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Critical review

Atmospheric pressure plasmas for surface modification of flexible and printed electronic devices: A review

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ABSTRACT

Recently, non-equilibrium atmospheric pressure plasma, especially those operated at low gas temperatures, have become a topic of great interest for the processing of flexible and printed electronic devices due to several benefits such as the reduction of process and reactor costs, the employment of easy-to-handle apparatuses and the easier integration into continuous production lines. In this review, several types of typical atmospheric pressure plasma sources have been addressed, and the processes including surface treatment, texturing and sintering for application to flexible and printed electronic devices have been discussed.

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1. Introduction

In recent years, there has been an increasing interest in flexible and printed electronic devices due to significant advantages including high process efficiency, large scale patternability, environmental friendliness, etc. [1–4]. The conventional low pressure plasma system as a depositional, etching, or surface modification tool for flexible and printed electronics poses economic and integration problems due the complexity arising from the necessity of vacuum systems, which makes it hard to integrate into a continuous production line. In this context, atmospheric pressure plasma (APP) technologies attract growing interest in the field of surface processing of flexible materials due to the absence of vacuum equipment, which results in several benefits such as the reduction of process and reactor costs, the employment of easy-to-handle apparatuses, and the easier integration into continuous production lines. [3–5]

This article summarizes the various types of APP sources. We also discuss the surface treatment, activation, texturing, and sintering of flexible substrates achieved using APP technology.

2. Atmospheric pressure plasma sources

APP sources can be classified on the basis of key parameters such as driving frequency, ignition type, and gas temperature, etc.

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On the basis of driving frequency or the method for voltage application to generate the plasma, APP sources can be divided as follows: (1) direct current (DC) discharges, (2) alternating current (AC) discharges, (3) radio frequency (RF) discharges and (4) microwave (MW) discharges [4–6].

APP sources operating at DC or low-frequency (AC) are characterized by a low electron temperature, low gas temperature, and a high breakdown voltage of a few kV. The discharges can also be used in a pulsed mode which provides more flexibility to tailor the discharge properties and enables the injection of higher power with a corresponding higher degree of ionization. APP discharges operating at radio frequency are characterized by higher plasma density and lower breakdown voltage. However, APPs operating at the microwave frequency of 2.45 GHz exhibit a high electron temperature and a high gas temperature [6].

Another way to classify APP sources is by electrode configuration. One such APP source is the dielectric barrier discharge (DBD) [3,5,6]. DBD sources have a simple electrode configuration and are easily implemented to produce plasmas. In addition to DBD APPs, other types of APP sources such as corona discharges and plasma jets are widely investigated. For the operation of the APP sources, high flow rates (slm scale) of He, Ar, or N_2 are generally used as the ignition and stabilization gas and small amounts of other reactive gasses (sccm scale) such as O_2, CF_4, CH_4, etc. are added for the required surface reaction during the APP operation.

2.1. Dielectric barrier discharges (DBDs)

Dielectric discharges are generated between two electrodes, in which at least one of the electrodes is covered by a dielectric material, thickness ranging from a μm to a few mm, to limit the discharge current. These discharges are typically operated in a non-thermal uniform glow-type plasma regime. The separation between two DBD electrodes varies from micrometers to centimeters and depends upon the gas mixture used and the applied voltage. One of the advantages of DBD discharges is manifold symmetry and, therefore, these discharges can be used for large-area surface modification. DBD discharges are typically operated at a frequency range from few hertz (AC) to megahertz (RF) and at an electrode voltage of few thousand volts [3,7,8].

There are various designs, constructions, electrode shapes, and dielectric barrier materials used in DBD sources. Depending upon the application, the DBD electrode shapes may be a planar or coplanar array. Typical DBD source designs are in Fig. 1. Fig. 1(a) is a simple planar direct parallel plate DBD system investigated for various substrate

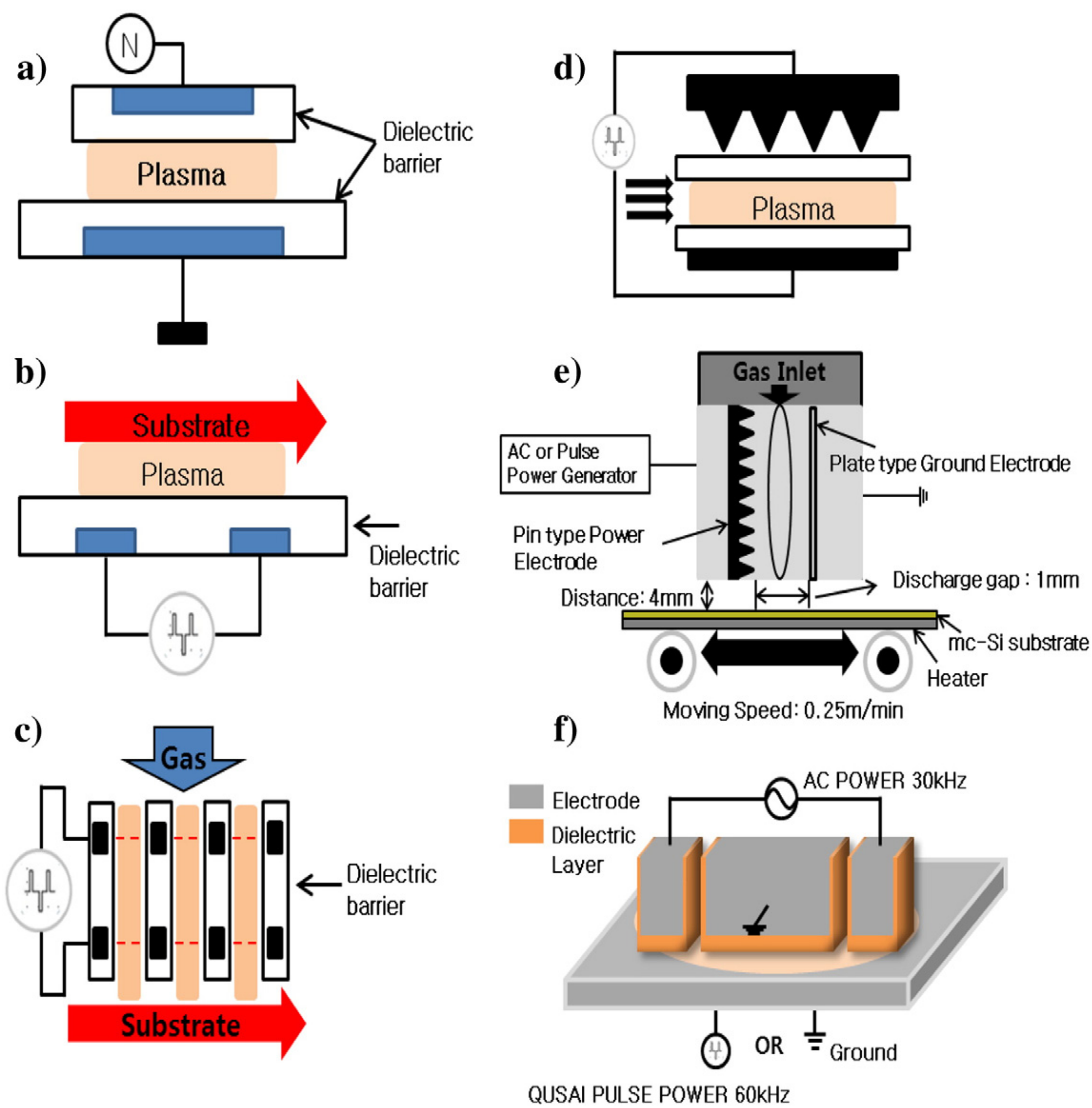

Fig. 1. (a) A simple planar direct DBD source, (b) surface-barrier DBD source, and (c) remote DBD source. Modifications of these sources are (d) multi-pin direct DBD source, (e) multi-pin remote DBD source, and a double-discharge DBD source composed of direct DBDs and remote DBDs.