Electrical and Optical Diagnostics of Dielectric Barrier Discharges (DBD) in He and N₂ for Polymer Treatment

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Synchronous, real-time optical and electrical diagnostics have been carried out on dielectric barrier discharges in flowing gases (air, He, N₂) at atmospheric pressure. A true “Atmospheric Pressure Glow Discharge” (APGD) is observed in N₂ when O₂ and H₂ concentrations are below ≈500 ppm and 2500 ppm, respectively, and the APGD regime can be beneficially modified by suitably chosen dielectric coatings. X-ray photoelectron spectroscopy (XPS) analyses of some APGD-treated polymer surfaces are presented.

KEY WORDS: Polymers; surface treatment; atmospheric pressure discharges; corona; glow; diagnostics.

1. INTRODUCTION

Dielectric barrier discharges (DBD), known since the mid-1800s and the object of intense R and D activity in the recent past, have been reviewed by Kogelschatz and coworkers.(¹) Industrial “corona” systems, ozonizers, excimer lamps, plasma displays, and high power lasers, are among various applications of “cold” plasmas at near-atmospheric pressure.

Corona and low-pressure glow discharges are used extensively to modify the surfaces of polymers, to render these more susceptible to adhesive bonding.(²)

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However, both those approaches have drawbacks: corona discharges in air are limited to a single type of chemistry (oxidation), their effect is spatially heterogeneous and may affect the rear surface of the polymer, and their beneficial effects tend to decay quite rapidly after treatment (so-called ageing). Low-pressure plasma treatment necessarily calls for expensive (vacuum) equipment, which can raise processing costs significantly. A possible compromise solution is provided by so-called atmospheric pressure glow discharge (APGD) processes, the object of this paper.

To establish whether a discharge process is of the pulsed, filamentary microdischarge (e.g. corona), or glow type requires a measuring scheme that responds to both. As will be shown presently, this is accomplished here by the simultaneous measurement of the voltage or current waveform across the interelectrode gap (or both) and the photomultiplier signal of light from the gap. As early as 1968, Bartnikas(3) had observed that helium may manifest pulsed, pulseless glow, or pseudoglow (a combination of the two former) discharges between metallic or dielectric-covered electrodes at atmospheric pressure, and a few years thereafter reported similar observations for air and nitrogen.(4) More recently, Hudon et al.(5) found that the amplitudes of spark-type discharge pulses diminished with time, as epoxy-coated electrodes aged in atmospheric air, first converting to pseudoglow and eventually to a true glow (APGD) regime; they attributed this to the lowered surface resistivity (about $10^9 \Omega \cdot \text{cm}$, eight orders of magnitude lower than the virgin epoxy). The objectives of the present work were, therefore, the following. First, to study discharges in He and N$_2$, two gases in which “APGD” behavior have been reported, (3, 4, 6-12) using dual electro-optical diagnostics; second, to investigate possible enhancement of APGD behavior via the use of dielectric coatings with selected electrical properties; and finally to conduct preliminary investigations of polymer surface modification in the APGD regime.

2. EXPERIMENTAL METHODOLOGY

The discharge system, shown schematically in Fig. 1, is composed of a hermetic Pyrex cylinder with metallic end-plates (1), connected to a vacuum pump (2) and to a gas flow control unit (3) (MKS, 10 slm). The top electrode (4) is connected to the high voltage (HV) power supply (5) (discussed later); motivated by the results of Hudon et al.,(5) we have coated the top electrode with various thermal plasma-sprayed dielectrics, most important with $\text{Al}_2\text{O}_3 + 13\% \text{TiO}_2$ (500 $\mu\text{m}$ thick) having a sheet resistance $>5 \times 10^7 \Omega \cdot \text{cm}$.(11) When the HV electrode was not coated with dielectric materials, stainless steel was used as the electrode material. To measure the voltage signal from the discharge, the top (powered) electrode is connected to a capacitive bridge built from corona-free vacuum capacitors (Jennings). The bottom grounded electrode (6) is micrometer-adjustable, the gap being