Electrochimica Acta 222 (2016) 657–667

Contents lists available at ScienceDirect

Electrochimica Acta

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

Research paper

Self-assembled liquid crystalline nanotemplates and their incorporation in dye-sensitised solar cells

Muhammad Akmal Kamarudin[a,*], Ammar A. Khan[a], Calum Williams[a], Girish Rughoobur[b], Suhana Mohd. Said[c], Shabeena Nosheen[a], Andrew J. Flewitt[b], Malik M. Qasim[a], Timothy D. Wilkinson[a]

[a] Center of Molecular Materials for Photonics and Electronics (CMMPE), Department of Engineering, University of Cambridge, Cambridge, 9 JJ Thomson Avenue, CB3 0FA, United Kingdom
[b] Electronic Devices and Materials Group, Department of Engineering, University of Cambridge, Cambridge, 9 JJ Thomson Avenue, CB3 0FA, United Kingdom
[c] Liquid Crystal Display Laboratory, Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 7 September 2016
Received in revised form 31 October 2016
Accepted 5 November 2016
Available online 6 November 2016

Keywords:
Liquid crystals
reactive mesogen
self-assembled nanotemplate
polymer electrolyte
dye-sensitised solar cells

ABSTRACT

Liquid junction dye-sensitised solar cells (DSSCs) suffer from solvent evaporation and leakage which limit their large-scale production. Here, we have prepared DSSC using a simple and cheap fabrication process with improved photovoltaic parameters and stability. A binary mixture of Smectic A (SmA) and Nematic Liquid Crystal (NLC) was used to provide a self-assembled template for a polymerisable reactive mesogen LC. The layered structure of SmA combined with a low viscosity NLC forms a polygonal structure that provides an ordered and continuous template for reactive mesogens. Once the reactive mesogen is polymerised under UV light, the SmA:NLC mixture is washed away, resulting in a polymer network template containing nanochannels. We demonstrate the incorporation of these templates into DSSCs and find that DSSCs containing these nanochannels show improved open-circuit voltage (V_{OC}) (0.705 V) and short-circuit current (J_{SC}) (13.25 mA cm^{-2}) compared to that of the liquid electrolyte (V_{OC} = 0.694 V and J_{SC} = 10.46 mA cm^{-2}). The highest obtained power conversion efficiency with Sm-PE was 5.94% which is higher than that of the reference solar cell (5.51%). These can be attributed to the improved ionic conductivity and ionic diffusion of Sm-PE where the presence of the nanochannels aided the ionic conduction in the polymer electrolyte. In addition, it is hypothesized that the light scattering effect of the polymerised reactive mesogen also contributed to the improved performance of the photovoltaic devices. This finding is important because it is known fact that when a polymer is added to liquid electrolyte, the ionic conductivity will decrease although the stability is improved.

1. Introduction

Dye sensitised solar cells (DSSCs) were first demonstrated in 1991 by O'Reagan and Graetzel [1]. These hybrid organic-inorganic solar cells have the advantage of being environmentally friendly and also allow easy and low-cost fabrication without sacrificing their relatively high efficiency compared to organic solar cells. One of the major components of DSSCs is the electrolyte which is a redox mediator responsible for the regeneration of the dye and the electrolyte itself. The electrolyte in the DSSC device can be divided into three different types: liquid electrolyte, gel polymer electrolyte and solid state electrolyte. The liquid electrolyte DSSC gives the highest efficiency of up to 13% for Cobalt-based electrolyte [2]. However, this type of electrolyte suffers from evaporation of the solvent which reduces its long term stability. To address this issue, researchers have proposed the solid electrolyte which is more stable but sacrifices in the efficiency of the device as the solid electrolyte exhibits a low ionic conductivity. By employing various additives and plasticisers, it was found out that gel polymer electrolytes provide a compromise between solid and liquid electrolytes making it possible to extend the lifetime of the device without having to significantly sacrifice the efficiency [3–6]. On example of such an additive the addition of liquid crystalline (LC) materials to the electrolyte matrix [7,8].

LC materials exhibit physical properties that are intermediate between those of solids and liquids under certain conditions, *i.e.* temperature or solvent concentration. In addition, different molecular composition leads to the formation of different phases,

* Corresponding author. Tel: +44 (0) 1223 7 48365.
E-mail address: mak65@cam.ac.uk (M.A. Kamarudin).

http://dx.doi.org/10.1016/j.electacta.2016.11.021

such as nematic, smectic and columnar [9]. These characteristics come from intermolecular interactions as well as molecule geometry (cylinder or disc-like) which tends to self assemble in a given direction and sometimes in orientational order. Nematic phase is the simplest type of LC phase. Nematic phase shows thread-like discontinuities when observed under a crossed-polarised microscope. The thread-like discontinuities form what is called the Schlieren texture, where two or four dark brushes meet. The molecules tend to assemble with the long axes pointing toward a certain direction. Unlike nematic phase, smectic is much more viscous due the structure is much more closer to a solid where smectic phase not only has an orientational order but also a positional order. The molecules also tend to align in layers.

Despite their unique electro-optical properties that have allowed them to be used almost universally in display applications, LCs have had very limited use in photovoltaic applications. The exceptions to this has been work performed on the development of organic solar cells employing disc-like discotic liquid crystalline (DLCs) materials that have been shown to support higher charge carrier mobility than that of amorphous materials which is needed for a good electronic device [10,11]. A recent paper by Sun et al. shows that NLC could be use in organic solar cell with a high efficiency of 9.3% which is exceptionally high for an organic photovoltaic device [12]. LCs have also been shown to improve the efficiency of DSSC where the light scattering effect and the passivation of the TiO_2 surface by the LC material have been cited for this improvement [7,8].

Reactive mesogens (RMs) are a type of polymerisable LC material with a reactive unit at one or both ends of the molecule, with an acrylate being the most common end group. RMs undergo

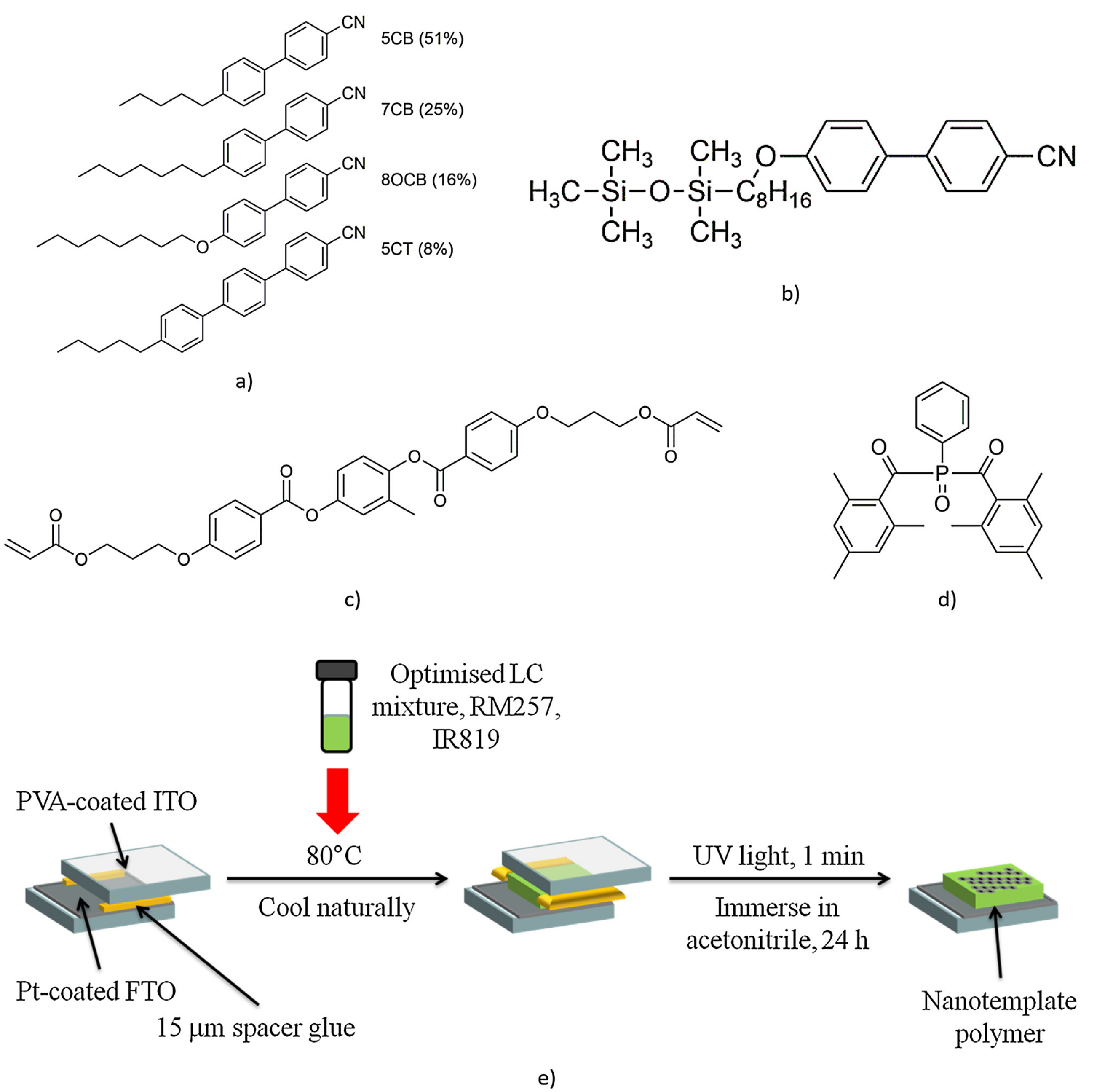

Fig. 1. Chemical structure of a) nematic E7, b) smectic 8/2 organosiloxane, c) the reactive mesogen, RM257, d) the photoinitiator, IR819 and e) schematic illustration of nanotemplate preparation.