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Low-energy hydrogen ion shower (LEHIS) treatment of polytetrafluoroethylene (PTFE) materials

Hernando S. Salapare III*, Gene Q. Blantocas, Virginia R. Noguera, Henry J. Ramos

Plasma Physics Laboratory, National Institute of Physics, University of the Philippines, Diliman, Quezon City 1101, Philippines

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ABSTRACT

The wettability and optical transmittance properties of hydrogen ion treated polytetrafluoroethylene (PTFE) materials were evaluated using contact angle, laser irradiation, scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR) tests. The materials were processed using low-energy hydrogen ion shower (LEHIS) produced by a gas discharge ion source (GDIS). The duration of treatment and ion shower energy were varied to determine their effects on the PTFE specimens. Mass spectrometry showed the ion shower constituents to be H^+ and H_2^+ species. Within the bounds of the discharge conditions, flux density for the H_n^+ beam measured a minimum of 0.06 A/m^2 and a maximum of 0.25 A/m^2. Both one- and two-way analysis of variance were employed to assist in the interpretation of the empirical data. Results showed that treatment using lower plasma discharge currents (I_d) improved material hydrophobicity with contact angles measuring a high of 115° while higher I_d resulted in enhanced hydrophilicity reducing contact angles down to 61°. Transmittance and wettability were found to correlate, i.e., a surface made more wettable became optically transmissive allowing as much as 99% signal transmittance. Conversely, a surface made more hydrophobic reduced light leakage to as low as 60%. As the material showed increased surface striations, its optical transmittance, wettability, and surface tension also increased. With no observable shifting of the IR-absorption peaks, the surface modification was essentially morphological in character.

1. Introduction

Since way back in the past century, polytetrafluoroethylene (PTFE) or more commonly known as Teflon has gradually developed to become the seminal material in numerous applications. By virtue of its incredibly versatile characteristics, its potential use in a modern technological society appears limitless—ranging from electrical and electronics, food packaging and processing, biomedical, chemical and mechanical to agricultural and aeronautical applications. Despite its obvious merits, PTFE is not without problems in certain usage. Nevertheless, the ease with which the surface attributes of PTFE can be manipulated without altering its bulk composition suggests that the logical focus should be towards tuning PTFE surface to suit a particular application. Surface modification allows for the change and improvement of the property of a material, consequently, making the processed material more useful in various aspects [1–3]. There is already an enormous body of work on surface modification methods of PTFE. Some of these techniques utilize flame [4], chemical [5], grafting [6–7], corona discharge [8], low-pressure plasma [9–11], and UV exposure [12]. This work presents the surface treatment of PTFE using low-energy hydrogen ion shower (LEHIS) irradiation.

PTFE is a pliable material and is resistant to high heat; it has been used as a reflective layer for back-light illumination mounted behind miniaturized flat panel displays. One problem using PTFE as a reflector is that it permits a small amount of light leakage via optical transmittance [13]. It is one of the objects of this contribution to establish the viability of LEHIS treatment to address such light leakage problem. Reduced optical leakage should improve the brightness of flat compact video screens employing PTFE reflective layers. In general, the current study wishes to ascertain the following: (i) viability of LEHIS to surface modify PTFE utilizing relatively short treatment times yet producing significantly high-throughput, (ii) the mechanism of

* Corresponding author. Tel.: +63 2 9204475; fax: +63 2 9280296.
E-mail address: hsalapare@nip.upd.edu.ph (H.S. Salapare III).

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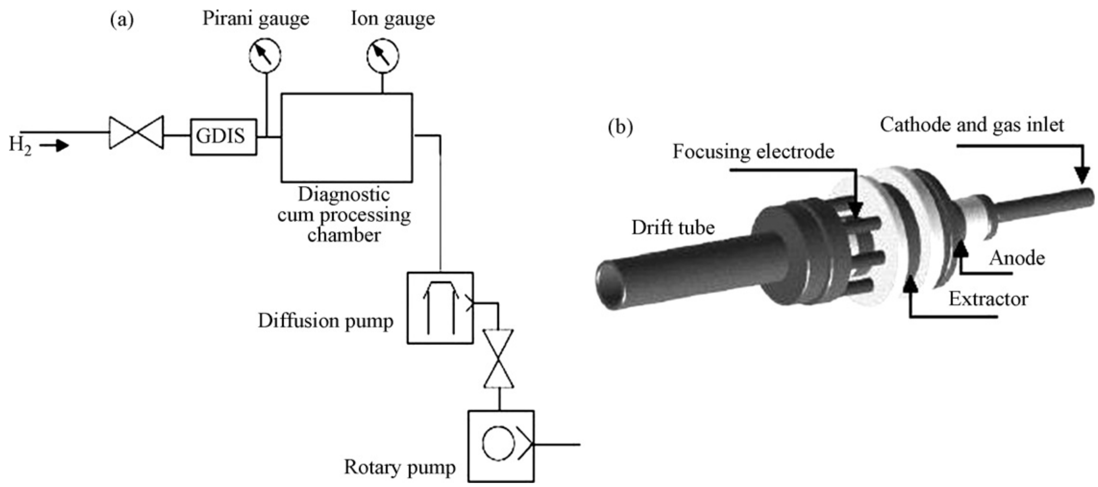

Fig. 1. Illustrations of the experimental setup. (a) Schematic diagram of the overall facility. (b) 3D figure of the GDIS.

surface modification as to whether it is physically or chemically based, or perhaps a combination of both, and (iii) the association between wettability and light leakage. The effectiveness of LEHIS as a surface modifier is assessed through contact angle measurements, scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), and optical transmittance.

2. Experimental setup and methodology

Clean and blow-dried PTFE samples measuring 1 cm × 2 cm are irradiated using LEHIS of a gas discharge ion source (GDIS) system. Fig. 1(a) shows the schematic diagram of the experimental setup and Fig. 1(b) presents a 3D figure of the GDIS. It has a compact discharge region of volume 0.8 cm^3 and an exit aperture of 2.0 mm in diameter. The extraction and focusing electrodes are grounded to ensure a diffused ion shower configuration. The GDIS fits a standard 70 mm knife-edge flange coupled to the diagnostic chamber whose volume is about 2400 cm^3. The system is evacuated by a 10.16-cm oil diffusion pump coupled to an 8-m^3/h rotary pump. Complete details of the facility are described in [1] and [14,15]. The pressures inside the chamber are monitored using Pirani and ionization gauges. The facility is evacuated up to a base pressure of 1.0×10^{-6} Torr. The total hydrogen gas filling pressure is kept at 3 mTorr for all the experimental runs. Plasma is produced when a potential difference, V_d, is applied across the discharge region. The PTFE samples are placed on a holder positioned 70 mm downstream from the entrance port of the processing chamber. This is the position determined to give maximum ion current density. Processing times of 15 and 30 min are considered. There are 13 test groups, each with three replicates. One group consisting of untreated samples and the remaining 12 groups made up of treated specimens. The treatment conditions are summarized in Table 1. The irradiation time and discharge conditions (V_d = discharge voltage, I_d = discharge current) are varied for each group.

3. Results and discussion

3.1. Ion-beam characterization

The charged particle species of the ion shower are determined using a cast steel mass spectrometer (CSMS). The design and operational characteristics of the device are reported in [14]. Typical hydrogen ion peaks detected by the CSMS for I_d = 1, 2, and 3 mA are shown in Fig. 2(a). Signal intensities are plotted against the scanning magnetic field. A detachable Faraday cup, 1 cm in diameter is placed at the same spot as the sample holder to measure the total beam current. Fig. 2(b) shows the ion flux density for different discharge conditions registering a high of 0.25 A/m^2 and a low of 0.06 A/m^2.

3.2. Contact angle measurement

The treated and untreated samples are subjected to contact angle test using an Intel® Play™ QX3™ Computer Microscope. The absorption of water droplet by a particular sample is recorded at a rate of one frame for every 5-s interval. For each sample, the time evolution of the contact angle is recorded at three different sites. Hence, the contact angle for a single time frame is actually a mean value, averaged over three different points on the sample.

Contact angle measurements as a function of time for some representative samples are shown in Fig. 3. Wettability is quantified by fitting the wetting model used in [16] to actual data. The model is expressed mathematically as

$$\frac{d\theta}{dt} = -k\theta \qquad (1)$$

where θ is the contact angle between the supporting solid surface and the tangent to the drop-shape of the liquid, and k being the change rate constant or the quantity that describes the angle's temporal recession in units of per second. Rising values of k signifies increasing surface wettability. k is sensitive to data fluctuations and its values are normally small in the order of 10^{-3} to 10^{-1}. Therefore a difference of 10^{-3} between the k-values of

Table 1
Summary of experimental parameters.

Treated group	Irradiation time (min)	Discharge voltage, V_d (kV)	Plasma discharge current, I_d (mA)
1	30	1.3	2
2	30	1	1
3	15	1.3	2
4	15	1	1
5	30	1.4	3
6	15	1.4	3
7	30	0.7	0.5
8	15	0.7	0.5
9	30	1.2	1.5
10	15	1.2	1.5
11	30	1.35	2.5
12	15	1.35	2.5