Solar Energy Materials & Solar Cells 163 (2017) 231–236

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Energy efficient hydrogel based smart windows with low cost transparent conducting electrodes

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ARTICLE INFO

Keywords:
Smart windows
Transparent conducting electrodes
Low-cost
Sn wire network
Hydroxy propyl methyl cellulose
Hydrogel

ABSTRACT

Indoor light control using thermotropic materials is an active area of research. While active materials are available to switch transmittance with temperature, large area heaters with desired transparency are not easily affordable. In this paper, the fabrication of thermochromic devices using inexpensive Sn mesh electrodes (5 Ω/□, transmission, 80%) produced by crackle lithography with hydroxypropyl methyl cellulose (HPMC) as active material is reported. When laminated and coated on the inner surface of a PET window (8×8 cm^2), the mesh served as a transparent heater to cause gelation in HPMC at ~40 °C to switch from water-clear transparency to paper-white opaqueness with 1 mm thickness of the active layer. The power consumption was only 0.2 W/cm^2. Few drops of a color ink produced interesting effects in this smart window prototype.

1. Introduction

Maintaining a working temperature indoor irrespective of climate variations is challenging and towards this, many energy saving passive methods such as thermal insulation or reflective ‘cool’ wall coatings [1], solar protection films for windows [2], wet roofing [3] etc. have been developed. Although the latter ones significantly reduce the in-flow of heat from roofs and walls in the hot season and thus, the air conditioning costs, they are inappropriate in winter as solar energy absorption is highly desired to avoid excessive energy consumption for room heating. Clearly, there is a demand for technologies to develop active materials and applications suitable for all weather conditions. ‘Smart window’ technology is one among them [4].

In contrast to traditional protection films with fixed optical properties [2], switchable solar control glazing coatings are highly desirable [5]. In this context, electrochromic [6] and thermochromic [7] materials are interesting due to their ability to modulate optical transparency with external stimuli, electrical field or temperature, respectively. In general, thermochromic materials are relatively affordable and due to simplicity of the design, the resulting devices are usually less expensive. However, scouting for a thermochromic material with desired operating temperature window is not always easy. For example, now-a-days inorganic metal oxide (VO_2) based coatings [8,9] are used in windows for controlling IR transmission but its transition temperature is much higher (68 °C) compared to ambient temperatures. To address this issue, often doping with tungsten, niobium, molybdenum, iridium or tantalum oxide is done to bring down the transition temperature [10,11]. In this context, thermosensitive polymers are impressive as the transition from transparent to opaque takes place at near-room temperature [12–14]. Specifically, hydroxypropyl methyl cellulose (HPMC) mixed with NaCl features a lower critical solution temperature (LCST) of ~35 °C [15,16]. Gel bears a water-clear look at low temperatures and becomes paper-white at high temperatures due to molecular aggregation induced optical scattering. HPMC possesses many novel properties; it is aqueous and non-toxic and its transition is highly reversible with haze free opacity and no wonder, it finds widespread applications in smart displays/windows [15,17]. Large area thermotropic windows with hydrogels have been fabricated and shown reversible transition under sunlight in prolonged out-door testing [17]. Later, electrical controlling has been combined along with solar to obtain transition below LCST. Fisher et al. and Gyenes et al. have developed hydrogel devices with transparent heaters composed of tin-doped indium oxide (ITO) [4,15].

A pertinent issue on way to commercialisation of thermochromic windows is related to the transparent heater, which is an important component of the device besides the thermochromic material itself. The heating is done by a joule heater which as the elegance demands, should remain essentially invisible when integrated into a window.

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http://dx.doi.org/10.1016/j.solmat.2017.01.039
Received 1 December 2016; Received in revised form 12 January 2017; Accepted 23 January 2017
Available online 01 February 2017
0927-0248/

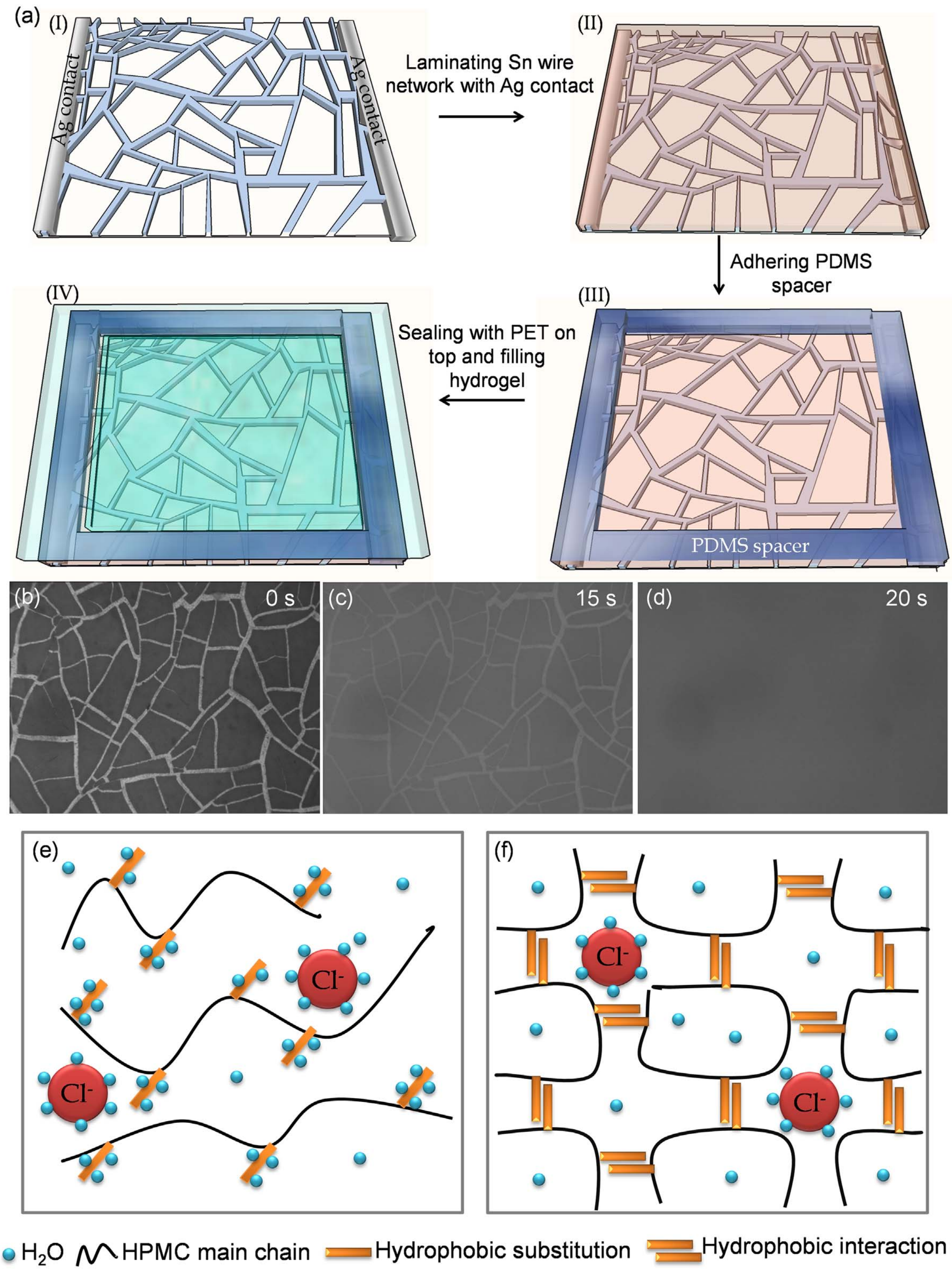

Fig. 1. (a) Schematic illustration of the fabrication steps of the hydrogel device. (b-d) Optical microscopic images of hydrogel device with a focus on Sn wire network. Images are captured with top light illumination. Pictorial representation of mechanism of hydrogel transition from transparent (e) to opaque state (f).

Typically, ITO coated transparent conducting glass is used in order to achieve uniform heating across the large areas [4,15]. However, producing window size conducting glass with uniform areal heating is not trivial if one takes into account of cost effectiveness, else such designs are already in use in aviation industry [18,19]. The main objective of this work is to make affordable smart windows composed of inexpensive TCEs and thermotropic gels. The affordable aspects relates to the use of the earth abundant inexpensive environmentally benign ingredients to produce transparent heaters which otherwise demand the expensive ITO. In this work, metal meshes produced by crackle lithography were used as affordable heaters for thermochromic windows [20,21]. For this purpose, metal mesh made of Sn (cost effective) was used which possessed sheet resistance of 5 Ω/□ and transmittance of ~80%. The specular transmittance of the hydrogel device could be switched from ~73% to less than 1% using 0.2 W/cm^2.