Journal of Industrial and Engineering Chemistry 92 (2020) 303–308

Contents lists available at ScienceDirect

Journal of Industrial and Engineering Chemistry

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

Solid cross linked-poly(ethylene oxide) electrolyte gate dielectrics for organic thin-film transistors

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ARTICLE INFO

Article history:
Received 12 August 2020
Received in revised form 14 September 2020
Accepted 16 September 2020
Available online 24 September 2020

Keywords:
Dielectric
Electrolyte
Poly(ethylene) glycol
Solid
Crosslink
Organic thin film transistor

ABSTRACT

Solid polymer electrolyte gate dielectric based on cross-linked poly(ethylene oxide) (CPEO) was developed and employed for organic thin-film transistors (OTFTs). Mechanical stability, high areal capacitance, and amorphous morphology of CPEO were achieved via the use of polyhedral oligomeric silsesquioxane (POSS) as cross-linker, dissolved ion [EMIM][TFSI] as electrolyte, and PEO with low molecular weight as polymer matrix, respectively. The resulting solid polymer electrolyte showed excellent insulating properties with low leakage current density (1.8×10^{-7} A cm^{-2} at 1 V) and high capacitance per area ($\sim$ 1 μF cm^{-2} at 100 Hz). Furthermore, dielectric properties of the developed polymer electrolytes including ionic conductivity as well as segmental relaxation time were investigated. The polyelectrolyte dielectric was employed for bottom-gate/top-contact organic thin-film transistors and the resulting devices showed decent electrical performance with a carrier mobility of 0.12 ($\pm$0.03) cm^2 V^{-1} s^{-1} and a current on/off ratio of 10^3 at low operating voltage of 5 V.
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Introduction

Organic thin-film transistors (OTFTs) are one of the essential components of various large-area, low-cost electronic devices, including displays, chemical sensors, and radio-frequency identification (RF-ID) tags [1–8]. For the development of future electronic devices such as wearable health care devices, low operating voltage is required due to the limited capacity of battery with thin and small device sizes [9]. However, OTFTs typically suffer from comparatively high operating voltage (over 20 V), which results in high power dissipation in organic circuitry. Gate dielectric layer, one of the important components in OTFTs, capacitively induces charge carriers in the semiconducting layer, determining the operating voltages of the resulting devices. High-capacitance dielectrics afford high carrier densities in channel layer at relatively low voltages, hence, resulting in low operational voltages. Furthermore, dielectric film quality affects leakage current densities and morphological properties of semiconductor film. Therefore, it is important to develop dielectric materials with high capacitance, low leakage current, as well as favorable film quality for high performance OTFTs.

Capacitance per unit area (C_i) is represented by the equation, $C_i = \varepsilon_0 \frac{k}{d}$, where ε_0 is the vacuum permittivity, k is the dielectric constant, and d is the thickness of dielectric film. Hence, high capacitance can be achieved by decreasing dielectric thickness and/or employing high-k dielectric materials. However, these methods exhibit a few drawbacks. For instance, small film thickness of the dielectric layer could result in non-uniform film, high leakage current, and low current on/off ratios [10,11]. Similarly, high-k dielectric materials usually suffer from charge traps at the semiconductor/dielectric interface and mobility degradation by high polarization [12,13]. Furthermore, very high areal capacitance above 1 μF/cm^2 is hard to achieve using these methods [14]. To this end, polymer electrolytes (i.e. polyelectrolytes) could be an alternative for high capacitance dielectric, affording enhanced charge carrier densities in the channel layer [15–22]. It is relatively easy to achieve very high areal capacitance using polyelectrolyte even at high dielectric film thickness due to the formation of thin ($\sim$1 nm) electrical double layer (EDL), which affords low operating voltages of OTFTs.

Polymer electrolytes consist of polymer matrix and dissolved ionic salt. Depending on the type of matrix and relative content of

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https://doi.org/10.1016/j.jiec.2020.09.015
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