Development and Characterization of Ion Mobility Spectrometer*)

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The stability of an atmospheric pressure plasma source (APPS) for ion mobility spectrometer applications was investigated. Optimizations of the APPS for the operation conditions such as coil size and position for a plasma inductive excitation, and the ignition wire location were attempted. Ignition of Ar plasma is facilitated by the difference in electric potential inside the coil and the distance between the coil and the aluminum base attached to the ground terminal. Characterization of the ignition conditions, *I-V* measurements using a Gerdien condenser, and noise level in the ion current output signals were done for the developed APPS. The insertion of the ignition wire was found to affect the amplitude and value of the transported ion current through the Gerdien condenser.

Keywords: atmospheric plasma, Gerdien condenser, ion mobility spectrometer, inductively coupled plasma

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1. Introduction

Many types of plasma sources that generate atmospheric pressure plasma have recently been developed to achieve highly efficient chemical analyses [1, 2]. Atmospheric pressure plasma sources (APPS) are used for direct ionization of gas phase compounds or evaporated samples producing the ions to be transported to the analytical devices [2]. These analytical devices vary from optical emission spectrometer for liquid phase samples [3], ion mobility spectrometer for atmospheric gas samples [4], and time-of-flight systems for proteins and lipids [5].

A critical requirement in chemical analysis for an APPS is its stability. The stability of the plasma source can be defined by the spatial profile and the temporal change of the plasma characteristics [6]. It is often observed that the stability of plasma increases with the increasing plasma density [7]. The geometry of the ion source is also an important aspect which should be optimized for further stability of the produced plasma. An example is the optimized conical torch with the improved performance of ICP leading to a more stable operation of the plasma [3].

This study investigates the conditions for stable ion production for use in ion mobility spectrometer. The present ion source is an inductively coupled APPS with an ignition wire assembly. Ignition characteristics of the plasma were investigated by variations of the coil sizes, coil position, and changes in the ignition wire location. The stability of the ion source was evaluated through *I-V* characteristics, temporal ion saturation variations, and noise level in the current output signal measured using a Gerdien condenser [8]. The Gerdien condenser, also known as the aspiration ion mobility spectrometer, is an inexpensive instrument designed for ion-mobility analysis and can accommodate a suitable structure to serve as the mass separator adaptive to large molecule mass analyses.

2. Methodology

2.1 The ion source

The RF plasma assembly is composed of a power supply and plasma load (Fig. 1). The 13.56 MHz RF power supply has a built-in matching network which consists of variable capacitors and an inductor connected in series. The efficiency of energy transfers between the electrical circuit and the plasma load depends on the proper tuning of the impedance matching to the electrical power supply system.

The plasma production structure is composed of heli-

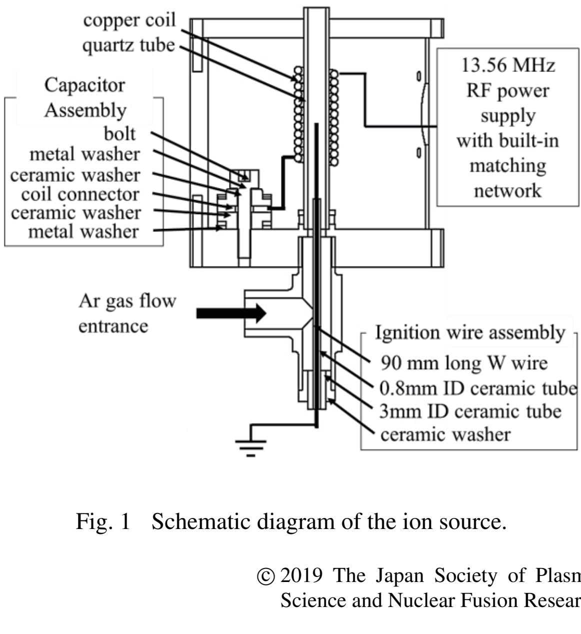

Fig. 1 Schematic diagram of the ion source.

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cal copper coil (2-mm diameter thickness), wound around a 5.7 cm long quartz glass tube (5 mm inner diameter, 7 mm outer diameter), and one end of the coil is connected to a capacitor assembly and the other end is connected to the power supply through a 1.0 m coaxial cable wire. A tubing connection from a gas cylinder creates an Ar gas flow inside the quartz tube regulated by a flow meter from 1 to 5 ℓ/min.

The capacitor assembly is composed of two ceramic spacers (15 mm OD, 2 mm thickness) and the ring wire connector to the inductor placed in between the spacers. These two ceramic spacers are fixed between two metal rings held at the ground electrical potential. A 2 mm diameter screw fixes the capacitor assembly in place. The ignition wire assembly is composed of 90 mm long tungsten wire placed inside two concentric ceramic tubes to keep the wire in the center position of the quartz tube. The ignition wire was originally placed as floating wire [9] but later attached to the ground terminal since it was found out that this electrical circuit configuration makes the evaluation of ion saturation current possible.

2.2 Ignition characteristics of the plasma

The ignition characterization of the APPS includes the ignition power, sustaining power and reflected power measurement from the power supply built-in multimeter. Ignition power is the minimum power that ignites the Ar plasma. The sustaining power is the power before the plasma starts to extinguish or becomes unstable. The ignition characteristics were observed for the following two operating conditions of the ion source:

1. Changing the distance of the copper solenoid coil to the grounded base without the ignition wire.
2. Changing the position of the ignition wire tip for a different number of coil turns.

The distance of the coil from the grounded base was changed as shown in Fig. 2 (b). The ignition characteristics of the plasma were studied for 1 to 7 mm coil to grounded base distance and the number of coil turns was changed from 6 to 12 turns.

In Fig. 2 (a) is shown the schematic diagram of the axial position of the wire tip with respect to the midsection of the copper solenoid coil. The changes in ignition characteristics of the plasma were observed when the wire tip position was changed.

2.3 Ion mobility signal measurements

The Gerdien condenser is composed of concentric cylindrical electrodes and a fan blower as shown in Fig. 3. The outer electrode sweeps the voltage gradient from −15 V to +15 V while the inner electrode held at ground potential measures the ion currents. A fan blower controls the flow of incoming ions depending upon the air speed drawn into the conduit. The orifice of the Gerdien condenser was positioned 17 mm from the discharge tip of the

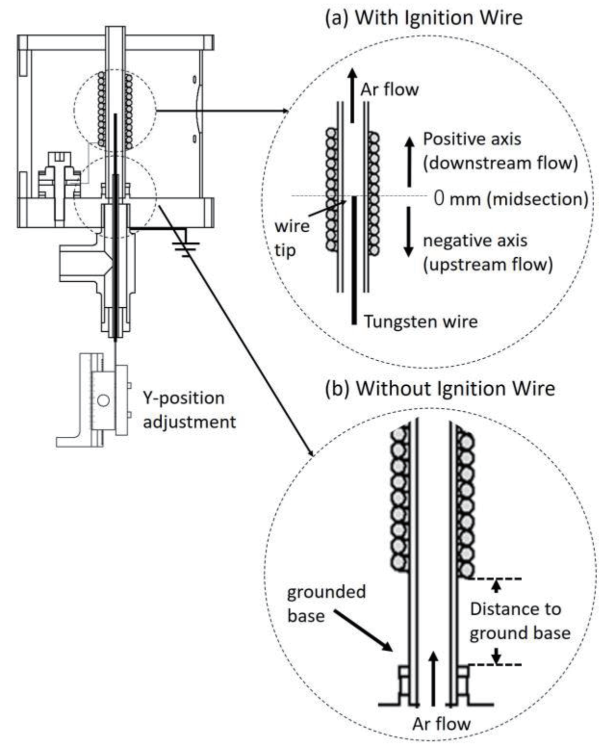


Fig. 2 Schematic diagram of the inductively coupled plasma.

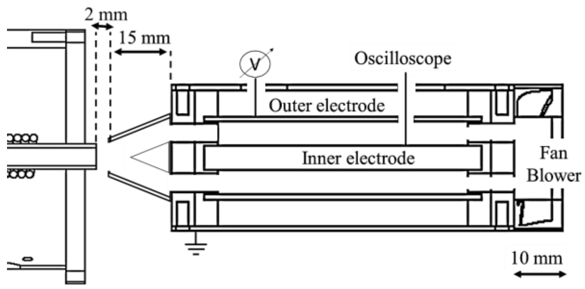


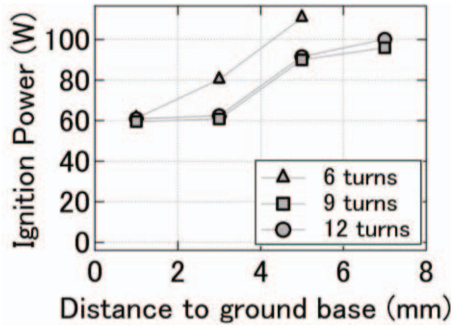
Fig. 3 Schematic diagram of the Gerdien condenser coupled to the atmospheric plasma source.

inductively coupled plasma. A conical glass tube guides the flow of incoming ions. Measurements of ion density and ion mobility from the *I-V* characteristics are discussed elsewhere [8].

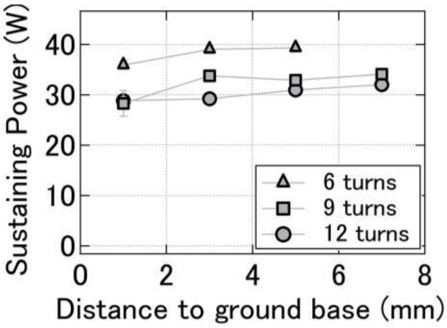
3. Results

3.1 Ignition characteristics

Figure 4 shows the ignition characteristics of the plasma when the coil position is changed, and the ignition wire is not used. Enlarging the distance of the coil and the grounded base significantly increase the ignition power and sustaining power. The ignition seems facilitated by the E-mode discharge due to the difference in electric potential of the coil to the grounded base. This is further confirmed by the increase in reflected power when moving the coil position away from the grounded base (data not shown).

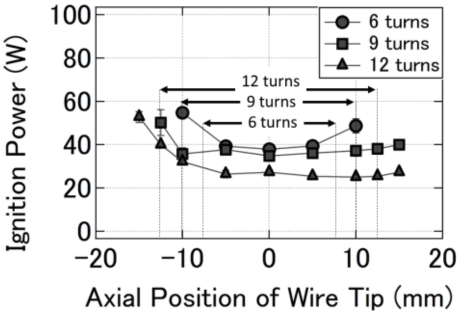


(a)

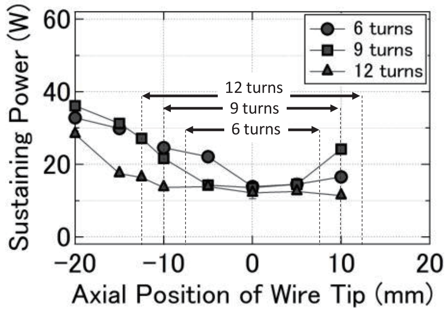


(b)

Fig. 4 (a) Ignition power and (b) sustaining power measured when the coil position to the ground base is changed.



(a)



(b)

Fig. 5 (a) Ignition power, (b) sustaining power measured when the ignition wire tip position is changed with respect to the midsection of the copper solenoid coil.

Increasing the number of coil turns from 6 to 12 significantly lowered the ignition and sustaining power. Minimum reflected power of 1.4 W is attained using the 12 coil turns.

Figure 5 (a) shows the ignition characteristics of Ar plasma when the axial position of the tungsten wire is varied. The ignition power of Ar plasma is observed to decrease when the wire tip position is moved towards the flow downstream. The ignition power also significantly lowered with increasing the number of coil turns. Ignition occurs due to the difference in electric potential from the wire tip located near the coil across the glass tube wall and the other tip attached to the ground terminal. Large electric potential difference can be formed by inductive coupling to the tungsten wire.

The sustaining power shown in Fig. 5 (b) have the similar trend with the ignition power. The reflected power also significantly decrease with the addition in the number of coil turns. The optimum ion source setting is obtained by setting the number of coil turns to 12 and the ignition wire tip axial position located at the midsection of the coil.

3.2 Plasma stability

The typical graphs of the *I*-*V* curve using the Gerdien condenser is shown in Fig. 6 using 20 - 50 W, 1 ℓ/min Ar plasma for different plasma conditions. At 40 W, the saturation values of the negative and positive ions increase when using the ignition wire. A lower voltage using 5 V resulted in ion saturation with plasma condition without

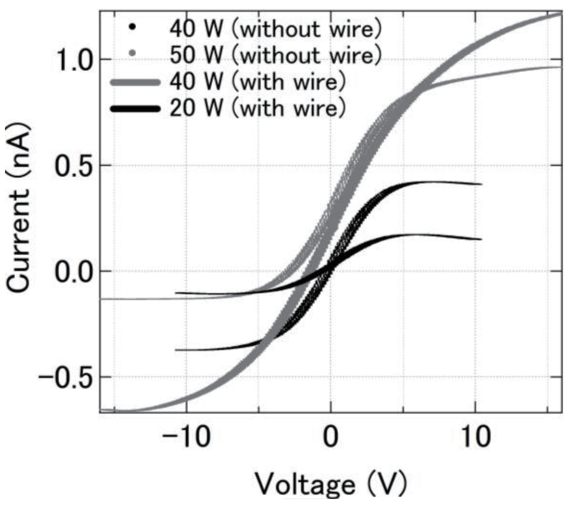


Fig. 6 Typical *I*-*V* measurements of the Gerdien condenser from the ICP with and without the ignition wire.

the ignition wire while a higher sweep voltage of 15 V resulted in ion saturation for the plasma condition using the ignition wire. An asymmetric *I*-*V* curve is present with high RF power which is 50 W (without wire) and 40 W (with ignition wire). This may be due to the increased oxidation with the rise in ion density. The total positive ion density rise is 10.8×10^6 cm^{-3} when the RF power is increased from 20 W to 40 W (with wire). Without the wire, a 5.8×10^6 cm^{-3} rise in total positive ion density is mea-

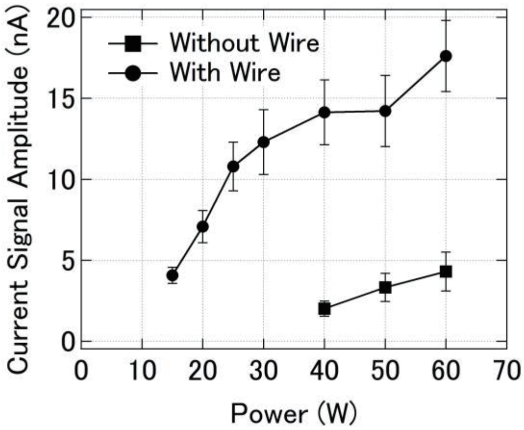


Fig. 7 Amplitude measurements of the temporal change in ion current saturation with +5 V constantly applied voltage to the Gerdien condenser.

sured when increasing the RF power from 40 W to 50 W. Ion mobility measurements reveals the possible presence of O^+ ions. There are several ways to recover the asymmetry including reduction in the applied RF power as shown by the symmetric *I-V* curve when the plasma was excited at 40 W without the wire, and 20 W with the wire.

The amplitude of the temporal changes in ion saturation current, which can be the noise onto the signal, of the output of the ion mobility spectrometer was measured for a constant applied outer electrode voltage of +5 V. The results are plotted in Fig. 7. Increase in amplitude is observed with an additional input of RF power. The amplitude also significantly increased when the ignition wire was used compared with the condition when no ignition wire was used. A minimum amplitude was measured when plasma was sustained with the minimum power of 15 W (with wire).

Frequency spectrum analyses of the signal measured by the Gerdien condenser is shown in Fig. 8. The peak signal changes with additional input of power. A consistent peak less than 40 Hz was observed when using the ignition wire using 40 - 60 W. For a frequency below 40 Hz, the measured noise is probably due to the thermal fluctuations and mechanical vibrations due to the mechanical fan.

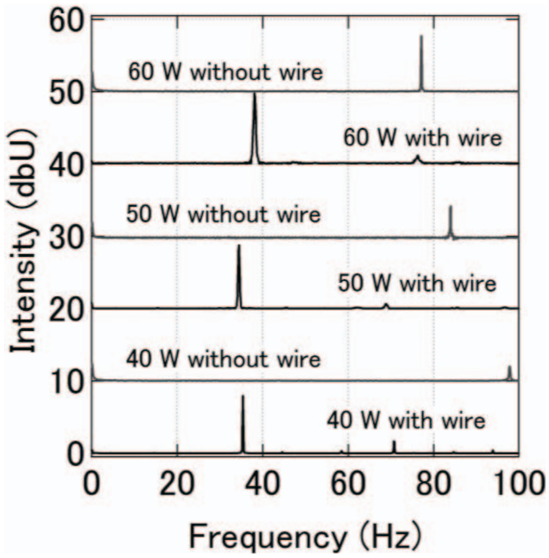


Fig. 8 Fourier transform signal analysis using the Gerdien condenser.

4. Conclusions

Smooth ignition of Ar plasma is facilitated by inserting a metal wire inside the glass tube held in the RF coil winding. Improved ignition was also observed with a change in wire tip location. The insertion of ignition wire tip results to more signal but it also increased the noise on the collected current. The power necessary to ignite Ar plasma by the developed APPS was reduced with an increase of the coil turn number and a decrease in the coil aluminum base distance.

[1] T.R. Covey *et al.*, Mass Spectrom. Rev. **28**, 6 (2009).
[2] S.K. Guharay *et al.*, IEEE T. Plasma Sci. **36**, 4 (2008).
[3] S. Alavi *et al.*, Anal. Chem. **90**, 5 (2008).
[4] A.A. Shvartsburg, *Differential ion mobility spectrometry: nonlinear ion transport and fundamentals of FAIMS* (CRC Press, 2008) p.2-115.
[5] A. Koch *et al*., Int. J. Mass Spectrom. **416**, 61 (2007).
[6] R. Schrittwieser *et al.*, Rou. J. Phys. **50**, 723 (2005).
[7] A.D. Patel *et al.*, Rev. Sci. Instrum. **89**, 043510 (2018).
[8] M.C.C. Lacdan and M. Wada, Plasma Fusion Res. **11**, 1401121 (2016).
[9] S. Kumagai *et al.*, Jpn. J. Appl. Phys. **51**, 01AA01 (2012).