Multipole Gauge for Pressure Measurement of Extremely High Vacuum

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Abstract

Multipole gauge with a configuration of electro-static potentials similar with the Lafferty gauge is suggested to extend a possible pressure measurement to a lower regime. Since the confinement time of electrons emitted from the cathode is very much lengthened by the multipole configuration, the filament current required becomes very small. In addition, the ion collection current can be taken several times higher than that by the Lafferty gauge. Since the rate of the photoelectron emission is estimated 4 orders of magnitude smaller than that of the Lafferty gauge, the possible pressure measurement may be 4 orders of magnitude extended to a low pressure regime.

1. Introduction

In order to measure the pressure of extremely high vacuum, XHV[1-5], one possible approach is to lengthen the life time of the electrons emitted from the cathode and to make high the electron density, for the enhancement of electron-neutral ionization. In addition, the electron secondary emission from the ion collector, caused by the soft Xray due to the loss of electrons from the cathode, has to be suppressed since such the photoelectron emission limits the pressure measurement.

The Lafferty gauge is well known as the vacuum gauge based upon the above principle[6-10]. Recent experiments showed that the Lafferty gauge could detect the pressure much less than 10^{-9} Pa, e. g. XHV[11]. In the Lafferty gauge, the electrons emitted from the cathode are confined in the azimuthal direction due to the $\vec{E} \times \vec{B}$ drift motion. The electron density has to be limited by the electron self potential and/or the radial diffusion[10]. Since there is not a magnetic well for such the electron confinement in the Lafferty gauge even if the walls are negatively biased, the radial loss may be due to the Bohm like diffusion with a diffusivity of $D=kTe/16eB$, where B is the magnetic field, Te the electron temperature, k the Boltzmann constant and e the electron charge. It is quite possible to confine the electrons by the multipole field instead of the $\vec{E} \times \vec{B}$ drift motion, in the configuration of electro-static potential similar the Lafferty gauge with negatively biased walls. In this multipole gauge, the electrons emitted from the cathode may be able to be very well confined both by the strong magnetic well and the electro-static potential. Then, the emission current of the cathode may be taken lower than that of the Lafferty gauge. And that the electron density may be taken close to the value of the electro-static potential limit.

In the followings, the principle of the multipole gauge is described.

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2. Principle of Multipole Gauge

The multipole gauge consists of ion collector with a potential of $-\phi_c$, and a shield wall with a potential of $-\phi_s$, and the multipole fields produced by the array of permanent magnets outside of the shield wall (Fig. 1). The electrons can be generated by the cathode if the anode is placed in the vicinity of the cathode. In order to inject the electrons into the gauge chamber, the energy has to be higher than the wall potential, ϕ_s. In the Lafferty gauge, there is an axial magnetic field for the electron to rotate in the azimuthal direction. In the multipole gauge, the electrons emitted from the cathode are confined by the strong magnetic well and the negative electro-static potential. For the electron confinement and the quick collection of ions produced by electron-neutral collisions, the condition for the electro-static potentials, $-\phi_s < -\phi_c$, is required.

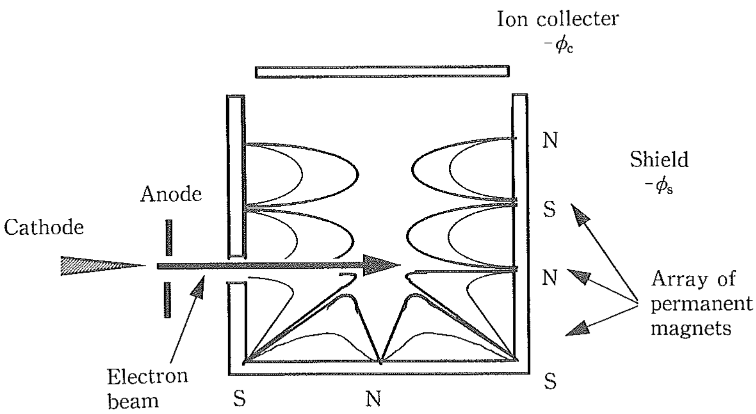

Fig. 1 Multipole gauge for pressure measurement of XHV.

The electron density balance in the multipole gauge is written as

$$V\frac{d}{dt}n_e = -\frac{n_e}{\tau_e}V + S_e, \qquad \cdots(1)$$

where $V=\pi a^2 b$ is the volume of the electron plasma, a the radius of the shield, b a half of the axial length of the shield, $S_e = I_f/e$ the electron number emitted per second, I_f the filament emission current and τ_e the electron confinement time. In the configuration of the multipole gauge, the radial diffusion of the electron may be similar to that of a tandem mirror or a long cusp[11]. Then, the conferment time may be expressed as

$$\tau_e \cong \tau_{ee}\frac{\Delta\phi}{T_e}e^{\Delta\phi/T_e}, \qquad \cdots(2)$$

where $\tau_{ee} = T_e^{3/2}/(3.2\times10^{-12} n_e \ln\Lambda)$ is the electron -electron collision time, $\ln\Lambda = \ln(1.55\times10^{13}\sqrt{T_e^{3/2}/n_e})$ the Coulomb logarithm, T_e the electron temperature and $\Delta\phi = \phi_s - \phi_e$ the potential difference between the shield and the electron plasma. The potential of the electron plasma, $-\phi_e$, is obtained by the Poisson's equation

$$\nabla^2\phi = -\frac{e}{\varepsilon_o} n_e, \qquad \cdots(3)$$

where ε_0 is the permittivity of free space.

Form Eq.(3) the potential of the electron plasma is roughly approximated as

$$-\phi_e \cong -\frac{e}{\varepsilon_o} a^2 n_e, \qquad \cdots(4)$$

In a steady state, the electron density becomes

$$n_e \frac{I_f/e}{\pi a^2 b} \tau_{ee} \frac{\Delta\phi}{T_e} e^{\Delta\phi/T_e}, \qquad \cdots(5)$$

For the electron confinement, there is a limit concerning the electrostatic potentials, e. g. ϕ_e and ϕ_s. The negative value of the value of the potential due to the electron plasma should not exceed the negative value of the shield potential, i. e.,

$$n_e < \frac{\varepsilon_o}{e a^2} \phi_s, \qquad \cdots(6)$$

For the condition of Eq.(6) to be satisfied, the electron density has to be adjusted according to Eq.(5). Compared a case of the Lafferty gauge with negatively biased walls, the electron density determined by Eq.(6) can be taken higher, e.g. close to the value of the potential limit. Since the electron confinement time is much longer than that of the Lafferty gauge, the filament current required can be taken small and then the photoelectron emission can be sufficiently reduced.

The ion collection current can be expressed by the following equation

$$I_c = e n_e \nu_{eo} V, \qquad \cdots(7)$$

where $\nu_{e0} = v_e n_0 \sigma$ is the electron-neutral collision frequency for ionization, n_0 the gas density, σ the ionization cross section, $v_e \sim \sqrt{KT_e/m_e}$ the electron velosity and m_e the electron mass.

3. Required Filament Current and Ion Collection Current of Multipole Gauge

For the calculation of the ion collection current, we assume the following parameters

$a = b = 0.05$ m,
$T_e = 20$ eV,
$\phi_s = 200$ V,
$\phi_c = 300$ V,
$\sigma = 10^{-20}$ m^2,

From Eq.(6), the maximum electron density, $n_{e,\,max}$, becomes 4.4×10^{12} m^{-3}. Since n_e has to be less than $n_{e,max}$, it is presumed that $n_e = 4\times10^{12}$ m^{-3}. Then, the potential difference, $\Delta\phi = \phi_s - \phi_e$, is 19.3 V. When $n_e = 4\times10^{12}$ m^{-3} and $T_e = 20$ eV, the filament current required is only 2.7×10^{-10} A. In the case of the Lafferty gauge, the electron conferment time, $\tau_e = a^2/(T_e/16B)$, is 1.6×10^{-4} s when $B = 0.08$ T. The electron confinement time of the multipole gauge is approximately 4 orders of magnitude longer, e. g., $\tau_e = 0.94$ s Thus, the required filament current can be 4 orders of magnitude lower.

This result means that the soft X ray limit can be extremely extended to the low pressure regime.

The ion collection current expressed in Eq.(7) becomes

$$I_c \cong 2 \times 10^{-3} P_o(Pa) \quad (A) \qquad \cdots(7)$$

where P_o is the pressure in Pa. In the case of the Lafferty gauge, the ion collection current should be several times lower than that of the multipole gauge since the electron density can not be taken so large.

4. Discussion and Summary

The multipole gauge for the pressure measurement of XHV has been suggested. In stead of the axial magnetic field in the Lafferty gauge, the multipole fields made by the array of the permanent magnets at the shield are employed for the confinement of the electron emitted from the cathode or the electron beam. Since the pressure of the electron plasma is very much lower than that of the magnetic pressure and that the magnetic well is formed to confine the electron population, the electron confinement time is taken very long, of order of second. Thus, the electrons emitted from the cathode, which radially diffuse to the shield wall, can be taken very small. Since the soft X-ray limit is due to the photoelectrons caused by this diffusion flow, the X-ray limit may shift to sufficiently low pressure regime. The ion collection current estimated is approximately 2 mA/Pa, which is several times larger than that of the Lafferty gauge.

It is known that the Lafferty gauge can detect the pressure of XHV below 10^{-9} Pa. If the present multiple gauge is employed, the pressure less than 10^{-13} Pa may be able to be detectable.

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