Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 125 (2016) 282–293

SOLAR ENERGY

www.elsevier.com/locate/solener

Influence of mud residues on solvent induced crystalized polycarbonate surface used as PV protective cover

B.S. Yilbas [a,*], H. Ali [a], N. Al-Aqeeli [b], N. Abu-Dheir [b], M. Khaled [c]

[a] ME Department and Center of Excellence in Renewable Energy, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia
[b] ME Department, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia
[c] CHEM Department, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia

Received 27 October 2015; received in revised form 10 December 2015; accepted 12 December 2015
Available online 7 January 2016

Communicated by: Associate Editor Jan Kleissl

Abstract

Polycarbonate wafers are used as protective cover for photovoltaic (PV) panels. Solvent crystallization of polycarbonate surface results in micro/nano spherulites and fibrils at the surface, which improve significantly surface hydrophobicity and self-cleaning characteristics of crystalized surface. Dust accumulation and mud formation on crystalized polycarbonate surface is critical for the performance of PV panels and it needs to be examined thoroughly. In the present study, experimental investigation of mud formed from the dust particles on crystalized polycarbonate surface is carried out to resemble the actual humid environments. The dry mud after effects on surface texture, hydrophobic, and optical transmission characteristics of crystalized polycarbonate surface are examined. Adhesion between the dry mud and crystalized surface are assessed and friction coefficient between the dry mud and crystalized surface is measured. It is found that crystalized polycarbonate surface has superior hydrophobic characteristics; however, mud residues at the surface cover micro/nano texture and lower surface hydrophobicity. Mud residues, remained at crystalized surface after water cleaning, increase friction coefficient and scratch hardness of the surface. In addition, mud residues lower optical transmittance of crystalized polycarbonate wafers.

Keywords: Polycarbonate; Solvent crystallization; Hydrophobicity; Dust; Mud

1. Introduction

Climate change results in regular sand storms taking place in the middle-east, particularly in Saudi Arabia (Kalderon-Asael et al., 2009), and desert dust is one of the major constitutes of the particles in storm. Small size dust particles can suspend in the air over many days after the storm is over and some of these particles settle on the exposed surfaces in environments. Although these particles are small in size, they cover large area over the time and modify optical, texture, and other characteristics of the surfaces. Mineral dust particles have tendency to absorb and scatter solar radiation (Alghamdi et al., 2015) while lowering solar power reaching surfaces and altering environmental temperatures. However, some of the incident solar power losses are partially compensated by long wave emission of radiation by dust particles (Wagner et al., 2009), which may not contribute considerably to solar power harvesting in terms of useful energy generation through concentrated solar heating, electricity generation by photovoltaics, thermal volumetric solar absorption, etc.

* Corresponding author.
E-mail address: bsyilbas@kfupm.edu.sa (B.S. Yilbas).

http://dx.doi.org/10.1016/j.solener.2015.12.010
0038-092X/

Minimization of dust settlement and accumulation on active surfaces of solar power applications is one of the recent challenges to be met. On the other hand, development of new and cost effective self-cleaning surfaces is promising to minimize and avoid after dust effects on active solar energy harvesting surfaces. One of the methods to minimize the efforts required to remove the settled dust particles at the surface is to modify surface texture and surface energy toward improving hydrophobicity. Low surface energy and texture consisting of micro/nano pillars give rise to improved surface hydrophobicity and low adhesion between dust particles and the surface (Yilbas et al., in press). Generating the cost effective hydrophobic surfaces toward solar energy harvesting applications is challenging because of keeping optical properties of the surface after texturing is difficult to achieve (Cui et al., 2012).

Considerable research studies were carried out to examine effect of dust particles on solar energy harvesting. A correlation between photovoltaic panel efficiency and amount of dust accumulated on the panel surface was studied by Al-Hasan and Ghoneim (2005). They proposed a linear relation to correlate the degradation of photovoltaic efficiency and the amount of dust accumulated on the module surface. The influence of sand and dust accumulation on photovoltaic modules performance was studied by Beattie et al. (2012). The findings qualitatively described the existing field data beyond the linear regime and they developed the correlation for field conditions, including analysis of photovoltaic module tilt, humidity and wind speed. Suppression of dust adhesion on a concentrator photovoltaic module using an anti-soiling photocatalytic coating was examined by Sueto et al. (2013). They demonstrated that the presence of electrostatic charges on the surface of the photovoltaic module was a main factor for the adhesion of dusts, and they could be suppressed by introducing anti-soiling photocatalytic layer. Energy yield loss caused by dust deposition on photovoltaic panels was studied by Sayyah et al. (2014). They presented a brief review of the energy yield losses caused by dust deposition on solar collectors, with particular emphasis on flat-panel photovoltaic (PV) systems while including some of the major studies reported on energy-yield losses on solar plants in operation in several regions of the world. The influence of desert environment on the performance of photovoltaics (PV) was investigated by Al Khuffash et al. (2014). They showed that coating of the PV panel could be a solution for dust accumulation at high irradiation levels. A study to analyze the effect of soiling losses on a solar photovoltaic system was carried out by Mejia and Kleiss (2013). They indicated that in California region, the soiling losses were in the order of 0.051% per day overall and 26% of the sites; however, the sites with small tilt angles ($<5°$) had large soiling losses. The effect of soiling on photovoltaic modules was examined by Appels et al. (2013). The findings revealed that the rain fall had little cleaning effect on smaller dust particles (2–10 μm); however, on bigger particles (pollen, approx. 60 μm) the cleaning effect was clearly visible.

Hydrophobicity of a surface depends and interfacial energies of solid and liquid, surface texture, and Laplace pressure as demonstrated by researchers (Bhushan et al., 2009; Jung and Bhushan, 2007). Mimicking the nature, such as lotus leaves surface, enables to create surfaces of superhydrophobic characteristics. A substantial increase in hydrophobicity can be achieved when a combination of chemical modification and surface roughness of the substrates is integrated (Han et al., 2005). Many techniques and processes have been developed to enhance the hydrophobicity of surfaces using this strategy (Shirtcliffe et al., 2004; Hwang et al., 2010; Huang et al., 2011; Yang et al., 2009; Kinoshita et al., 2010; Latthe et al., 2009; Ma et al., 2005; Zhang et al., 2010); however, some of these techniques involve multi-step procedures and harsh conditions or required specialized reagents and equipment. In addition, micro/nano texturing of surfaces by a laser controlled ablation provides improved surface hydrophobicity (Yilbas et al., 2014a); however, thermal stress field developed in the laser textured substrates can limit the practical applications. Surface crystallization of polymeric materials, such as polycarbonate wafers, gives rise to hierarchical textures compose of micro/nano structures. 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 (Cui et al., 2012). One of the techniques to crystallize polymeric material surfaces is to use solvents, such as acetone, through the immersion technique (Cui et al., 2012). Although crystallization process is fast and generates hierarchical texture structures at surfaces, optical characteristics of the crystalized surfaces change because of the chain restrictions of large size molecules in crystal structures (Yilbas et al., 2014b). On the other hand, polycarbonate wafer (p-hydroxypheyl) is one of the candidates to replace silicon base protective glasses for photovoltaic applications. This is because of its low density, high fracture toughness, and mechanical flexibility.

Considerable research studies were carried out to examine crystallization of polycarbonate wafers. Selective etching of pressure-crystallized bisphenol-A polycarbonate though dimethylacetamide at room temperature was carried out by Lu and Huang (Lu and Huang, 2012). They suggested that by controlling the etching process, unique hierarchical structures, composed of nano-structured micrometer-sized crystalline entities of bisphenol-A polycarbonate could be created on the surfaces. Therefore, the selective etching was reported to be a more effective route to reveal the inner structures of polymer crystals, as well as to fabricate new surface active materials, such as a super-hydrophobic surface with self-cleaning effect. The effect of crystallization on hydrolytic stability of polycarbonate was investigated by Zhou et al. (2013). They showed that the surface-crystallized polycarbonate had superior hydrolytic stability than amorphous polycarbonate, because of the stability of the chemical structures of surface-crystallized polycarbonate, which was much higher