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Quantitative Evaluation of Effect of Multiphoton Ionization in Laser Thomson Scattering Diagnostics

レーザートムソン散乱診断における多光子電離の影響の定量的評価

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Absolute efficiencies of multiphoton ionization due to frequency-doubled Nd:YAG laser (532nm) were determined for rare gases and some molecular gases (N_2, O_2, SF_6, CF_4), aiming at assessing its effect on laser Thomson scattering diagnostics. It was found that Xe has particularly a large multiphoton ionization efficiency and could easily produce more electrons than is present in usual plasmas.

1. Introduction

Laser Thomson scattering (LTS) is now a powerful tool for determining electron temperature and density for low-temperature plasmas. In some measurements, such as for obtaining information close to the wall or electrodes, very high spatial resolution is required, and the laser beam is tightly focused. To obtain sufficient signal intensity from a small scattering volume, one needs very high laser intensity in the focal region. This may bring about production of electrons in the scattering volume via multiphoton ionization, and thereby interfere the LTS measurements. In the present work, we evaluate absolute efficiencies of multiphoton ionization for rare gases and some molecular gases (N_2, O_2, SF_6, CF_4), to assess the effect of multiphoton ionization in LTS measurements.

2. Experimental procedure

The beam from a frequency-doubled Nd:YAG laser (532nm) was focused in the center between a parallel-plate probe (see Fig. 1) placed in a vacuum chamber. A great care was taken for the focal point to come exactly at the center. The probe consists of a main probe and dummy probes as shown in the figure, so that the main probe can collect the charge from a well-defined spatial volume. The probe was DC-biased at 15V and the probe signal was sent to a digital oscilloscope using a circuit shown in Fig. 2; the signal was averaged over many laser shots in the oscilloscope and further averaged in a PC to obtain a sufficient signal-to-noise ratio.

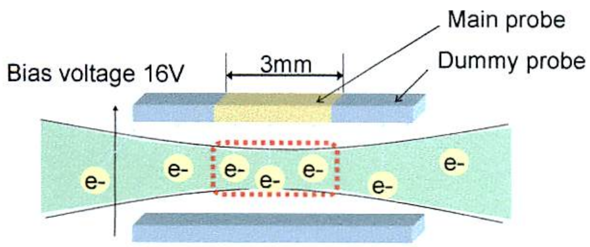

Fig. 1 Parallel-plate probe for collecting the charge generated via multiphoton ionization.

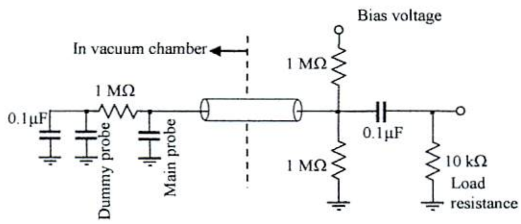

Fig. 2 Probe biasing and signal collection circuit.

An example of probe signals obtained in the case of SF_6 is shown in Fig. 3. The waveform depends on the gas species and the total amount of charge produced, because of different ion masses and different degree of space charge effect. In the particular case of Fig. 3, the space charge effect is small and the electron current and the ion current are observed separately because

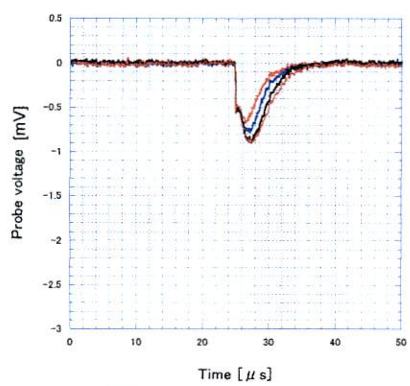

Fig. 3 Probe signal for SF_6 at a laser energy of 270mJ with varying SF_6 pressure (4-10Pa).

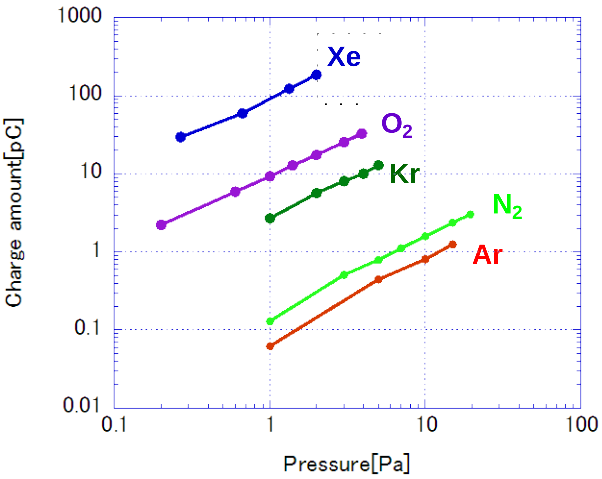

Fig. 4 Pressure dependence of the charge production due to multiphoton ionization at a laser energy of 250mJ

ion current develops gradually due to heavy mass of SF_6^+. In any case, the total amount of charge produced via multiphoton ionization is obtained by integrating the current signal such as in Fig. 3.

Figure 4 shows the dependence of the charge production on the gas pressure, indicating good linearity of the measurement.

Figure 5 shows the laser energy dependence of the charge production. The slope of the curves show saturation tendency in the high energy end. The slopes of the curves in the low energy end should give the number of photons necessary for ionizing ground-state atoms and molecules. The theoretical values (ionization potential / laser photon energy) are compared with experimental values (curve slope) in Table 1. As seen in the table, experimental values are somewhat smaller

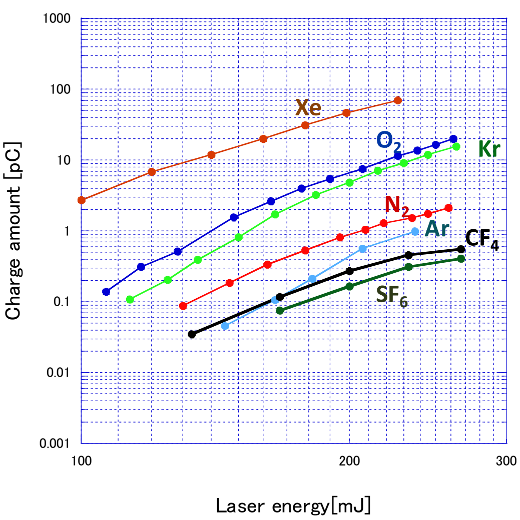

Fig. 5 Laser energy dependence of the charge production due to multiphoton ionization.

Table 1 Multiphoton ionization efficiency for various gases due to frequency-doubled Nd:YAG laser (532nm) at a laser energy of 200mJ, laser pulse width of 6ns, and laser beam diameter of 70μm. The number of laser photons necessary for ionizing the ground-state atoms and molecules are also shown.

	Inization Potential (eV)	Number of Necessary photons (theoret.)	Number of Necessary photons (exptl.)	Multiphoton inization efficiency
Ar	15.76	7(6.67)	7.0±0.4	9.7×10^{-5}
Kr	14.00	7(6.01)	7.3±0.5	3.7×10^{-3}
Xe	12.13	6(5.21)	6.5±0.3	1.2×10^{-1}
N_2	15.58	7(6.69)	5.8±0.5	2.7×10^{-4}
O_2	12.07	6(5.18)	7.1±0.8	9.8×10^{-3}
CF_4	15.9	7(6.82)	5.1±0.2	1.0×10^{-4}
SF_6	15.5	7(6.65)	4.2±0.1	7.7×10^{-5}

than the theoretical value for some gases.

In separate measurements, the laser beam profile in the focal region was carefully measured using a knife-edge method, and the laser pulse width was also measured using a high-speed photo diode. Based on these measurements multiphoton ionization efficiency was derived as shown in Table 1. The table indicates that in the case of Xe, multiphoton ionization would easily produce more electrons than is present in the plasma. The multiphoton efficiency at other energy may be estimated on the basis of Fig. 5