Characteristics of small-bore glow discharge positive columns in neon-nitrogen gas mixtures

N. Sasaki [(*)1], M. Nogaku [1], A. Yoshimura [1], Y. Uchida [2]

[1] *Sendai National College of Technology, 48 Nodayama, Medeshima-Shiote, Natori, 981-1239, Japan*
[2] *New Energy and Industrial Technology Development Organization, MUZA Kawasaki Central Tower, 1310 Omiya-cho, Saiwai-ku, Kawasaki, 212-8554, Japan*
(*) tb262@sendai-nct.ac.jp

Characteristics of small-bore Ne-N_2 mixture glow discharge positive columns are experimentally investigated with varying the mix ratio of N_2 and compared with the results reported previously with respect to Ne-Ar mixture discharges. The following are obtained: the pressure dependence of reduced electric field and the neutral gas temperature are strongly influenced by the addition of N_2 in contrast with Ne-Ar mixture, and except for the region of several Torr a decrease of electron temperature is observed with increasing the quantity of N_2.

Introduction

Many investigations of dc discharge positive column have been performed experimentally and theoretically so far; as a result, a lot of knowledge about various physical processes in the positive column has been obtained. However, studies of discharge of gas mixture with varying mix ratio are not so many compared with those of pure gases, although gas mixtures are frequently used in the present application field of plasma [1, 2].

By the way, the small-bore discharge systems are important because they are utilized in useful devices, such as gas lasers and display panels [3, 4]. Therefore it is expected to study them from various perspectives. Kaneda et al. have generated the rare gas plasmas in narrow-tube or capillary-tube with inner diameter of 0.5-3 mm, and studied the characteristics of plasma parameters in detail with varying working pressure and discharge current [5]. It has been reported that there is a considerable difference in the pressure dependence of electron temperature between light rare gases (He and Ne) and heavy rare gases (Ar, Kr and Xe). As mentioned above, it is also very interesting to estimate the effect of gas mixing on the plasma properties. So we have investigated the small-bore Ne-Ar gas mixture discharge positive columns [6], and obtained the experimental result that the addition of Ar to Ne gives an interesting effect on the pressure dependence of electron temperature.

In these days molecular gases are often used in plasma processing technique, and so it is important to study discharge plasmas of gas mixtures containing molecular gases. Nitrogen (N_2) is well known as a useful molecular gas in applications of plasma, and recently it has been investigated actively as a candidate of substitutes for an insulating gas of SF_6. Consequently, at this time we try to clarify the effects of addition of N_2 on characteristics of positive columns of Ne small-bore discharges comparing with the results obtained in Ne-Ar mixtures.

Experimental setup

The experiments are performed for the pressure range of 0.1-30 Torr, a fixed current of 10 mA and seven mix ratios of N_2 (0, 0.02, 0.1, 0.3, 1, 3 and 10 %) in a small-bore Pyrex glass tube [6]. Gas mixtures of premixed types are used as working gases and a small amount of gas flow from the anode to the cathode is allowed to prevent the accumulation of impurity in positive columns due to cathode sputtering. The plasma parameters and the neutral gas temperature are measured by two single probes and a thermocouple composed of thin chromel and alumel wires respectively.

Experimental results and discussion

In Fig. 1(a) the pressure dependences of the reduced electric field E/p_0 in Ne-N_2 mixtures are presented with the mix ratio of N_2 as a parameter. It is seen that E/p_0 decreases monotonously with pressure at the small mix ratios of N_2 (< 0.1 %), while with increasing N_2 the variation of E/p_0 shifts its direction from the declining tendency obtained in Ne at a certain value of pressure depending on the quantity of N_2, and then E/p_0 varies almost constant with pressure. This result in Ne-N_2 mixtures is very different from the case of Ne-Ar mixtures (Fig. 1(b)), because the variation of E/p_0 in the latter

does not show the distinct dependence on the mix ratio of Ar (< 10 %). As mentioned below, the behavior of E/p_0 is due to the fact that the axial electric field is strongly affected by N_2.

Fig. 2(a) shows the dependence of electron temperature T_e on pressure. As described in [6], the variation of T_e in Ne-N_2 mixture is also divided into two pressure regions separated each other at several Torr. In the lower pressure region, T_e decreases somewhat abruptly with pressure, while in another region T_e shows a slight dependence on pressure. Addition of N_2 gives rise to the decrease of T_e except for the region of several Torr where the influence of N_2 on T_e is not shown clearly.

The variations of neutral gas temperature T_g which is an important physical parameter to consider power dissipation processes in the positive column are given in Fig 2(b). From this figure, T_g begins to show an abrupt increase at the distinctive pressure mentioned in the variation of E/p_0 (Fig. 1(a)). The electric field, not shown here, also varies with pressure in the same way as T_g. Since the mixing of N_2 results in a large decrease in electron energy due to the vibrational excitation of N_2 by electron impact, the electric field has to increase to maintain discharge plasmas. So it is considered that the increase of T_g is caused by the increase of electric field (power input) under a fixed discharge current and the dominant gas heating process is the vibrational-translational energy transfer.

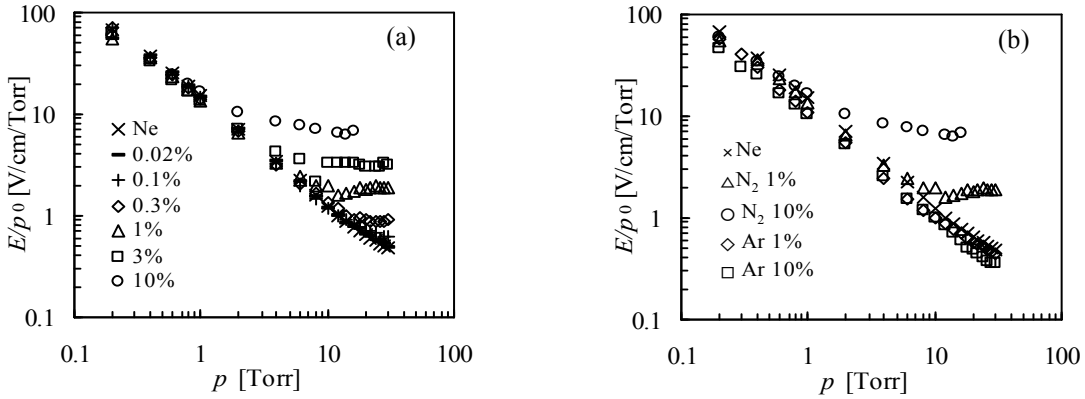

Fig. 1: (a) Pressure dependences of the reduced electric field E/p_0 with the mix ratio as a parameter for Ne-N_2 mixtures and (b) a comparison between Ne-N_2 and Ne-Ar mixture systems.

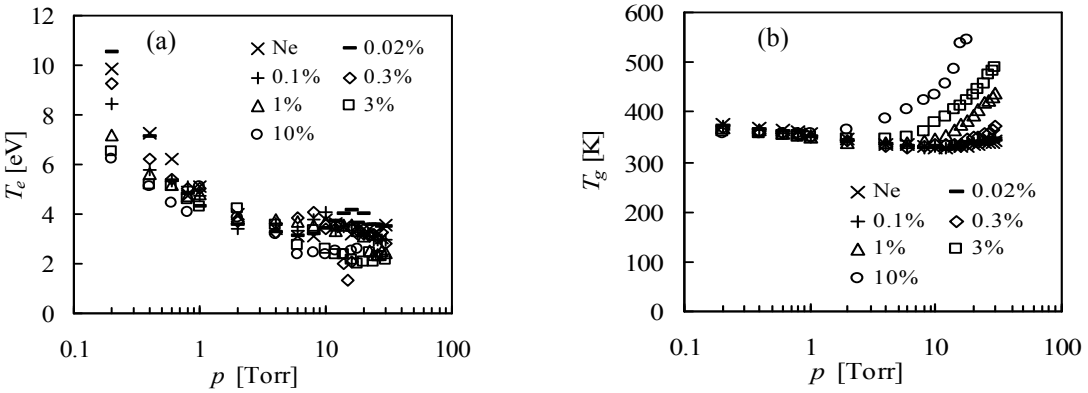

Fig. 2: Pressure dependences of the electron temperature T_e (a) and the neutral gas temperature T_g (b) with the mix ratio as a parameter.

References

[1] T. Kimura, K. Ohe, *Jpn. J. Appl. Phys.* **31** (1992) 4051.
[2] N. Sasaki et al., *Proc. XXIV ICPIG* (Warsaw) **3** (1999) 21.
[3] Y. Okamoto, *Jpn. J. Appl. Phys.* **15** (1976) 719.
[4] J. Smith, *IEEE Trans. Electron Devices* **ED-22** (1975) 642.
[5] T. Kaneda et al., *J. Phys. D: Appl. Phys.* **23** (1990) 500.
[6] N. Sasaki et al., *Proc. XXX ICPIG* (Belfast) **C8-086** (2011).