SAKARYA ÜNİVERSİTESİ FEN BİLİMLERİ ENSTİTÜSÜ DERGİSİ
SAKARYA UNIVERSITY JOURNAL OF SCIENCE
e-ISSN: 2147-835X
Dergi sayfası: http://dergipark.gov.tr/saufenbilder

Geliş/Received
21-05-2017
Kabul/Accepted
22-09-2017

Doi
10.16984/saufenbilder.315161

Solvent effects on the performance of the PVA gate dielectric based organic thin film transistors

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ABSTRACT

In this study, we prepared top-gate bottom-contact transistor and characterized. Poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEH:PPV) was used as active layer and Polyvinyl alcohol (PVA) as used gate dielectric material. We investigated solvent effect on the transistor parameters of the devices. Dimethyl sulfoxide (DMSO) and ultra-pure water were used as solvent for PVA. Effect of DMSO on transistor parameters was investigated and clearly seen that DMSO have positively influence transistor parameters such as mobility, on/off ratio and Vth values. Output and transfer properties of OFET's that has been fabricated by using PVA dissolved in ultra-pure water and DMSO were analayzed. Mobility of the OFET increased when DMSO used as solvent of PVA. Hole mobility's are found as $3.07x10^{-5}$ cm^2 V^{-1} s^{-1} from PVA:water based device and $2.17x10^{-4}$ cm^2 V^{-1} s^{-1} from PVA:DMSO based device.

Keywords: Organic gate dielectric, OFET, Solvent effect, DMSO, MEH:PPV

PVA Kapı dielektrik tabanlı organik ince film transistörlerin performansı üzerindeki solvent etkileri

ÖZ

Bu çalışmada, üst kapı alt kontak transistörü hazırladık ve karakterize ettik. Aktif tabaka olarak poli [2-metoksi-5- (2-etilheksiloksi) -1,4-fenilenevinilen] (MEH: PPV) kapı dielektrik malzemesi olarak Polivinil alkol (PVA) kullanılmıştır. Cihazların transistör parametreleri üzerinde çözücü etkisini araştırılmıştır. PVA için çözücü olarak dimetil sülfoksit (DMSO) ve ultra saf su kullanılmıştır. DMSO'nun mobilite, açma / kapama oranı ve Vth değerleri gibi transistör parametrelerini olumlu etkilediği açık bir şekilde görülmüştür. Ultra saf su ve DMSO içinde çözünmüş PVA kullanılarak imal edilen OFET'lerin out-put ve transfer özellikleri incelenmiştir. OFET'in hareketliliği, DMSO'nun PVA çözücüsü olarak kullanıldığında artmıştır. Delik hareketliliği PVA: su bazlı cihazdan 3.07x10-5 cm2 V-1 s-1 ve PVA:DMSO tabanlı cihazdan 2.17x10-4 cm2 V-1 s-1 olarak bulunmuştur.

Anahtar Kelimeler: Organic kapı yalıtkanı, OFET, Çözücü etkisi, DMSO, MEH:PPV

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1. INTRODUCTION

In recent years Organic Field Effect Transistors (OFETs) have attracted attention because of the unique properties of the semiconductor organic materials such as flexibility, low-cost, low temperature fabricating and large area applications [1-3]. OFETs have found many application area in electronics such as sensors, electronic papers, radio frequency identification (RFID) tags, smart cards, electronic skins, and organic active matrix displays [4-7]. Performance of the OFET devices depend on not only organic semiconductor materials but also dielectric layer and morphological, physical and chemical properties of dielectric/semiconductor interface [8-10]. When OFETs operate charge carriers collect and flow in the semiconductor near the interface of semiconductor/dielectric. Because of that morphological and electrical properties of the dielectric layer are very important for fabricating of OFET devices [11-13]. In this case, solvents of the dielectric materials can be very effective on the device performance due to the fact that morphological and electrical properties of the dielectric layers direct depend on the their solvents properties [14,15]. Recently, Ukah and co-worker published an article about solven effect on OFET parameters. They used PMMA as dielectric material and dissolved in high dipole moment solvent propylene carbonate (PC) and low dipole moment butyl acetate (BTAc). They observed that highg dipole moment solvent PC enhanced device performance [16]. Organic Field Effect Transistors (OFETs) have received considerable interest in recent several years [17-18]. Poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEH:PPV) is a kind of PPV derivative that has good mobility and good solubility in organic solvents. It has been known that polyvinyl alcohol (PVA) is a high-k polymer with many advantages such as good surface order effect, and low-cost materials [19].

In this study we prepared top gate contact transistor and characterized. Poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEH:PPV) was used as active layer and Polyvinyl alcohol (PVA) as used gate dielectric material. We investigated solvent effect on the transistor parameters of the devices. Dimethyl sulfoxide (DMSO) and ultra-pure water were used as solvents for PVA. We report on the study of the electrical characteristics and operational stability of top gate bottom contact OFETs with thin pristine PVA gate dielectric dissolved in ultra-pure water which has dipole moment (1.84 D). These results are compared with devices from pristine PVA gate dielectric dissolved in DMSO with a large (3.96 D) dipole moment. Effect of DMSO on transistor parameters was investigated and clearly seen that DMSO positively influence on transistor parameters. Mobility, on/off ratio and Vth values improved with used DMSO as solvent for PVA instead of Water.

2. EXPERIMENTAL

ITO substrates were cleaned with detergent, de-ionized water, acetone and isopropyl alcohol in ultrasonic bath respectively. PVA was dissolved in deionized water (50mg/ml) and in DMSO (70mg/ml) at 80 oC for 1 hour with magnetic stirrer. Dissolved PVA was coated on ITO substrate with spin coating method for 60s (deionized water) and 15 min (DMSO) (~150nm).PVA coated ITO substrates were annealed for 24 hours at 100 oC. After that we coated MEH:PPV was dissolved in 1,2 dichlorobenzene (6mg/1ml) on PVA with spin casting. Finally, top contact source/drain (70 nm) silver electrodes defining a channel length and width of 400 µm and 50 µm, respectively, were thermally evaporated onto the MEH:PPV layer by using shadow-mask. Fabricated devices were characterized with keithley 4200 semiconductor characterization system. Dielectric properties of the PVA layers was characterized with keithley impedance analyzer.

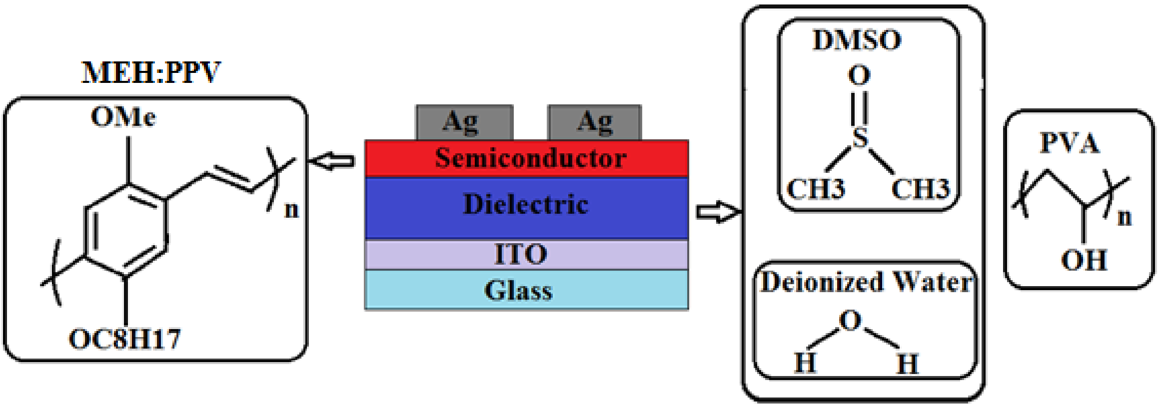

Figure 1. Schematic illustration of a bottom-gate/top-contact-structured polymer-based field-effect transistor and the chemical structures of the polymer gate dielectrics (PVA), the solvents for these gate dielectrics (DMSO and Deionized water), and the semiconducting polymer (MEH:PPV) used in this study

3. RESULT AND DISCUSSION

Capacitive properties of PVA thin films that prepared with different solvents were investigated via impedance spectroscopy. PVA was solved in ultra-pure water and DMSO and then it was coated on ITO coated glass substrate. Finally Ag was coated on PVA by thermal evaporation. Figure 2 shows the dielectric properties of the PVA thin film in the MIM diod structure. It is clearly seen that form the figure 2 using of DMSO as solvent increase the capacity of the PVA thin film. It can be attributed that dipole moment of the DMSO larger that ultra-pure water because that capacity of the PVA thin film increase from 15 nF/cm^2 to 50 nF/cm^2. Enhanced dielectric properties of the PVA in DMSO can be attributed the distance of the mean square end-to-end of polymer chains. This distances can be increased by high dipol moment solvents. Because of that polymer chains can be placed as more extended and more stacked [16]. High capacity of the PVA thin film enhance the transistor parameters of the OFET devices fabricated with PVA gate dielectric.

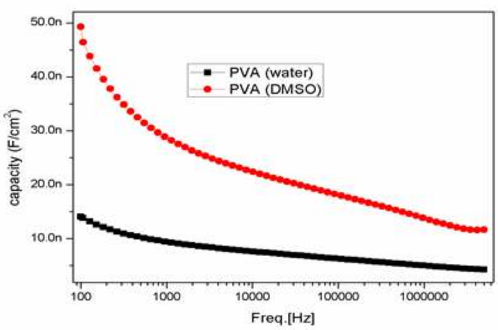

Figure 2. Capacitive properties of PVA dielectric films solved in ultra-pure water (dark dashes) and DMSO (red dashes) at different frequencies.

Figure 3 shows the output (a) and transfer (b) characteristics of the OFET device fabricated with PVA gate dielectric solved in ultra-pure water. As shown in Fig. 3 (a), device exhibit typical characteristics of the p-type field-effect transistor biased at negative source-drain voltage (V_{DS}) and negative gate voltage (V_{GS}). Figure 3 (b) gives the transfer characteristic of the device, I_{DS} versus V_G curve is given at a fixed V_{DS} = -50 V condition. It is clearly seen that form figure 3 (b) device shows ideal gate modulation with 10^2 on/off ratio and $[I_{DS}]^{1/2}$ versus V_G graph is given in the figure 3(b). Mobility (μ) of the OFETs were calculated from Eq. 1 to each transfer characteristic.

$$I_{DS} = (\frac{WC_i}{2L})\mu(V_G - V_{th})^2 \quad (1)$$

Where W is channel width, L is channel length, V_{th} is the threshold voltage and C_i is the effective capacitance of the dielectric material. Mobility (μ), Vth and Ion/off values were calculated as 3.07x10^{-5}, +15 V and ~10^2 respectively for ultra-pure water solvent based OFET. Figure 4 shows the output (a) and transfer (b) characteristics of the OFET device fabricated with PVA gate dielectric solved in DMSO. As shown in Fig. 3 (a), device exhibit typical characteristics of the p-type field-effect transistor biased at negative source-drain voltage (V_{DS}) and negative gate voltage (V_{GS}). Figure 4 (b) gives the transfer characteristic of the device, I_{DS} versus V_G curve is given at a fixed V_{DS} = -50 V condition. It is clearly seen that form figure 3 (b) device shows ideal gate modulation with 10^3 on/off ratio and $[I_{DS}]^{1/2}$ versus V_G graph is given in the figure 3(b).

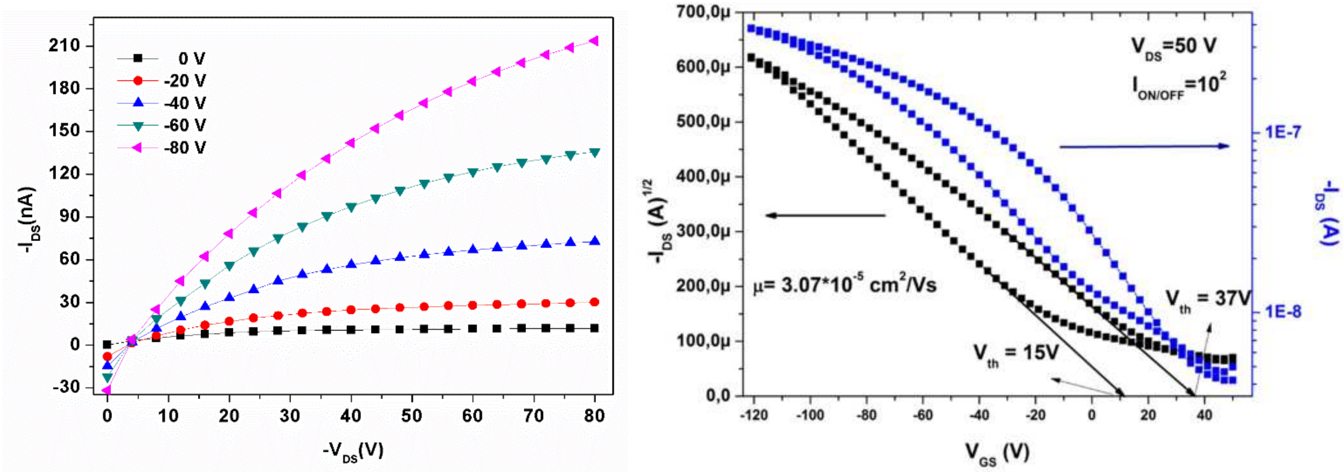

Figure 3. Output and transfer characteristic of OFET produced with thin film PVA dielectric solved in ultra-pure water

OFET parameters of the DMSO based device were calculated from Eq. 1 and $[I_{DS}]^{1/2}$ versus V_G graph. Mobility (μ), Vth and Ion/off values were calculated as $2.17x10^{-4}$, -5 V and ~10^3 respectively for DMSO solvent based OFET. Table 1 also summarized OFET parameters of the devices based ultra-pure water and DMSO solvent for PVA as gate dielectric material. It is clearly seen that form the table 1, OFET parameters of the devices are enhanced by using DMSO solvent for the gate dielectric.

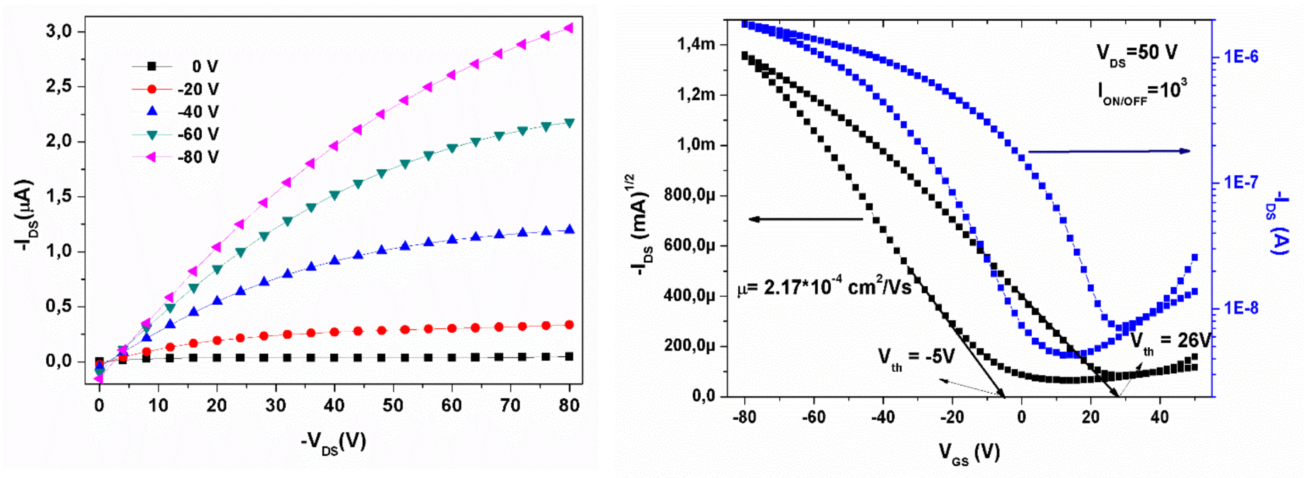

Figure 4. Output and transfer characteristic of OFET produced with thin film PVA dielectric solved in DMSO

OFET parameters of the DMSO based device were calculated from Eq. 1 and $[I_{DS}]^{1/2}$ versus V_G graph. Mobility (μ), Vth and Ion/off values were calculated as $2.17x10^{-4}$, -5 V and ~10^3 respectively for DMSO solvent based OFET. Table 1 also summarized OFET parameters of the devices based ultra-pure water and DMSO solvent for PVA as gate dielectric material.

Table 1. Performance parameters of the fabricated OFETs.

Solvent	V(Operation Voltage)	$I_{on/off}$	V_{th}(V)	μ(cm^2 $V.s^{-1}$)
Ultra-pure water	**-120**	**10^2**	**+15V**	**$3.07x10^{-5}$**
DMSO	**-80**	**10^3**	**-5V**	**$2.17x10^{-4}$**

It is clearly seen that form the table 1, OFET parameters of the devices are enhanced by using DMSO solvent for the gate dielectric. It can be attributed that DMSO increase the capacitance of the PVA because of that it has larger dipol moment according to ultra-pure water. Besides PVA film is smoother and more contentious as DMSO is a solvent that evaporates later than ultra-pure water. Because of this properties using of DMSO as a solvent more suitable for ink-jet printing method. Coating methods as ink-jet printing are important for mass production of OFET devices.

4. CONCLUSIONS

Solvent effect on the OFET parameters were investigated to improve the operation voltages and field effect mobility of OFETs, DMSO and ultra-pure water were used as solvents for PVA gate dielectric materiel. Firstly, significant improvement in the dielectric properties of PVA is demonstrated with DMSO solvent. Hole mobility's are found as 3.07x10-5 cm2 V−1 s−1 from PVA:water based device and 2.17x10-4 cm2 V−1 s−1 from PVA:DMSO based device. In addition on/off ratio and Vth were improved by using DMSO as solvent for PVA dielectric. These results show that using of DMSO as a solvent is a feasible and simple method to improve the device performance of OFETs based PVA dielectric. Besides using of DMSO as a solvent can be gives promising result for mass production methods as ink-jet printing for the OFETs.

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