. The gas pressure P around the AIG can be expressed as follows,

$$P = \frac{1}{S_{AIG}} \frac{I_{ion}}{(I_{emi} - I_{ion})}, \quad (1)$$

where S_{AIG} is the sensitivity of the AIG against the gas pressure. Since the gauge detects ionized charges, the sensitivity of the AIG is dominated by the cross-section of the electron-impact ionization of gas species [3]. The spatial profile of the electrostatic potential in a standard operation of the AIG is plotted in Fig. 1 (b). The standard range of the collision energy of the electron impact is 0 - 180 eV.

3. Experimental Setup

The test stand chamber is assembled in order to analyze the sensitivity of the AIG in a variety of gas species [4]. As shown in Fig. 2, two mass flow controllers (MFC), two capacitance manometers (CM), AIG, butterfly valve and vacuum pumps (TMP, RP) are installed to the test stand. Two different gases can be injected to the chamber at flow speeds controlled by MFCs individually. The gas pressure in the chamber is monitored by using the CMs. Here two CMs with different resolutions and ranges of gas pressure measurement are installed in order to cover wider range of gas pressure in the chamber. One CM is mainly responsible for the gas pressure around 10^{-2}~10^{-1}Pa, while the other CM measures the gas pressure around several Pa.

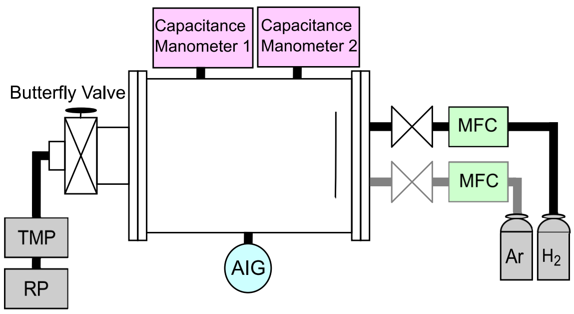

Fig. 2 A schematic drawing of the calibration test stand.

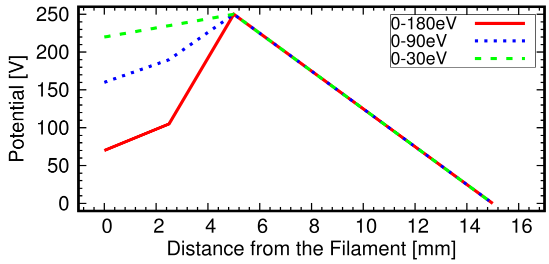

Fig. 3 Plots of the three types of electrostatic potentials applied in this research.

In the previous research, the change in the amount of I_{ion} in a mixed gas environments was observed [4]. Since the main cause of the change is considered to be the change of the ionization cross-section, the change of the AIG sensitivity can be varied by the collision energy of the electrons. Therefore, in the following experiments, three different profiles of the grid-potentials are used in order to change the rage of collision energy of the thermal electrons in the gauge. The electrostatic potentials of the filament and the control grid are raised to reduce the collision energy without changing the electric field between the acceleration grid and the ion collector (Fig. 3).

4. Experimental Results

4.1 Results in pure gases

By using the test-stand, the calibration of the AIG against pure gases are performed before the measurements in mixed gases. The result with hydrogen gas is plotted in Fig. 4 and the results with argon gas is plotted in Fig. 5. As can be seen in both plots, the AIG show good linear sensitivity against the gas pressure as predicted in the Eq. (1).

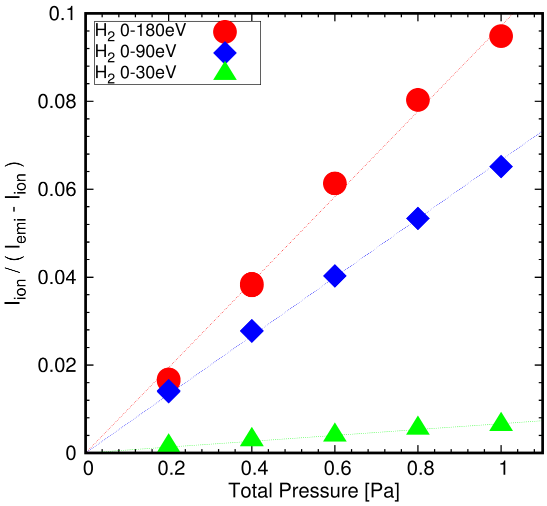

Fig. 4 The output signal of the AIG in pure hydrogen gas is plotted against the total gas pressure of the test stand. The straight lines indicate the fitting curve.

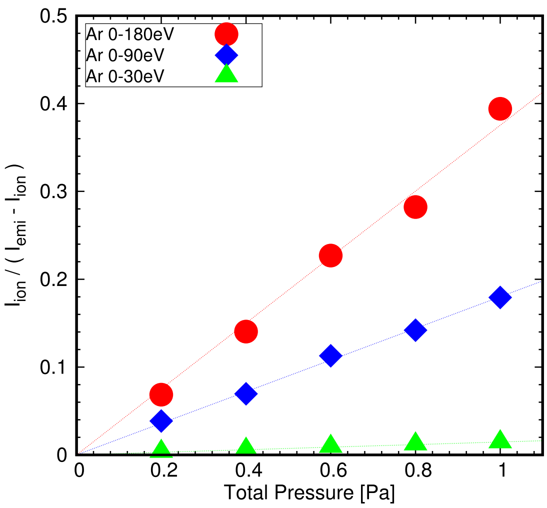

Fig. 5 The output signal of the AIG in pure argon gas is plotted against the total gas pressure of the test stand. The straight lines indicate the fitting curve.

Table 1 The sensitivity of the AIG in pure gases.

Collision Energy (eV)	0-180	0-90	0-30
H_2 100%	0.097	0.067	0.0067
Ar 100%	0.38	0.18	0.015

In addition, it can be observed that the sensitivity of the AIG is changed as the range of the collision energy is varied. From the slopes of the plots, the sensitivity of AIG against the gas, which corresponds to the S_{AIG} in Eq. (1) can be evaluated. The evaluated sensitivity of the AIG is tabulated in Table 1.

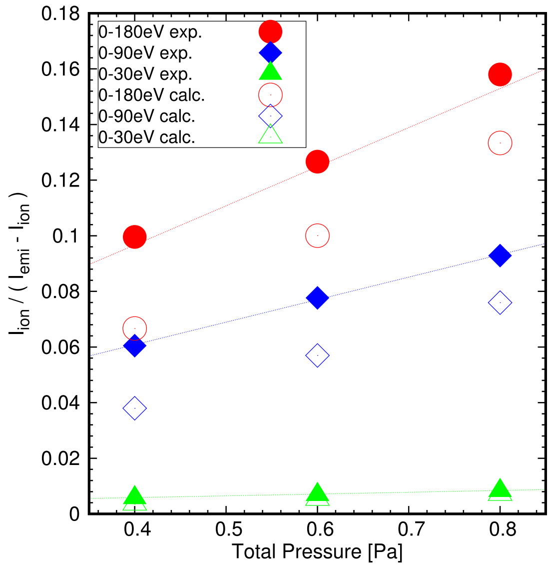

Fig. 6 The output signal of the AIG in mixture gas of 25% Ar and 75% H_2 is plotted against the total gas pressure. The theoretical values of the AIG signal are shown as the open points. The straight lines indicate the fitting curve.

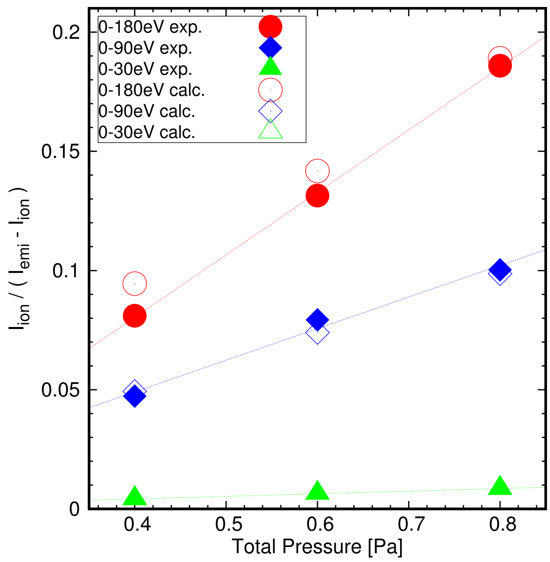

Fig. 7 The output signal of the AIG in mixture gas of 50% Ar and 50% H_2 is plotted against the total gas pressure. The theoretical values of the AIG signal calculated from Eq. (1) and the Table 1 is shown as the open plots. The straight lines indicate the fitting curve.

4.2 Results in mixed gases

Mixed gas environments are produced in the test-stand and the AIG is calibrated against the mixture gases. The rate of mixture is varied from three cases; the mixture rate for the first case is; 25% Ar with 75% H_2, for the second case is 50% Ar and 50% H_2, and for the third case is 75% of Ar and 25% of H_2.

The result with the first case is plotted in Fig. 6. The

Table 2 The sensitivity of the AIG in mixed gas.

Collision Energy (eV)	0-180	0-90	0-30
Ar 25% H_2 75%	0.15	0.081	0.0064
Ar 50% H_2 50%	0.26	0.13	0.011
Ar 75% H_2 25%	0.40	0.16	0.013

theoretical values of the AIG signal calculated from the Eq. (1) and the Table 1 is indicated by the open points. Here the AIG signal still has a linear dependency on the total gas pressure although the value of the experimental signal is higher than the calculated values. Therefore the increase of the gauge signal seen in the previous research is observed again. However, the slopes of the experimental points is less steep than that of the calculated points which indicates that the actual sensitivity of the AIG in the mixture condition is degraded. It is also notable that the experimental results are showing an offset of the signal.

The results in the second case are plotted in Fig. 7. Unlike the result in the 25% Ar case, no obvious difference between the experimental and calculated results were observed in 50% Ar and 75% Ar cases. The results indicate that the change of the gauge signal and the gauge sensitivity depends on the mixture rate of the mixed gases. The evaluated sensitivities of the AIG in the mixed gases are tabulated in Table 2.

5. Discussion

As the previous research suggested [5], existence of the metastable argon atom is considered to be the cause of the signal increase and the sensitivity degradation in the AIG. The followings are the collision reactions of metastable atoms.

$$\mathrm{Ar} + \mathrm{e} \longrightarrow \mathrm{Ar}^* + \mathrm{e}, \quad (2)$$

$$\mathrm{Ar}^* + \mathrm{H}_2 \longrightarrow \mathrm{ArH}^+ + \mathrm{H} + \mathrm{e}, \quad (3)$$

$$\mathrm{Ar}^* + \mathrm{H}_2 \longrightarrow \mathrm{Ar} + \mathrm{H}_2^+ + \mathrm{e}. \quad (4)$$

Assuming that the cross-section of these reactions are comparably large as the other ionization reactions of Ar or H_2, the degradation of the sensitivity can be explained as the degradation of the ratio (charge/atom), which corresponds to the ratio of (current/pressure). By assuming the degradation is only caused by the ArH^+ ion, the reaction cross-section of the ArH^+ becomes to be nearly a half of the electron-impact ionization cross-section of H_2.

On the other hand, the cause that the AIG signal showed an offset in 25% Ar case is unclear. Since the AIG signal keeps to have linear dependence on the gas pressure at 0.4 - 0.8 Pa, the reaction causing the offset should have a pressure point of saturation and only matters in the lower gas pressure range. The phenomena will be investigated with more detailed data in lower gas pressure range in future.

6. Summary

The sensitivity of the AIG in mixed gases was analyzed by using the test stand. It was found that the signal of the AIG is increased while the sensitivity of the AIG is degraded by the mixture 25% Ar and 75% H_2 case. The degradation of the sensitivity is considered to be caused by the increase of ArH^+, which has smaller (charge/atom) ratio in comparison with atomic ions like H^+. It can be assumed that the cross-section of ionization by the metastable argon has strong dependency on the mixing ratio of the gas and has nonlinear tendency in lower gas pressure such as 0.1 Pa. Since the typical gas pressure of the divertor simulation experiments will be performed with gas pressures around several Pa, the degradation of the AIG sensitivity in Ar 25% case will be the main concern of the measurements.

Acknowledgments

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