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Wetting and other physical characteristics of polycarbonate surface textured using laser ablation

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ABSTRACT

Surface texturing of polycarbonate glass is carried out for improved hydrophobicity via controlled laser ablation at the surface. Optical and physical characteristics of the laser treated layer are examined using analytical tools including optical, atomic force, and scanning electron microscopes, Fourier transform infrared spectroscopy, and X-ray diffraction. Contact angle measurements are carried out to assess the hydrophobicity of the laser treated surface. Residual stress in the laser ablated layer is determined using the curvature method, and microhardnes and scratch resistance are analyzed using a micro-tribometer. Findings reveal that textured surfaces compose of micro/nano pores with fine cavities and increase the contact angle to hydrophobicity such a way that contact angles in the range of 120° are resulted. Crystallization of the laser treated surface reduces the optical transmittance by 15%, contributes to residual stress formation, and enhances the microhardness by twice the value of untreated polycarbonate surface. In addition, laser treatment improves surface scratch resistance by 40%.

1. Introduction

Adhesion of dust onto surfaces results in a loss of optical transmittance from transparent/semi-transparent surfaces and remains a challenging problem for solar applications. In photovoltaic applications, optical transmittance of the protecting glass becomes critical issue to sustain efficiency and output power of the photovoltaic cells over long periods. Although a glass layer protects the photoactive area from environmental hazardous, dust accumulation at the glass surface lowers device efficiency and the output power in the long term because of the reduced optical transmittance. Similarly, in solar thermal applications dust accumulation on mirrors has significant negative impact on performance. This situation becomes significantly important in the areas where dust accumulation is unavoidable such as dry and desert environments. One of the solutions to prevent or minimizing the dust accumulations at the protective glass surfaces is to texture the surface for enhancing hydrophobic while creating a self-cleaning effect at the surface. Superhydrophobic surfaces have been shown to have remarkable water-repelling and self-cleaning properties [1–6]. To improve hydrophobic characteristics, nano/micro texturing of the surface becomes necessary, similar to the surfaces that are widely observed in nature, such as lotus leaves, rice leaves, red rose petals, fish scales, etc. [7–12]. Many techniques and processes have been developed to enhance the hydrophobicity of surfaces [13–21]; however, some of these techniques involve multi-step procedures and harsh conditions or required specialized reagents and equipment. Some of these techniques include phase separation [13], electrochemical deposition [14], plasma treatment [18], sol–gel processing [19], electrospinning [20], and solution immersion [21]. In addition, surface free energy of substrate materials can be modified through altering chemical composition at the surface via chemical and physical reactions, and introducing coating or alloying elements. Micro/nano texturing of surfaces have many challenges in terms of cost, processing time, equipment, and skilled man power requirements; however, it was demonstrated that laser controlled ablation can be used effectively to texture surfaces at micro/nano levels [22]. Since laser surface processing involves precision operation and non-mechanical contact, mechanical and chemical defects can be minimized at the surface with considerably high processing speed. Although laser controlled ablation has several advantages over the conventional surface texturing processes, thermal effects on textured surfaces, and optical and mechanical characteristics need to be examined in detail,

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particularly, to achieve desired surface textures pertinent to improve hydrophobicity for photovoltaic applications.

Polycarbonate glass is one of the candidates to replace silicon base protective glasses for photovoltaic applications. This is because of its high transmission of solar radiation, low density, high fracture toughness, and mechanical flexibility. However, polycarbonate glass surface is hydrophilic and it is hard to repel accumulated dust particles from the surface [23]. Since dust accumulation at the protective glass surface reduces the solar radiation energy reaching the photovoltaic surface, preventing dust accumulation at the protective glass surface becomes necessary to improve solar transmission. This can be achieved via texturing a polycarbonate glass surface while creating a hydrophobic affect. It should be noted that reduced transmission efficiency (as defined through the solar energy reaching at the photovoltaic active surface area over the solar energy reaching at the protective glass surface) lowers photovoltaic device output power. Utilizing chemical or thermal processes to texture polycarbonate glass via crystallization reactions have advantages over other texturing methods such as mechanical texturing. This is because of chain flexibility of polycarbonate molecules in the glass structure, which presents high crystallization ability when subjected to solvents such as acetone [23]. Considerable research studies were carried out to examine hydrophobicity improvement for polycarbonate surfaces [24–31]. The effects of crystallization on hydrolytic stability of polycarbonate were studied by Zhou et al. [24]. They demonstrated that the surface-crystallized polycarbonate glass had better hydrolytic stability than amorphous polycarbonate glass because of: (i) the reduced rate of the elongation at break of surface-crystallized polycarbonate glass, which was much smaller than that of amorphous polycarbonate glass during hydrolysis, (ii) the impact strength of amorphous polycarbonate glass reduced rapidly in the early stage of hydrolysis, (iii) the stability of the chemical structures of surface-crystallized polycarbonate glass, which was higher than that of amorphous polycarbonate glass during hydrolysis, resulting in fewer changes in the glass transition temperature. A new chemical technique for preparation of superhydrophobic polymer surfaces was introduced by Yilgor et al. [25]. They indicated that a spin-coated parent polymer by a dilute solution containing hydrophobic silica and polymer forming tetrahydrofuran thin film resulted in rough surfaces with homogeneously distributed silica particles in 1–10 μm range and the coated surfaces displayed superhydrophobic characteristics with large contact angles and low hysteresis. Superhydrophobic and superhydrophilic polycarbonate glasses by tailoring chemistry and nano-texturing due to plasma processing were studied by Palumbo et al. [26]. They showed that etching process allowed for formation of nanopillars tens of nanometers wide and up to a micrometer high, which were responsible for a unique behavior of the surface. Hierarchical polymeric textures through solvent-induced phase transformation were examined by Cui et al. [27]. The findings revealed that crystallization of the polymer led to the formation of a hierarchical structure composed of microporous spherulites covered with nano-fibrils, which in turn resulted in superhydrophobic wetting behavior. Forming a superhydrophobic polycarbonate fiber network from hydrophilic polycarbonate through electrospinning was studied by Li and Barber [28]. They indicated that complex surface geometries were obtained after the process, which in turn improved the wetting behavior of polycarbonate fiber network. A method for creating superhydrophobic polymer surfaces was introduced by Hurst et al. [29]. The method combined sanding and reactive ion etching treatment of the polymer surface generating micro and nanoscale surface roughness, which was followed by subsequent coating of a fluorinated silane molecule modifying the surface chemistry. They indicated that the resulting polymer surfaces retained their superhydrophobicity over long periods while demonstrating the stability of the micro and nanoscale surface roughness and the hydrophobic surface coating. Superhydrophobic surfaces, from hydrophobic or hydrophilic polymers via nanophase separation or electrospinning/electrospraying, were investigated by Papadopoulou et al. [30]. They demonstrated that the films, produced by hydrophilic polymers via electrospinning/electrospraying method, were hydrophobic and a narrow contact angle range was observed. However, films produced by the same polymers and their blends via phase separation presented a wide range of contact angles in contrast to the case of hydrophobic polymers. The findings, therefore, revealed that the detrimental role of random surface morphology on contact angle values could be counterbalanced by the inherent hydrophobicity of the polymer. Nanocarbon-induced rapid transformation of polymer surfaces into superhydrophobic surfaces was studied by Han et al. [31]. The method consisted of dipping polymer sheets in a solvent in which the polymer was partially soluble and then inducing solution crystallization by dipping the sheet in a poor solvent for several seconds. They demonstrated that the resulting surfaces had superhydrophobic features.

Although crystallization of polycarbonate glass provides micro/nanosize textures at the surface, once the crystallization is completed surface morphology and attenuation characteristics of the crystallized surface change because of the rigidity of molecular chains in the crystalline structure [23]. Consequently, optical transmittance reduces considerably for the crystallized surface despite the hydrophobicity of the surface increases significantly. Although laser ablation of polycarbonate surface triggers crystallization process because of the thermal effects, this undesirable effect may be minimized under the high speed and controlled ablation process. In addition, laser treatment alters the mechanical properties of the treated section; such as microhardness enhancement at the surface and residual stress formation in the treated layer. Nevertheless, laser control ablation can minimize the changes in the mechanical properties and, at the same time, it can form a surface texture improving the hydrophobicity. In the present study, laser texturing of polycarbonate glass via laser controlled ablation is presented. Topology, hydrophobicity and mechanical characteristics of the ablated surfaces are examined using the analytical tools. Mechanical characteristics include microhardness, scratch resistance, and micro-stresses are presented. The analytical tools used include optical, scanning electron, and atomic force microscopes, X-ray diffraction, Fourier transform spectroscopy, micro-tribometer, and goniometer.

2. Experimental

Polycarbonate glass of 3 mm thickness was used as workpieces. Polycarbonate glass was derived from A PBA (p-hydroxypheyl) and it had excellent optical clarity with high toughness. The CO_2 laser (LC-ALPHAIII) delivering nominal output power of 2 kW was used to irradiate the workpiece surface. The nominal focal length of the focusing lens was 127 mm. The laser beam diameter focused at the workpiece surface was ~0.25 mm. Argon assisting gas emerging from the conical nozzle and co-axially with the laser beam was used. Laser treatment tests were repeated several times by incorporating different laser parameters and laser treatment parameters leaded to the desired surface quality in the sense of wetting were selected. The details of laser treatment process are given in [22]. Laser treatment conditions are given in Table 1.

Material characterization of the laser treated surfaces was carried out using optical microscope, SEM, AFM, and XRD. Jeol 6460 electron microscopy is used for SEM examinations and Bruker D8 Advanced having CuKα radiation is used for XRD analysis ($\lambda = 1.54180 \times 10^{-10}$ m). A typical setting of XRD was 40 kV and 30 mA and scanning angle (2θ) was ranged 10°–60°. Surface