Pressure Measurement in XHV Region Using Nonresonant Multiphoton Ionization by Picosecond Pulsed Laser

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By means of nonresonant multiphoton ionization using a picosecond pulsed YAG laser, pressure measurement for H_2 , CO and CO_2 gases was carried out in the XHV pressure range. It was experimentally verified that pressure measurement was possible in the range of 10^{-11} Pa, and this pressure measurement method had pressure sensitivity of the same order of magnitude for the three molecules.

1. Introduction

A great obstacle to the pressure measurement in the XHV region by means of nonresonant multiphoton ionization using lasers has been noise. In the case of excimer lasers, the scattered laser light produces noise.¹⁾ Although this noise is significantly large, it can be removed by properly designing an ion-detection head.²⁾ However, other noise of unknown origin still remains. For this reason, it had until recently possible only to measure pressures to 7×10^{-10} Pa by means of the excimer laser.²⁾

Then, a picosecond pulsed laser was used for the purpose of increasing the ionization probability of molecules. As expected, saturation of ionization was realized for H_2 , CO, CO_2 , and Xe by means of nonresonant multiphoton ionization.^{3,4)} In addition, use of the picosecond pulsed laser was found to bring an unexpected advantage in that the noise due to scattered laser light was not generated.⁵⁾ This fact enabled us to use an ion-detection head with a much simpler structure, compared with that in the case of excimer lasers.

In the early stage of the experiment, however, noise similar to that in the excimer laser still remained. After some experiments, it was found that the noise seemed to result from photonstimulated desorption of ions at the view ports of the vacuum chamber, and could almost be removed through laser irradiation for about one hour at a repetition frequency of 10 Hz. As a result, pressure measurements in the 10^{-11} Pa range for H_2 , and in the 10^{-12} Pa range for Xe were realized.⁶⁾

In this paper, other results for H_2 , and results for CO and CO_2 will be represented.

2. Measurement System and Method

The measurement system has already been described in Ref. 6. The second harmonics of a picosecond pulsed YAG laser (Continuum PY61C) was used. Its wavelength and pulse energy are 532 nm (2.33 eV) and about 30 mJ/pulse, respectively. The repetition frequency of the laser was 10 Hz in the present experiments. The laser light was focused into the center of the ionization box of an ion-detection head through a lens with a focal length of 250 mm and then the view port of the vacuum system. Ions generated in the focused region (ionization space) were led into an electron multiplier (Channeltron) under an applied voltage of +10 V, and were charge-amplified with a gain of about 10^6 (at -2.5 kV).

A preamplifier (Ortec 9305) with a rapid response was combined with the collector electrode of the multiplier. The generated ions produced a series of voltage pulses at the output of the preamplifier. Each pulse corresponds to a single ion. This ion-detection system can produce a pulse with the peak value of a few 100 mV for one incident ion. Therefore, by counting the number of pulses with a pulse counter (SRS SR400), it was possible to determine the number of laser-generated ions precisely.

The distance between the ionization space and the multiplier is about 1 cm. Thus, the time of flight differs with the mass of the ion. Therefore, by setting the gating of the pulse counter at the appropriate time interval, one can selectively count

Fig. 1 Pressure measurement by means of an Extractor gauge (horizontal axis) and the nonresonant multiphoton ionization (vertical axis) for H_2 . The collector current of the Extractor gauge was directly measured by a small-current ammeter.

the number of ions with any mass.

Pressure in the vacuum system was monitored by an Extractor gauge (Leybold IE514). However, we obtained pressure values by directly measuring the collector current of the Extractor gauge with a precise small-current ammeter (Keithley 617).

Sample gases were introduced into the vacuum chamber through two variable leak valves. By keeping the pressure between the two valves at 10^{-1} Pa to 10^{-5} Pa, it was possible to control the pressure in the XHV range.

3. Experimental Results and Discussion

The vacuum system used can realize lower pressures than the limit of pressure measurement of the Extractor gauge.⁷⁾ The pressure measurement for H_2 gas was carried out at such a low background pressure. Figure 1 shows the result. The horizontal axis represents the collector current of the Extractor gauge. A collector current of 10 fA (1×10^{-14} A) corresponds to 1×10^{-10} Pa. The vertical axis represents the count of pulses per 1000 laser shots, which is equal to the number of generated ions.

As seen in Fig. 1, the Extractor gauge shows the measurement limit at about 2.3×10^{-10} Pa, and has no pressure sensitivity below this pressure. On the other hand, the count of pulses continues to vary below this value of pressure; namely the method of pressure measurement by means of this multiphoton ionization with the picosecond laser still has pressure sensitivity at lower pressures than the

Fig. 2 Pressure measurement for CO gas. The horizontal axis represents the total pressure measured with the Extractor gauge, and the vertical axis the CO partial pressure measured by the nonresonant multiphoton ionization.

measurement limit of the Extractor gauge. In Ref. 6 we discussed how this method had a linearity for pressure measurement even at such low pressures. Therefore, Fig. 1 shows that this method of pressure measurement can measure pressures in the range of 10^{-11} Pa. These results are in agreement with the previously reported result.⁶⁾

As seen in Fig. 1, at pressures over 1×10^{-8} Pa, the linearity of this method for the pressure measurement begins to degrade. Such a tendency was also observed in the case of other gases. The authors guess that is because, as the number of pulses increases, the pulse counter fails to count them precisely due to the overlapping of pulses.

As described in Ref. 6, the combination of the Extractor gauge and the small-current ammeter enables us to measure pressure change on the order of 10^{-11} Pa at a pressure in the range of 10^{-10} Pa. Introducing CO gas into the vacuum chamber from the background pressure of 4×10^{-10} Pa (40 fA), the authors measured the total pressure with the Extractor gauge, and setting the gating of the pulse counter between $2.2 \mu\text{s}$ and $3.2 \mu\text{s}$, the partial pressure was measured by the laser ionization method. The result is shown in Fig. 2. The horizontal axis represents the total pressure (collector current) measured with the combination of the Extractor gauge and the ammeter. The vertical axis represents the count of pulses within the gating time, that is, between $2.2 \mu\text{s}$ and $3.2 \mu\text{s}$, which corresponds to the CO partial pressure.

Fig. 3 Pressure measurement for CO gas. The horizontal axis represents the CO partial pressure measured by the combination of the Extractor gauge and a small current ammeter.

The CO partial pressure measured with the Extractor gauge can be estimated by subtracting from the measured pressure the background pressure excluding the CO partial pressure, which can be determined from the ratio of the total count of pulses to the CO count of pulses measured at the background pressure by the laser ionization method. Figure 3 was obtained in such a fashion. Now the horizontal axis represents the CO partial pressure obtained by the subtraction (transformed into Pa representatin with the sensitivity correction) measured with the Extractor gauge.

Figure 4 shows the result for CO₂ gas. The horizontal axis represents the CO₂ partial pressure measured with the Extractor gauge, which was estimated through the same process as that described above.

As seen in Figs. 1, 3 and 4, the pressure sensitivity for H₂, CO and CO₂ is of the same order of magnitude in this method of pressure measurement. When saturation of ionization is realized for nonresonant multiphoton ionization of some molecules, the pressure sensitivity should be approximately equal for those molecules. Therefore, the result obtained here is reasonable.

4. Conclusions

By means of nonresonant multiphoton ionization using a picosecond pulsed YAG laser, pressure measurement for H₂, CO and CO₂ was carried out

Fig. 4 Pressure measurement for CO₂. The horizontal axis and the vertical axis represent the CO₂ partial pressure measured by the Extractor gauge and the nonresonant multiphoton ionization, respectively.

in the XHV pressure region. Similarly to the previous results, it was found that the pressure measurement for H₂ and CO could be realized even in the range of 10⁻¹¹ Pa by this method. Also, the three molecules were found to have pressure sensitivity of the same order of magnitude in this method of pressure measurement.

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