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Battery-drive atmospheric pressure plasma jet for mass spectrometry applications

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ABSTRACT

This paper presents a battery-drive atmospheric pressure plasma jet (APPJ) as the ion source for ambient mass spectrometry analysis of Chinese herbs. The AP plasma jet is generated under a dielectric barrier discharge (DBD) scheme in a low-cost glass tube for producing high density ions. Volatile specimens in solid Chinese herbs is directly analyzed using the mass spectrometry without delicate sample preparation procedures. The developed APPJ ion source can generate stable plasma for MS analysis under a low power consumption of 1.56 W. The generated ion intensity reaches 10^8 ion/cm^3 and the temperature of the APPJ ion source is lower than 50°C under normal operation. Experimental results indicate that the developed APPJ ion source can successfully detect the solid samples of ground coffee beans and a mixed sample of Chinese herbs. The characteristic ingredients for the solid samples can be rapidly ionized with the APPJ ion source and then detected by the mass spectrometer in seconds. The APPJ-MS system developed in the present study provides a simple yet high efficient way for detecting the ingredients of natural products under an ambient mass spectrometry apparatus.

1. Introduction

Mass spectrometry (MS) has become one of the most powerful tools for bio- analytical applications including proteomics, biomarker identifications, fast drug screenings and many other aspects. A mass spectrometer determines the mass of a molecule by measuring the mass-to-charge ratio (m/z) of its ions generated by adding or eliminating charges of the molecule [1]. In general, electro-spray ionization (ESI), matrix-assisted laser desorption ionization (MALDI) and laser desorption ionization (LADI) are common methods for desorption and charging the samples prior to the MS analysis [2]. However, these ion sources are usually bulky and expensive, and the sample preparation procedures for using these are relatively delicate and time-consuming.

Alternatively, plasma is a powerful technique for generating energetic ionic molecules which are usually used for surface modifications and specialty chemical reactions. In addition, plasma is also an efficient method for ionizing gaseous specimens in mass spectrometry applications since the charge on the ionized gas is easily to transfer to the sample molecule by collision. However, the generation of plasma obeys the Paschen law that the gas breakdown characteristic of a gap relates to the product of the gas pressure and the gap length [3]. Therefore, the lower electric field is required for discharging gas molecules under a low pressure condition [4]. For ambient mass spectrometry detection, the plasma needs to be generated under the atmospheric condition since the samples for ambient MS detection is usually applied under the atmospheric pressure condition. Therefore, a high electric field is required for discharging the gas molecules for typical large scale plasma generation system. Several researches have reported the mathematical models [5–7] and the numerical simulations [8] for resolving the discharging gas molecules

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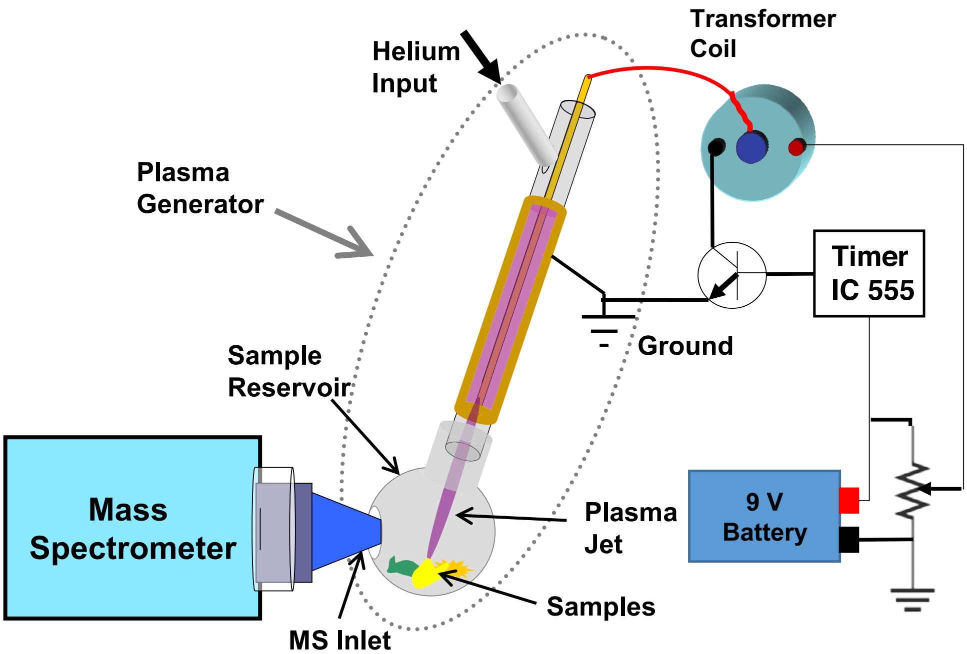

Fig. 1. Schematic presentation of the system diagram for the proposed battery-drive atmospheric pressure plasma jet for MS application.

under micro-scale environments. The discharged gas molecule collides the sample molecule and transfers the electric charge to the sample molecule for MS detection. Therefore, it is typically single charge for the sample ionized with the plasma ion source.

Some large scale plasma generators including inductive couple plasma (ICP), capacitive couple plasma (CCP) and microwave induced plasma (MIP) have been reported to be used as the ion sources for MS applications [9]. ICP ion source needs a high frequency alternating current for inducing the plasma discharge and the power consumption for ICP system is high [10,11]. A CCP system is typically produced with a 13.56 MHz RF power supply to generate helium plasma between two conductive plates [12]. However, the gap between the two conductive plates is normally smaller than 1.0 mm such that CCP system meets the dimension for micro-fabricated devices. Therefore, several micro-CCP system have been developed for mass spectrometry examination of gaseous samples [13,14]. Researches have also showed the molecular masses of halogens, phosphorus, sulfur and other transition elements were quantitatively analyzed using gas chromatography with the assistance of a MIP source [15]. Nevertheless, MIP system relies on bulky and delicate microwave source and waveguide for conducting microwave for discharging gas molecules. The power consumption and the generated heat are considerable. Alternatively, JEOL Ltd. developed a needle-type plasma generator to be the ion source for mass spectrometry applications. This new analytic method is known as the direct analysis in real-time (DART) which can directly analyze samples without pretreatment or mixing processes [16–18]. However, a relative large gas consumption and a high voltage up to several kV are required for this method. Recently, a symmetric atmospheric plasma source has also been reported for detecting non-polar compounds without breaking the chemical bonds of the compounds due to its zero floating potential at the outlet [19]. Alternatively, an atmospheric dielectric barrier discharge (DBD) plasma generator is also an ideal ion source for charging samples for MS applications. In addition, a DBD-based plasma system is easy to miniaturize due to its simple discharge construction, building a portable and low-cost MS analyzing system with low power consumption. Therefore, it is beneficial to develop a miniaturized atmospheric pressure plasma system which can be driven using a simple 9 V battery as the ion source for MS detection.

This research develops an APPJ-MS system to detect the solid sample of Chinese herbs in an atmospheric pressure condition. A simple yet efficient dielectric barrier discharge scheme is used to produce high density plasma for directly desorption and charging the volatile compounds in the Chinese herbs. Therefore, delicate sample pretreatment processes can be excluded with this method. The performance including the ion intensity and the ionization stability of the proposed system are experimentally investigated. Chinese herbs including clove, angelica and two mixed samples composed of these two Chinese herbs and their extracted solution are used to evaluate the performance of the APPJ-MS detection system.

2. Materials and methods

Fig. 1 shows the schematic showing the system setup for the proposed battery-drive APPJ ion source for MS application. The APPJ device was powered by a home-built electronic circuit composed of a transformer coil (1:200), a bipolar junction transistor as the pulse switch, a timer IC circuit (IC555) for frequency control and a 9 V battery as the power supply. The 9 V DC power