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Contact angle analysis of low-temperature cyclonic atmospheric pressure plasma modified polyethylene terephthalate

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ABSTRACT

Polyethylene terephthalate (PET) films are modified by cyclonic atmospheric pressure plasma. The experimentally measured gas phase temperature was around 30 °C to 90 °C, indicating that this cyclonic atmospheric pressure plasma can treat polymers without unfavorable thermal effects. The surface properties of cyclonic atmospheric pressure plasma-treated PET films were examined by the static contact angle measurements. The influences of plasma conditions such as treatment time, plasma power, nozzle distance, and gas flow rate on the PET surface properties were studied. It was found that such cyclonic atmospheric pressure plasma is very effective in PET surface modification, the reduced water contact angle was observed from 74° to less than 37° with only 10 s plasma treatment. The chemical composition of the PET films was analyzed by X-ray photoelectron spectroscopy (XPS). Atomic force microscopy (AFM) was used to study the changes in PET surface feature of the polymer surfaces due to plasma treatment. The photoemission plasma species in the continuous cyclone atmospheric pressure plasma was identified by optical emission spectroscopy (OES). From OES analysis, the plasma modification efficiency can be attributed to the interaction of oxygen-based plasma species in the plasma with PET surface. In this study, it shows a novel way for large scale polymeric surface modification by continuous cyclone atmospheric pressure plasma processing.

1. Introduction

Polyethylene terephthalate (PET) films are emerging as significant polymeric materials for a variety of manufacturing applications by reason of their excellent mechanical strength, moderate biocompatibility, high transparency, low cost, and admirable corrosion resistance characteristics [1–4]. However, the intrinsic low surface free energy of PET films remains a major impediment to its industrial use, leading to significant poor adhesion and poor printability [5–8]. Surface modification method can be enhanced by the surface free energy by altering the physicochemical surface features of PET films. To date, different chemical and radiation-induced surface modification methods have been employed to increase surface free energy of PET films [9–12]. However, both chemical surface modification and irradiation surface modification require professionally well-trained personnel to operate and the cost of operation is high. As a result, effective and safe surface modification method is rightly demanded. To overcome these issues, atmospheric pressure plasma treatment can be seen as an effective alternative to existing conventional surface modification methods with several advantages such as dry process and pollution control. Because of the existence of these merits, the scientific effort in atmospheric pressure plasma technique has arisen in recent years. In particular, increasing plasma dimension or extending discharge gap between the electrodes in order to make the atmospheric pressure plasma sources more suitable to practical applications receives much attention in the development of atmospheric pressure plasma techniques [13–18]. To date, the currently available atmospheric plasma sources have commonly suffered from their miniature plasma volumes or sizes, and consequently limited their surface modification applications. For example, the size and the shape of the items to be modified are restricted by the electrode spacing of the corona discharge, dielectric barrier discharge, and the resistive barrier discharge. The atmospheric pressure plasma jets have potential for large surface modification when a scanning mode of operation is used. But their high power consumption may not only make the surface modification process expensive, but may also cause undesirable changes or even damages on various materials due to the high power density and thus high heat flux carried by the plasmas. In this study, we present a new plasma source, i.e., a low-temperature atmospheric plasma, which can treat large scale surface of heat sensitive polymeric material.

With this in mind, we present novel cyclonic atmospheric pressure plasma system and describe the modification of PET surfaces by this novel plasma processing, so that the large scale PET surfaces can be modified at low-temperature nature. In this study, therefore, the investigation has been focusing on the modification effects of PET surfaces. The change of static contact angles on cyclonic atmospheric pressure plasma treated PET surfaces was measured depending on

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plasma exposure time and compared with the results, taking into account the surface changes. Optical emission spectroscopy was used to characterize plasma species in cyclonic atmospheric pressure plasma for elucidating the possible modification mechanism. This paper reported the experimental results obtained through such investigations.

2. Experimental

2.1. Atmospheric pressure plasma deposition system

Polyethylene terephthalate (PET) films were modified by cyclonic atmospheric pressure plasma system as shown in Fig. 1(a). The novel design of this atmospheric pressure plasma is based on the use of two rotating double-pipe type discharge jets to form plasma cyclone at a plasma rotational speed of at least 200 rpm. The cyclonic atmospheric pressure plasma consists of a gas compartment and two discharge jets placed certain distance apart inside the gas compartment. The double-pipe type discharge jets used for the cyclonic atmospheric pressure plasma treatment are similar to that reported in [19]. The high-speed gas flow rate argon (30 slm) is introduced from the upside the plasma system and passes through the gas compartment as the ionization gas. An electrical field is applied to ignite the plasma glow discharge by a 13.56 MHz RF power supply. A capacitive coupled RF plasma source power is in continuous mode. The sample is mounted on an X–Y movable table in order to simulate in-line processing at variable line speeds. It means that the sample passes once or a number of times through the glow region of the plasma. Because of this movement, the plasma volume increases dramatically from the thin cyclone discharge thread without the crossed fields to a large region. Fig. 1(b) shows the infrared thermal imaging of cyclonic atmospheric pressure plasma with touching the substrate. The sensitivity of infrared thermal measuring technique is 150 mk at 25 °C scene temperature. The radiant temperature profile of cyclonic atmospheric pressure plasma measured by infrared thermal analysis was similar to those by thermocouple thermometer analysis in Fig. 1(b) at low temperature (30 °C–85 °C) measured with a thermocouple thermometer.

2.2. Modified surface characterization and analysis

Argon gas which used to create atmospheric pressure plasma was an industrial grade with 99.995% purity and purchased from Min-Yang Gas Corporation. Poly (ethylene terephthalate) (PET) samples (0.5 mm thick) were supplied by Goodfellow Corporation. The polymer films were cut into strips and were used as samples for atmospheric pressure plasma surface modification experiments. Prior to use in experiment, each polymer sample was cleansed in an ultrasonic soap water bath for 30 min, thoroughly rinsed with DI water for 60 min, and dried completely in the air. The static contact angles of polymer samples were measured by projecting an image of an automatic sessile droplet resting on a membrane surface with a Magic Droplet Model 100SB Video Contact Angle System (Sindatek Instruments Corporation, Taipei, Taiwan). After the atmospheric pressure plasma modification treatments, the untreated polymer samples and the plasma modified polymer samples were placed on a vertically and horizontally adjustable sample stage. After the 0.1 μL water droplet has made contact with the polymer surface, a snapshot of the image was taken. The captured image was saved and contact

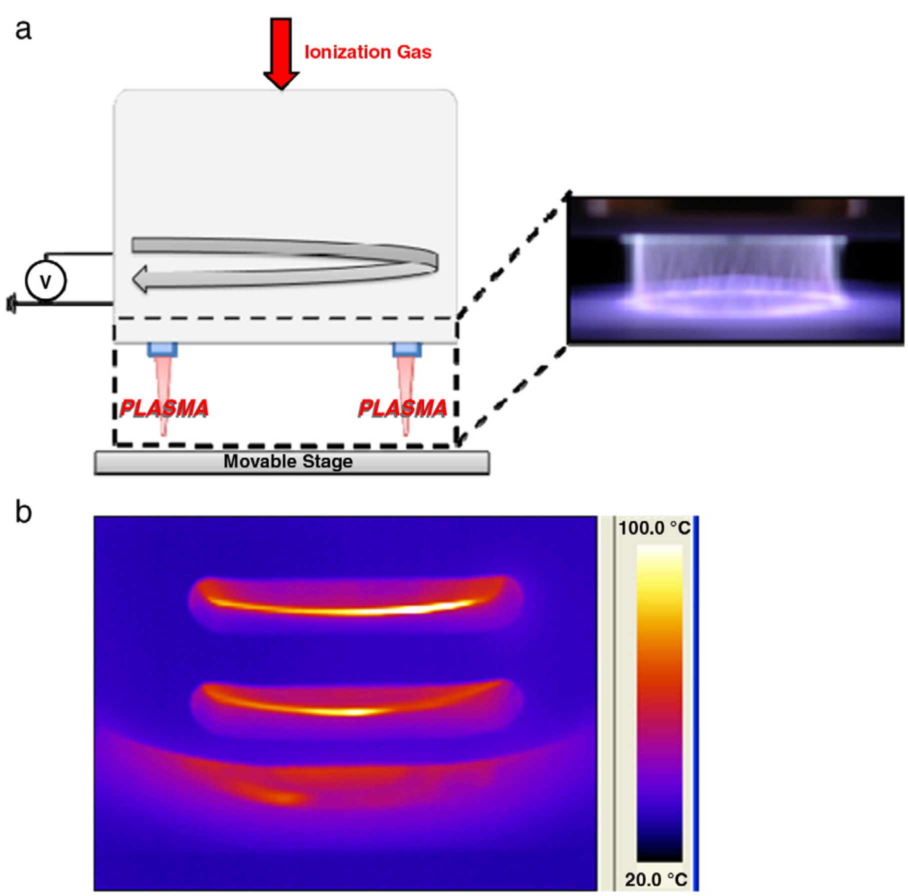

Fig. 1. Schematic diagram of cyclonic atmospheric pressure plasma system.