Gas Pressure Measurements in Pure and Mixed Gases at Around 1.0 Pa by Using ASDEX Type Fast Ionization Gauge[*)]

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Sensitivity of the ASDEX type fast ionization gauge (AIG) to several species of gases; hydrogen, nitrogen, noble gases and their mixtures have been investigated. Mixtures of hydrogen-helium and hydrogen-argon with total gas pressure from 0.2 Pa to 1.5 Pa are investigated in order to simulate the environment of divertor regions. It has been found that the observed output current of AIG in mixed gases are larger than the theoretical output current evaluated from the partial pressures and the sensitivities for pure gases. The enhancement of the AIG sensitivity observed in mixed gas conditions suggests that the ionization is enhanced due to the mixing of different gases. A qualitative analysis on the ionization reactions and their cross-sections has indicated that ionization related with metastable atoms of helium or argon is causing the changes in AIG sensitivity.

Keywords: ASDEX gauge, ionization gauge, gas pressure measurement, mixture gas

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1. Introduction

Measurement of neutral gas pressure in divertor region is crucial for an operation of a fusion reactor with radiator divertor scenario. Because of its fast time resolution and high durability against electromagnetic forces, the ASDEX type fast ionization gauge (AIG) is planned to be operated in the divertor region of fusion experimental device, ITER [1–4]. When the gauge is applied for a divertor region, it is expected that the gas which surrounds the gauge will be consisted of multiple species of gases such as hydrogen (or deuterium), helium and argon [5]. In such situations, the sensitivity of the AIG can vary with the rate of mixture gases and the evaluation of the total gas pressure requires careful treatments. Therefore, in this research, effects of mixed gas environments on the measurement of total gas pressure with the AIG are investigated by using the test stand chamber capable of simulating mixed gas conditions. Then, changes in AIG sensitivity are analyzed from the viewpoint of changes in the ionization cross sections of gases.

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2. ASDEX Type Fast Ionization Gauge

As shown in Fig. 1 (a), the AIG has filament, control grid, acceleration grid and ion collector plate aligned lin-

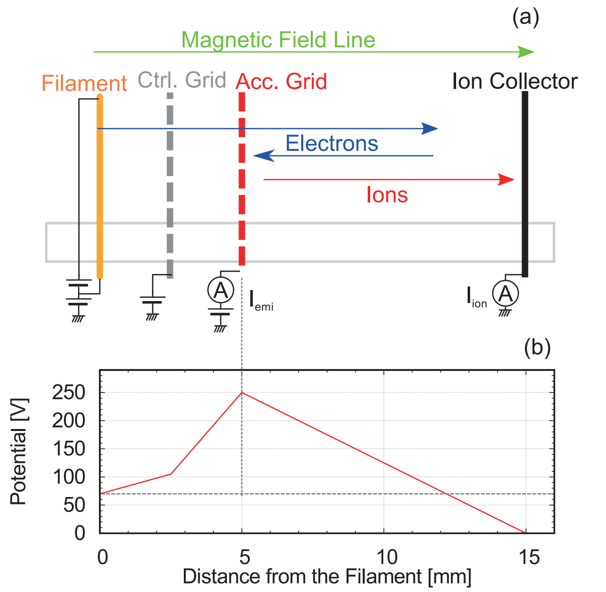

Fig. 1 (a) Schematic diagram and the electronics of the ASDEX type fast ionization gauge. (b) Spatial profile of the electrostatic potential in the ionization gauge.

early. The linear geometry of the gauge grids enables the AIG to be operated in a magnetic field without losing a linear dependence of its sensitivity on gas pressure. 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 have high durability against electromagnetic forces. In an operation, thermal electrons emitted from the filament is used for the ionization of gas atoms or molecules. Thermal electrons emitted from the filament are accelerated toward the control grid and the acceleration grid by the electric field between the filament and the grids. The number of thermal electrons are monitored at the acceleration grid as the emission current I_{emi}. When the gas is ionized by thermal electrons in between the acceleration grid and the collector, the ion is guided by the electric field and moves to the ion collector and therefore the ion current measured at the ion collector 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,

$$P = \frac{1}{A} \times \left(\frac{I_{\mathrm{ion}}}{I_{\mathrm{emi}} - I_{\mathrm{ion}}} \right), \tag{1}$$

where A is the sensitivity of the AIG on the gas species under measurement. In later sections of this paper, product of P and$A$ is referred as an output of the AIG.

From the spatial profile of the electrostatic potential plotted in Fig. 1 (b), it can be seen that ionization due to the thermal electrons mainly occur in the area spanning from 5 mm to 12 mm in the distance from the filament and the average collision energy of the electron is 90 eV.

3. Experimental Apparatus

In order to investigate the sensitivity of the AIG in pure gases and mixed gases, calibration experiments are performed in the test stand chamber. As shown in Fig. 2, the test stand chamber is equipped with two mass flow controllers (MFC), two capacitance manometers (CM), AIG, butterfly valve and vacuum pumps (TMP, RP). Two different gases can be injected to the chamber at flow speeds controlled separately by MFCs. 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. Since the sensitivity of CM is constant for all gas species, the gas pressure indicated by the CM is used for the calibration of the AIG. In order to assist the control of the gas pressure in the chamber, the vacuum pumping speed is changed by opening or closing the butterfly valve.

The AIG is designed to endure 3 T of magnetic field strength. However, the sensitivity of the AIG is affected and usually becomes larger in a magnetic field. Since the calibration chamber does not have magnetic field, the calibration in the magnetic field must be performed before actual measurements in devices with the magnetic field [4].

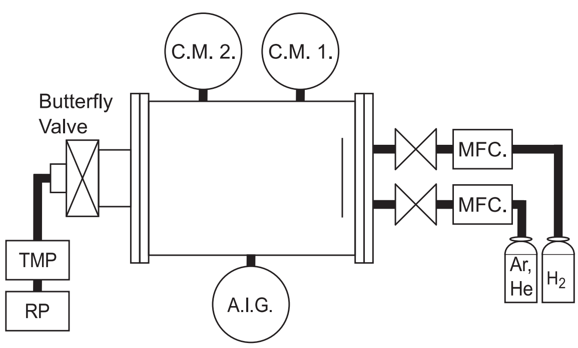

Fig. 2 The diagram of the calibration test stand chamber for the ASDEX type fast ionization gauge.

4. Experimental Results

4.1 Calibration for pure gases

By using the test stand chamber, the AIG has been calibrated for pure gases of hydrogen, nitrogen, helium, neon, argon, krypton and xenon. The result of calibration is summarized in Fig. 3. The linear dependence of the AIG output on gas pressure can be observed. In addition, it can be observed that the slope of the plot is different for each gas species. The sensitivity of the AIG in pure gases are evaluated from the slope of the plots. The difference of the slopes in the plot indicates that sensitivity of AIG depends on the species of the gas.

Since the ion is used as the measure of the gas pressure, the sensitivity of AIG has strong relationship with ionization cross-section. As tabulated in Table 1, the relative sensitivities of AIG and BA gauge in each gas species are very similar. This similarity of the sensitivity indicates that the ionization cross-section of the gas is determining the sensitivity of the ionization gauges. As shown in

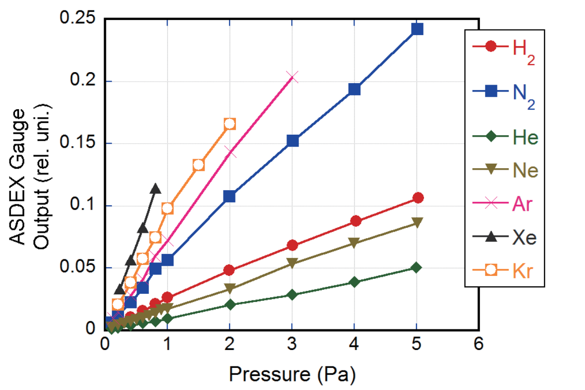

Fig. 3 The output of AIG obtained from the calibrations against many species of gas is plotted against the pressure monitored by capacitance manometers.

Table 1 Sensitivities of AIG and BA gauges [6] normalized for hydrogen gas are tabulated with electron impact ionization crosssections [7].

Gas	Relative Sensitivity (AIG)	Relative Sensitivity (BA gauge)	Relative Ionization Cross-Section
H_2	1	1	1
N_2	2.25	2.3	2.6
He	0.46	0.48	0.38
Ne	0.67	0.78	0.66
Ar	2.9	3.6	3.0
Kr	3.8	4.5	4.5
Xe	6.4	6.3	5.56

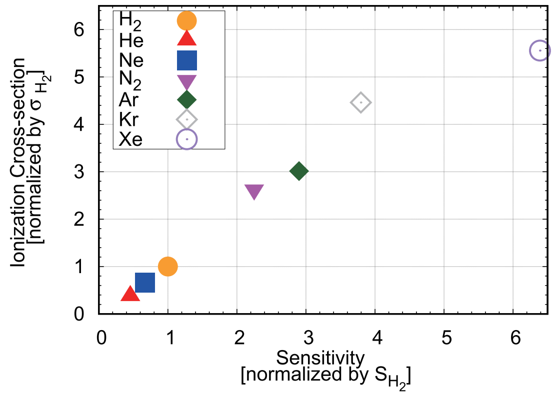

Fig. 4 Electron-impact ionization cross sections of gases normalized against hydrogen plotted against the relative sensitivities of the AIG.

Fig. 4, the ionization cross-sections and the sensitivity of AIG shows linear correlations.

Table 1. Sensitivities of AIG and BA gauges [6] normalized for hydrogen gas are tabulated with electron impact ionization cross-sections [7].

4.2 Calibration for hydrogen-helium mixture

The mixture of hydrogen and helium in fusion plasmas is inevitable because hydrogen isotopes are the fuels of fusion and helium is the product of fusion reactions.

For hydrogen and helium, mixed gas environments are simulated in the test stand chamber and the behavior of the AIG output has been investigated. The output values obtained from the experiments are compared with the output from theoretical calculations based on partial pressure. The specific equation for the calculation is,

$$output = P_{\mathrm{H2}}A_{\mathrm{H2}} + P_{\mathrm{He}}A_{\mathrm{He}}. \quad (2)$$

Where P_{H2} and P_{He} are the partial pressures of each gases, and A are the sensitivity of the AIG on each gases. As seen in Fig. 5, increase of the AIG output from the theoretical calculation, which is equivalent to the increase of the gauge sensitivity, has been observed in the experiments in

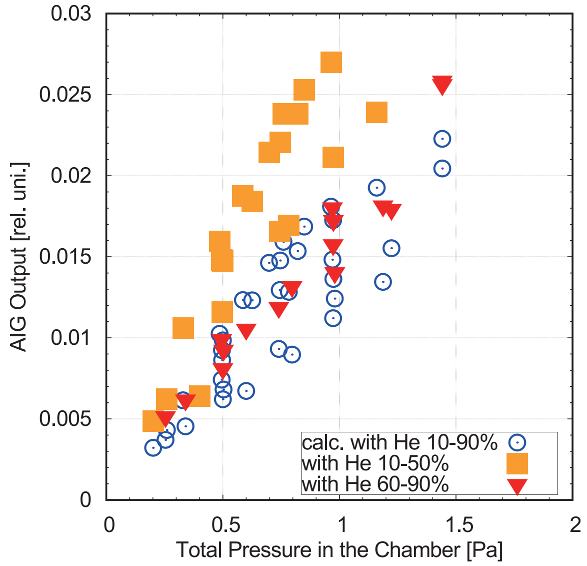

Fig. 5 The output of AIG experimentally observed and theoretically calculated in mixed gas of hydrogen and helium plotted against the total gas pressure.

the mixed gas of hydrogen and helium. Especially in hydrogen rich cases (He rate 10~50 %), large increase of the sensitivity has been observed and the sensitivity is approximately 1.6 times higher than that from the calculations.

4.3 Calibration for hydrogen-argon mixture

An injection of radiator gas such as argon in divertor region is necessary to mitigate the heat flux on divertor plates. Therefore, the combination of hydrogen and argon is also an important pair of gases for the monitoring of the gas pressure around divertor region. With the same procedures as the hydrogen-helium case, mixed gas environments of hydrogen-argon has been investigated. The results are summarized in Fig. 6 and here the increase of the AIG sensitivity has also been observed. However, in the case of hydrogen-argon mixture, the largest discrepancy between the experimental and theoretical results has been seen in argon rich (Ar rate 60 - 90 %) cases and the sensitivity has become 1.5~1.6 times larger than the calculations. On the other hand, for the cases of hydrogen rich conditions (Ar rate 10 - 50 %), the experimental results and the calculations agreed well.

5. Discussions

The increase in the AIG sensitivities in mixed gases can be considered as the enhancement of an ionization reactions in the AIG. From Fig. 1 (b), it is expected that the ion produced in the AIG is immediately pushed to the collector plate and disappears from the region with lifetime less than 10^{-8} seconds. Therefore the 2nd or higher ionization due to electron impacts on ions is not likely to be the cause of the changes in sensitivity, and ionizations due to collisions between neutral particles are the most plau-

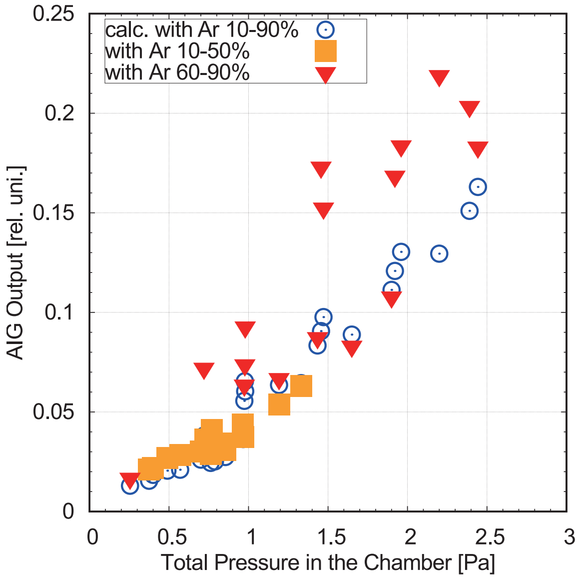

Fig. 6 The output of AIG experimentally obtained and theoretically calculated in mixed gas of hydrogen and argon plotted against the total gas pressure.

sible cause. For such ionization reactions, collision of the metastable state atoms (He^* or Ar^*) on a neutral particles is generally known. Also, the typical mean free path of neutral particles at pressure of 1.0 Pa is around 10^{-2} m, which is comparable to the scale of the AIG. Therefore in this section, ionization reactions related with metastable atoms and their cross-sections are discussed [8, 9].

For hydrogen-helium mixture case, excitation energy of the metastable helium (20.6 eV) is higher than the ionization energy of hydrogen atom (13.6 eV) and therefore ionizations due to penning transfer can occur. The reaction is expressed as following,

$$\mathrm{He}^* + \mathrm{H} \rightarrow \mathrm{He} + \mathrm{H}^+ + e. \tag{3}$$

The cross-section of this reaction is approximately 2 orders larger than these of electron impact ionizations of hydrogen molecule and helium atom. In addition, the metastable states of helium can be produced by one or two collision processes between thermal electrons and helium atom. Therefore as the mixed gas becomes more hydrogen rich, more hydrogen atom will be produced by the ionization of hydrogen molecules and will be ionized by metastable helium atoms.

For the case of hydrogen-argon mixture, penning transfer is not expected since the energy of the metastable argon atom (11.5 eV) is smaller than the ionization energy of hydrogen atom. However, the following reaction between the metastable argon atom and hydrogen molecule can enhance the ionization.

$$\mathrm{Ar}^* + \mathrm{H}_2 \rightarrow \mathrm{ArH}^+ + \mathrm{H} + e. \tag{4}$$

Since this reaction has cross-section in similar order of electron impact ionization of argon atom [10], it is expected that the sensitivity of AIG becomes off from the calculation as the number of metastable argon is increased.

The allowable concentration of helium in the core region of fusion plasma is said to be 10 % [11]. Also, it is reported that the concentration rate of argon in the core region should not exceed 0.8 % to avoid the degradation of plasma parameters [12]. These concentration rates of impurities can be higher in edge or divertor regions. Therefore it is will be beneficial to investigate the behavior of AIG in mixed gases such as hydrogen-helium or hydrogen-argon.

6. Summary

Sensitivity of the AIG in pure and mixed gases has been investigated. In pure gases, the sensitivity of the AIG has been found to be determined by the ionization cross-section of the gas species. However, in the mixed gas environments, the observed sensitivity tends to be higher than theoretical calculations because of the enhancement of ionizations by metastable atoms. The change in the AIG sensitivity in mixed gas is analyzed qualitatively from the viewpoints of ionization reaction related with metastable atoms. More precise measurements and quantitative analysis will be performed in future.

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