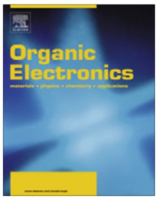
Organic Electronics 14 (2013) 1170–1176

Contents lists available at SciVerse ScienceDirect

Organic Electronics

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



Pentacene organic thin-film transistors with solution-based gelatin dielectric

Lung-Kai Mao [a], Jenn-Chang Hwang [a,*], Ting-Hao Chang [a], Chao-Ying Hsieh [a], Li-Shiuan Tsai [a], Yu-Lun Chueh [a], Shawn S.H. Hsu [b], Ping-Chiang Lyu [c], Ta-Jo Liu [d]

[a] *Department of Materials Science and Engineering, National Tsing Hua University, Hsin-Chu City 30043, Taiwan*
[b] *Department of Electrical Engineering, National Tsing Hua University, Hsin-Chu City 30043, Taiwan*
[c] *Department of Life Science, National Tsing Hua University, Hsin-Chu City 30043, Taiwan*
[d] *Department of Chemical Engineering, National Tsing Hua University, Hsin-Chu City 30043, Taiwan*

ARTICLE INFO

Article history:
Received 19 October 2012
Received in revised form 2 February 2013
Accepted 13 February 2013
Available online 26 February 2013

Keywords:
Gelatin
Field-effect mobility
OTFT
Pentacene

ABSTRACT

Gelatin is a natural protein in the field of food, pharmaceutical and tissue engineering, which works very well as the gate dielectric for pentacene organic thin-film transistors (OTFTs). An aqueous solution process has been applied to form a gelatin thin film on poly(ethylene terephthalate) (PET) or glass by spin-coating and subsequent casting. The device performance of pentacene OTFTs depend on the bloom number (molecular weight) of gelatin. The pentacene OTFT with 300 bloom gelatin as the gate dielectric in air ambient exhibits the best performance with an average field-effect mobility (μ_{FE}) value of ca. 16 $cm^2 V^{-1} s^{-1}$ in the saturation regime and a low threshold voltage of -1 V. The high performance of the pentacene OTFT in air ambient is attributed to the water resided in gelatin. The crystal quality of pentacene is not the key factor for the high performance.

1. Introduction

Organic thin-film transistors (OTFTs) are attractive for soft electronics because of flexibility, lightweight, large-area applicability and low cost [1,2]. One of the objectives in the research of OTFTs is to raise up the field-effect mobility (μ_{FE}) comparable to inorganic thin-film transistors (TFTs) so that OTFTs can be applied in practical applications such as e-paper, radio-frequency identification (RFID) tags, and biosensors [3–7].

The device performance of OTFTs strongly depends on the choice of gate dielectric, although carriers transports along the channel in the organic semiconducting layer during operation [8–10]. A simple approach to enhance μ_{FE} is to select properly a gate dielectric material in match with the chosen organic semiconductor in OTFTs. For instance, various gate dielectrics have been reported for pentacene OTFTs in the past, such as poly(methyl methacrylate) (PMMA), poly(vinyl pyrrolidone) (PVP), TiO_2-polymer composite, chicken albumen, silk fibroin and AlN [11–17]. Among them, silk fibroin have attracted attention since it may raise up the μ_{FE} value to ca. 23 $cm^2 V^{-1} s^{-1}$ reported by Wang et. al. [15]. The μ_{FE} value is higher than amorphous $InGaO_3(ZnO)_5$ (a-IGZO) TFTs [18].

Silk fibroin is a natural protein and surprisingly serves as an excellent gate dielectric for pentacene to deposit on. The enhanced crystal quality of pentacene on silk fibroin results in a very high μ_{FE} value. The success of silk fibroin in pentacene OTFTs supports that a complex protein structure may be in good match with small molecules such as pentacene at the molecular level. In order to understand deeper the role of natural protein in the device performance of OTFTs, we further investigate the possibility of using other natural proteins as the gate dielectric.

Gelatin is a low-cost natural protein with biocompatible, bioresorbable and biodegradable characteristics. It may be extracted from bone, skin, cartilage and connective tissues. Gelatin has been extensively applied in fields of food, pharmaceutical and tissue engineering. In drug

---

* Corresponding author. Tel.: +886 3 5722577.
E-mail address: jch@mx.nthu.edu.tw (J.-C. Hwang).

1566-1199/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.orgel.2013.02.010

delivery and tissue engineering applications, gelatin has been processed into various nano- or micro-spheres such as nano and microgels [19–22]. In this article, we present the device performance of OTFTs with type A gelatin as the gate dielectric. In general, gelatin contains major amino acids of glycine (Gly), proline (Pro), and 4-hydroxyproline (Hyp). The typical amino acid sequence of the type A gelatin has been reported to be Ala-Gly-Pro-Arg-Gly-Glu-4Hyp-Gly-Pro [23]. The gelatin thin film for OTFTs is formed by casting, which works very well as the gate dielectric for high performance pentacene OTFTs although its ammonic acids are quite different from silk fibroin.

2. Materials and methods

The type A gelatin (Sigma–Aldrich) of 70, 175 or 300 bloom was chosen to prepare the aqueous solution of gelatin (16% w/v) by dispersing 16 g gelatin powders in 100 ml distilled water and followed by heating on a hotplate with stirring at 80 °C for 30 min. The bottom gate configuration was used to fabricate pentacene OTFTs with gelatin as the gate dielectric, which is sketched in Fig. 1a. A gelatin thin film was coated onto a poly(ethylene terephthalate) (PET) or glass substrate patterned with 70 nm Au gate electrodes by spin-coating and subsequent casting at 60 °C for 36 h. The secondary structures of the cast gelatin thin film were analyzed using Fourier transform infrared ray-attenuated total reflection (FTIR-ATR). The cast gelatin thin film on the Au gate electrode was determined to be ca. 1140 nm thick using field emission scanning electron microscopy (FESEM; Fig. 1b). Pentacene (99%, Sigma–Aldrich) without purification was put in a crucible before evaporation. A pentacene layer of 65 nm thick was thermally evaporated at room temperature onto the cast gelatin thin film through a shadow metal mask at a base pressure of 1×10^{-6} torr. The deposition rate of pentacene was kept at 0.3 Å/s that was monitored by a quartz crystal oscillator. The morphology of the pentacene layer of 65 nm was measured using atomic force microscope (AFM; Fig. 1c). 70-nm-thick Au was finally thermally deposited onto pentacene to define source and drain electrodes. The channel length and width were 50 μm and 600 μm, respectively. The device characteristics of OTFTs were measured using Agilent 4155C. Capacitance versus frequency curves in the range of 1 K to 1 MHz were taken to determine the dielectric constant of gelatin using Agilent 4284 impedance analyzer. Quasi-static capacitance versus voltage curves were taken by sweeping voltage across a MIM structure using Agilent B1500. The sweeping rate of voltage in the quasi-static capacitance method is the same as that used for taking transfer characteristics of OTFTs. The quasi-static capacitance value was more accurate in the derivation of μ_{FE}.

3. Results and discussion

3.1. Effect of molecular weight of gelatin on device performance

Pentacene OTFTS were fabricated on PET using gelatin of three different kinds of molecular weight [20,000–25,000 Mw (70 bloom), 40,000–50,000 Mw (175 bloom) and 50,000–100,000 Mw (300 bloom)] as the gate dielectric. The μ_{FE} value in the saturation regime ($\mu_{FE,sat}$), the on/off current ratio, the threshold voltage, the subthreshold swing, and the maximum interface trap density (N_{SS}) value were derived from their output and transfer charac-

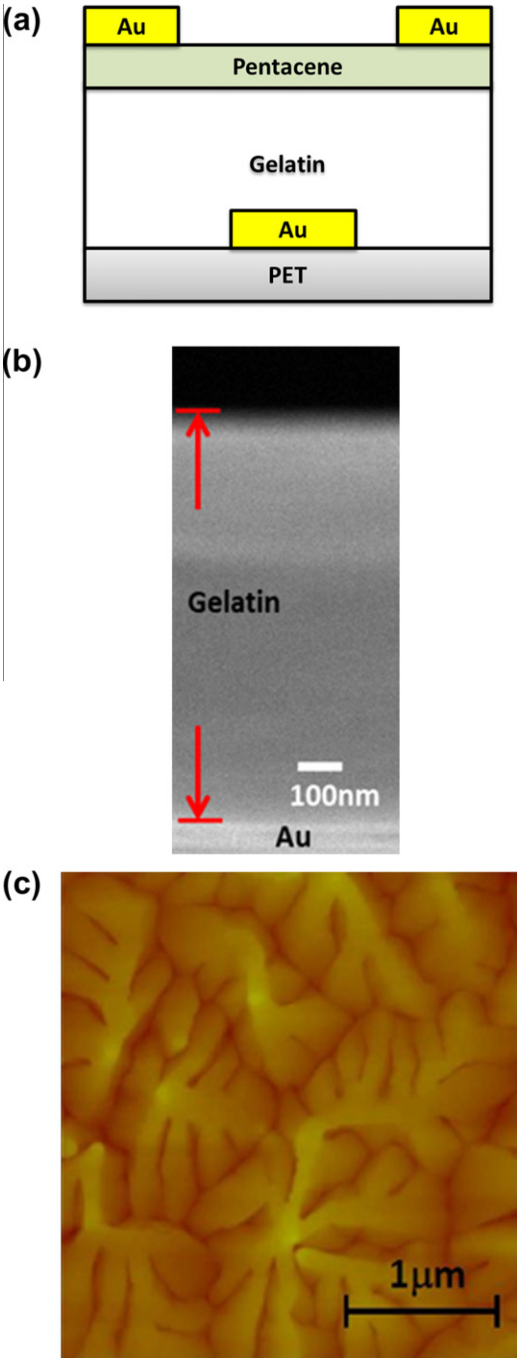


Fig. 1. (a) Schematic of the pentacene OTFT with gelatin as the gate dielectric. (b) Cross-sectional view of the FESEM image showing the thickness of the gelatin/Au/PET structure. The thickness of gelatin is ca. 1140 nm. (c) AFM image showing the morphology of the 65 nm pentacene layer on gelatin.