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Research Article

Evaluation of Industrial Poly(tert-butyl acrylate)-(PtBA) as Insulator Layer in p-Channel Organic Field Effect Transistor-(p-OFET): Fabrication and Electrical Characterization of PtBA-p-OFET

Ahmet DEMİR [a,*], Ahmad badreddin MUSATAT [b]

[a] *Department of Physics, Faculty of Faculty of Arts & Sciences, Düzce University, Düzce, TURKEY*
[b] *Department of Chemistry, Faculty of science, Sakarya University, Sakarya, TURKEY*
** Corresponding author's e-mail address: ahmetdemir@duzce.edu.tr*
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ABSTRACT

Poly(tert-butyl acrylate) (PtB-p-A) has been investigated as a promising insulator layer for p-channel organic field effect transistors (p-OFETs) using the p-type semiconductor Poly(3-hexylthiophene-2,5-diyl (P3HT) due to its favorable insulating properties, good film-forming ability and electrical charge separation properties. Top-gate, bottom-contact PtBA-p-OFET devices are fabricated with Indium Thin Oxide (ITO) source/drain electrodes and a P3HT organic semiconductor layer. The frequency-dependent capacitance of the PTBA-p-OFETs was studied through a plot to determine the key parameters, including the threshold voltage (V_{Th}), field-effect mobility (μ_{FET}), and the current on/off ratio ($I_{on/off}$) of the device. The PTB-p- OFETs exhibit field-effect mobility value of 6.13x10^{-4} (cm^2/V.s), an on/off current ratio of 1.11x10^2, and a threshold voltage of -15.8 V. The capacitance-frequency characteristics of the capacitor structure were analyzed and found to have as 7.6 nF/cm^2 per unit area. This work presents PTBA as a promising for high-performance p-OFET applications.
Keywords: *Industrial PtBA, Effective Capacitance, and Mobility, PtBA-p-OFET.*

Endüstriyel Poli(tert-butil akrilat)-(PtBA)'nın p-Kanal Organik Alan Etkili Transistör-(p-OFET)'de Yalıtkan Katman Olarak Değerlendirilmesi: PtBA-p-OFET'in Üretimi ve Elektriksel Karakterizasyonu

ÖZET

Poli(ters-bütil akrilat) (PTB-p-A), üst-kapı, alt-kontak tipinde üretilen p-kanal organik alan etkili transistörlerde (p-OFET'lerde) p-tipi yarı iletken olan Poli(3-hekzil tiofen-2,5-diil) (P3HT)'nin kullanılmasıyla izolatör katman olarak araştırılmıştır. Bunun sebebi, PTBA'nın olumlu izolatör özellikleri, iyi film oluşturma yeteneği ve elektrik yükü ayırma özellikleridir. İndiyum kalay oksit (İTO) kaynak/oluk elektrodları ve P3HT organik yarı iletken tabakası kullanılarak PTBA-p-OFET cihazları üretilmiştir. PTBA-p-OFET'lerin frekans bağımlı kapasitesi, eşik gerilimi (V_{Th}), alan etkili hareketliliği (μ_{FET}) ve akım aç/kapat oranı ($I_{on/off}$) gibi ana parametreleri belirlemek için karakteristik grafikler çizilmiştir. PTB-p- OFET'ler 6,13x10^{-4} (cm^2/V.s) değerinde alan etkili hareketliliği, 1,11x10^2 akım aç/kapat oranı ve -15,8 V eşik gerilimine sahiptir. Kondansatör yapısının kapasite-frekans özellikleri incelenmiş ve birim alan başına 7,6 nF/cm^2 olduğu bulunmuştur. Bu çalışma, PtBA'nın yüksek performanslı p-OFET uygulamaları için umut verici bir malzeme olabileceğini göstermektedir.
Anahtar Kelimeler: *Endüstriyel PtBA, Etkili Kapasite ve Hareketlilik, PtBA-p-OFET.*

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I. INTRODUCTION

Organic field effect transistors (OFETs) have emerged as a cornerstone technology for the development of flexible and bendable electronics, offering a promising alternative to conventional inorganic semiconductors. The pursuit of easily processable and manufacturable p-channel OFETs is driven by the need for complementary logic circuits that require both p-type and n-type transistors for efficient operation. Despite significant advances in p-type materials, n-channel OFETs have faced challenges in achieving comparable levels of charge carrier mobility, stability and processability [1]–[5]. the use of organic materials with high charge carrier mobility plays a crucial role in improving the performance of organic field effect transistors (OFETs). However, various strategies such as partial chemical doping can potentially contribute to improving charge mobility in OFETs [6]–[8]. Overcome low charge mobility, a wide variety of organic materials have been investigated in recent years for incorporation into the dielectric and semiconductor layers of OFETs [9]. Organic polymeric semiconductor materials are primarily intended to display good solubility in organic solvents. Significant research efforts have been devoted to the search for novel π-conjugated molecules to achieve high charge carrier mobility in OFETs [10]. Among π-conjugated materials, poly(3-hexylthiophene) (P3HT) polymer has emerged as one of the most important and widely used materials in OFETs as a p-type organic semiconductor that serves as an active layer material in organic electronics research due to its relatively good charge carrier mobility. Therefore, most semiconductor and photonic devices require thin-film deposition of organic materials. For the performance of OFETs, semiconductor materials must also be used in combination with a compatible insulator material. Another promising insulator material that is compatible with such a p-type semiconductor such as P3HT is PtBA [11]. Furthermore, the performance of organic electronic devices using a compliant insulator and organic semiconductors together is mainly determined by the charge transport mobility (μ), threshold voltage (V_{Th}) and current on/off ratio ($I_{on/off}$) and charge transfer, which is the key property that drives the performance of the devices [12]–[16].

On the other hand, Poly(tert-butyl acrylate) is an insulator polymer with a wide band gap, soluble in organic solvents and well compatible with p-type semiconductors [17]. PTBA is also known for its excellent film-forming abilities, chemical resistance, and thermal stability, which are essential characteristics for the insulating layers in OFETs [18]. The evaluation of PTBA in OFETs is particularly interesting as it opens up possibilities to improve device performance through materials engineering. Previous studies have extensively investigated device behavior in thin-film transistors with enhanced hole mobility by mixing diF-TES with ADT, with a percolation threshold of 39 wt%, and in air-stable PTBA-based transistors [19], [20] [18,19], also by the role of film crystallinity [21], while others correlated the phase behavior of PtBA films with field effect mobility [22]. However, the bulky tert-butyl groups bend the polymer backbone, helping to form dipoles throughout the material due to the steric hindrance caused by the tert-butyl moiety, which may affect chain packing and aromatic π stacking [23]. Additionally, the substituents provide steric protection of the conjugated backbone, giving PTBA-p good environmental, thermal and air stability suitable for practical applications [24]. Collectively, these studies highlight the potential of PTBA films to improve the field-effect mobility and stability of thin-film transistors due to their strong anisotropy. At the same time, PTBA exhibits a broadband optical absorption from UV to visible wavelengths due to its energy levels [25], [26]. The development of PtBA-based p-channel OFETs (PtBA-p-OFETs) represents an important step forward in the field of organic electronics. The flexibility, tunability and solution-processability of conjugated polymers make them ideal candidates for various electronic devices. This research paper aims to explore recent advances in PtBA-p -OFETs, focusing on the potential applications of PtBA in organic electronic devices. By addressing critical aspects of charge carrier mobility, stability and manufacturability, we aim to highlight the progress made towards the commercialization of p-channel industrial polymer-based organic semiconductors devices and their integration into next-generation electronic devices.

II. Experimental

Experimentally, commercially available pre-patterned indium tin oxide (ITO) substrates were employed as source/drain contacts, and a poly(3,4-ethylenedioxythiophene):polystyrene sulfonate (PEDOT:PSS) composite formulation was utilized as the gate electrode for fabricating organic field-effect transistor (OFET) devices with a PtBA insulator, the molecular shape of which is shown in Figure-1.

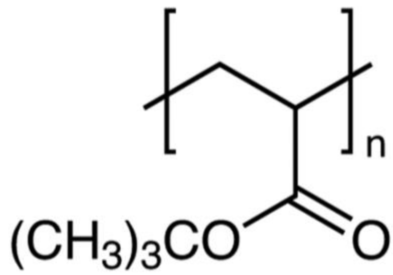

Fig 1. The molecular shape of PtBA.

The pre-patterned substrates underwent a sequential cleaning process, involving ultrasonic deionized water baths, acetone, and ethanol treatments. A final cleaning step with isopropyl alcohol was performed, followed by drying with inert nitrogen gas. Poly(3-hexylthiophene) (P3HT), whose molecular shape is given in Figure-2 and dissolved in chlorobenzene at a concentration of 10 mg/mL, was then used to form an active layer on pre-patterned substrates by spin coating at 3000 rpm for 60 seconds.

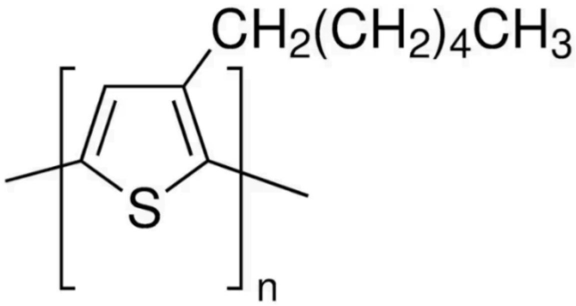

Fig 2. The molecular shape of P3HT.

The films were then annealed at 150°C for 60 seconds on a hot plate to remove solvents. The PtBA polymer insulator material, dissolved in Butanone (20 mg/mL), was spin-coated onto the active layer at 1500 rpm for 60 seconds, forming an insulator layer. The film was also annealed at 120°C for 60 seconds on a hot plate. Finally, the PEDOT:PSS composite formulation, functioning as the gate electrode, was spin-coated on the insulator layer at 1000 rpm for 30 seconds, completing the OFET device construction with PtBA insulator as shown in Figure-3. The fabricated OFET devices were vacuumed to remove the dimethyl sulfoxide (DMSO) solvent from the PEDOT:PSS composite formulation, preparing them for evaluation. A Keithley 2612B source measure unit (SMU) instrument, along with an OFET test board, was utilized to investigate the current-voltage (I-V) characteristics of the OFET devices. The gate-source voltage (V_{GS}) was varied in intervals of 0V to -80 V, while the drain-source voltage (V_{DS}) was swept over a range of 0 to -60 V. Additionally, the capacitance-frequency (C_i-f) characteristics for the PtBA-based OFET devices were measured using a GW Instek 8105 LCR meter. Entire measurements were conducted in the dark at room temperature.

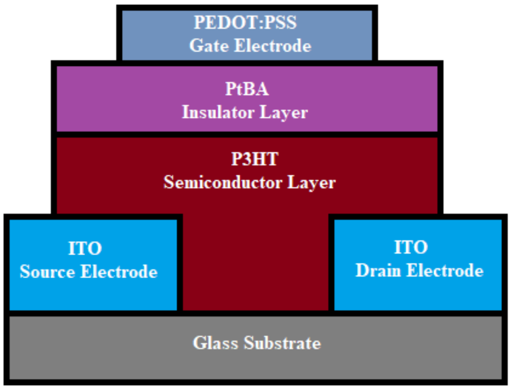

Fig 3. The schematic representation of the completed PtBA-p-OFET device.

III. Results and Discussion

The capacitance of the PEDOT:PSS/PtBA/P3HT/ITO (PtBA-pOFET device) structure was measured at frequencies ranging from 100 Hz to 1 MHz to assess the device's mobility. Figure 4 shows the frequency-dependent capacitance characteristics of the PtBA-p-OFET. Clearly, the capacitance of PTBA was measured as 7.6 nF/cm^2 per unit area. In organic field-effect transistors which rely on a capacitive effect for operation, the capacitance of the insulating layer is a crucial parameter as it directly influences the calculated charge carrier mobility [27]–[29]. At the low switching frequencies typically used when evaluating mobility in these devices, the relevant capacitance value is the static capacitance of the insulator.

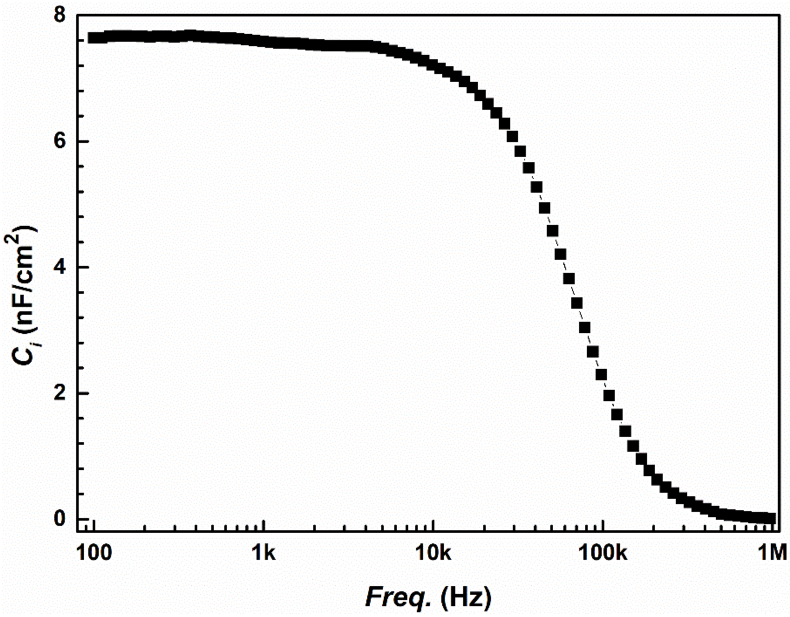

Fig 4. The effective capacitance plots against frequency of ITO/PtBA/ITO.

The PtBA-p-OFET devices exhibited robust output characteristics when tested in complete darkness using a Keithley 2612B SMU controlled by a computer, as shown in Figure 5. The devices demonstrated a well-defined saturation regime at a -60 V source-drain bias, owing to the high anisotropy of the PtBA insulator and the p-type conductivity of the P3HT semiconductor. The performance of the OFETs can be optimized by employing the PtBA gate insulator, which exhibits excellent polarizability and charge separation capabilities, as reported in previous studies [30], [31]. The strong polarization at the P3HT/PtBA interface leads to the efficient excitation of charge carriers, facilitated by the good compatibility between the two materials. Consequently, the PtBA-p-OFET devices displayed stable and consistent behavior over the tested voltage range of 0 V to -80 V, with 20 V steps.

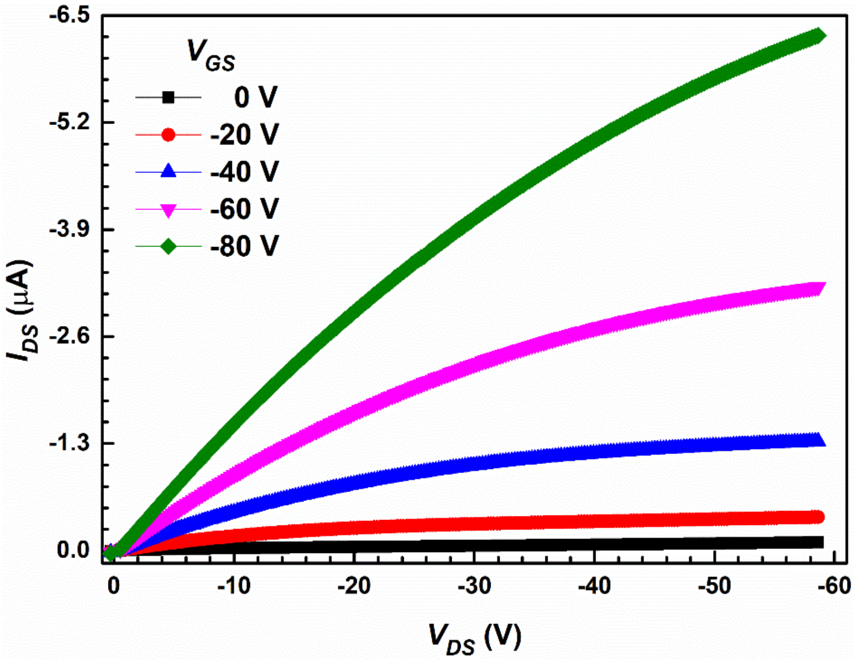

Fig 5. The output characteristics of the PtBA-OFET.

Figure 6 presents the transfer characteristics of the OFETs with the source-drain current (I_{DS}) plotted on both left y-axis logarithmically and right y-axis as the square root versus the gate-source voltage (V_{GS}). The current on/off ratio ($I_{on/off}$) can be determined from the left axis as the ratio of the maximum I_{DS} to the minimum I_{DS}, following previous reports [32]. Furthermore, the OFETs' threshold voltage (V_{Th}) is calculated by expanding the linear area of the square root plot on the right axis to intersect the x-axis, a typical procedure [27]. In this way, both the subthreshold slope and field-effect mobility can be estimated from the transfer curves, allowing characterization of the key electrical parameters of the fabricated devices.

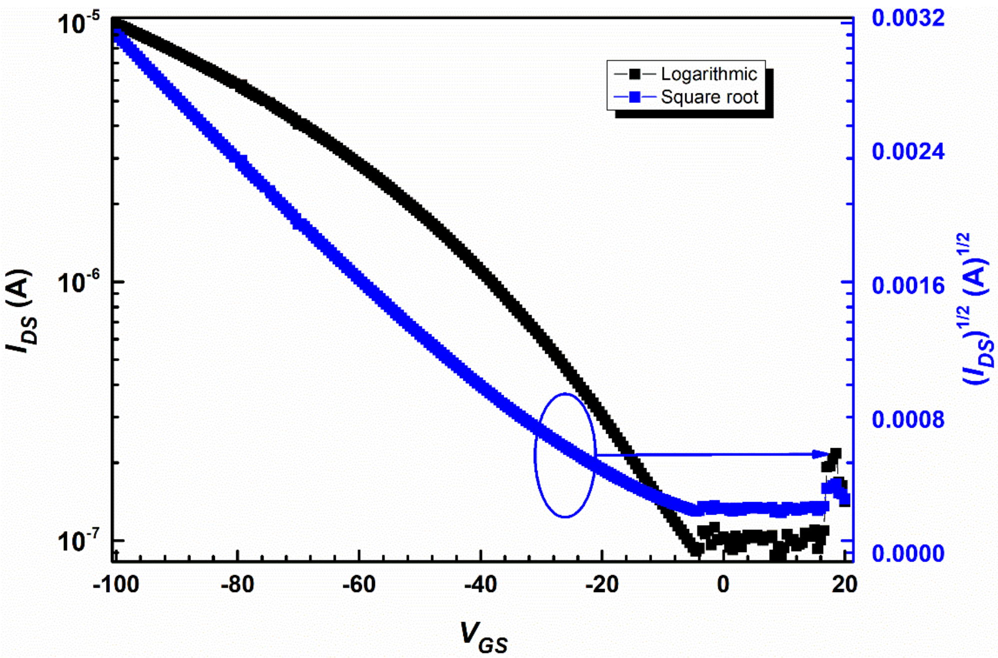

Fig 6. The Transfer characteristics of the PtBA-OFET.

Equation (1) defines field effect mobility (μ_{FET}) as the greatest drain current (I_{DS}) for a given gate voltage (V_{GS}). [33]–[35].

$$I_{DS} = \left[\mu_{FET}\frac{WC_i}{2L}\right](V_{GS} - V_{Th})^2 \quad (1)$$

C_i can be defined as the capacitance of the insulator layer and μ_{FET} denote the field-effect mobility of the device

$$\alpha = \left(\frac{WC_i}{2l}\right)^{\frac{1}{2}} \quad (2)$$

succeeding each material is coated on top of each other for the fabrication of the PTBA-p-OFET device, The PEDOT:PSS and PTBA layers served as the polymeric gate contact and insulator layers, respectively, with the P3HT acting as the active layer. on the saturation regime, the mobility was calculated using the best fit of the transfer characteristics on the right axis of Figure 6. To obtain the mobility values of the devices, use equation (2), where α represents the slope taken from the best fit on the right axis from Figure 6, the figure shows the μ_{FET}, $I_{on/off}$, V_{Th} values of the PtBA-p-OFET polymer-based structure, which were 6.13x10^{-4} cm^2/V.s, 1.11x10^2, and -15.8 V, respectively. It is also known that as high the $I_{on/off,}$ the transistor may operate quicker and obtain superior device performance [33]. On the other hand, values for these parameters are highly consistent with the literature [36].

IV. CONCLUSION

This study presents a comprehensive evaluation of industrial poly(tert-butyl acrylate) (PtBA) as an insulating layer for p-channel organic field-effect transistors (p-OFETs) using the p-type semiconductor poly(3-hexylthiophene-2,5-diyl) (P3HT). Based on the obtained results, the fabricated PtBA-p-OFET devices exhibited favorable electrical characteristics, including a field-effect mobility (μFET) of 6.13x10^{-4} cm^2/V·s, an on/off current ratio ($I_{on/Ioff}$) of 1.11x10^2, and a threshold voltage (VTh) of -15.8 V. Also, the frequency-dependent capacitance analysis of the PTBA insulating layer revealed a capacitance value of 7.6 nF/cm^2 per unit area, indicating its suitability as a dielectric material for p-OFET applications. The output and transfer characteristics of the PTBA-p-OFET devices demonstrated stable and well-defined saturation behavior, confirming the compatibility and effectiveness of the PTBA insulator with the P3HT semiconductor. The high dielectric, good polarizability, and charge separation capabilities of PtBA contribute to the observed improvements in the device performance parameters, highlighting its potential as a promising insulator material for good-performance p-channel organic electronics. This work showcases the practical potential of industrial PTBA as a solution-processable and compatible insulator for developing advanced p-OFET devices. All over our findings pave the way for further exploration and optimization of PTBA-based organic electronics, targeting applications in flexible, lightweight, and large-area display technologies, as well as integrated circuits and sensors.

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V. REFERENCES

[1] A. Facchetti, “Semiconductors for organic transistors,” *Mater. Today*, vol. 10, no. 3, pp. 28–37, Mar. 2007, doi: 10.1016/S1369-7021(07)70017-2.

[2] R. Kim *et al.*, “High-Mobility Air-Stable Naphthalene Diimide-Based Copolymer Containing

Extended π-Conjugation for n-Channel Organic Field Effect Transistors," *Adv. Funct. Mater.*, vol. 23, no. 46, pp. 5719–5727, Dec. 2013, doi: 10.1002/adfm.201301197.

[3] T. Marszalek, M. Wiatrowski, E. Dobruchowska, J. Jung, and J. Ulanski, "One-step technique for production of bi-functional low molecular semiconductor–polymer composites for flexible OFET applications," *J. Mater. Chem. C*, vol. 1, no. 19, p. 3190, 2013, doi: 10.1039/c3tc30163j.

[4] C. Lee, W. Lee, M. Song, H. Kim, and Y. Kim, "Thermal Sensing Characteristics of Low-Voltage n-Channel Organic Field-Effect Transistors With Triple Layers of Naphthalenediimide-Containing Conjugated Polymer and Gate-Insulating Polymers," *IEEE Trans. Electron Devices*, vol. 70, no. 2, pp. 720–725, Feb. 2023, doi: 10.1109/TED.2022.3228217.

[5] S. Kola, J. Sinha, and H. E. Katz, "Organic transistors in the new decade: Toward n-channel, printed, and stabilized devices," *J. Polym. Sci. Part B Polym. Phys.*, vol. 50, no. 15, pp. 1090–1120, Aug. 2012, doi: 10.1002/polb.23054.

[6] S. Nam, J. Kim, H. Lee, H. Kim, C.-S. Ha, and Y. Kim, "Doping Effect of Organosulfonic Acid in Poly(3-hexylthiophene) Films for Organic Field-Effect Transistors," *ACS Appl. Mater. Interfaces*, vol. 4, no. 3, pp. 1281–1288, Mar. 2012, doi: 10.1021/am300141m.

[7] C. D. Dimitrakopoulos, S. Purushothaman, J. Kymissis, A. Callegari, and J. M. Shaw, "Low-Voltage Organic Transistors on Plastic Comprising High-Dielectric Constant Gate Insulators," *Science (80-.).*, vol. 283, no. 5403, pp. 822–824, Feb. 1999, doi: 10.1126/science.283.5403.822.

[8] G. Wang, J. Swensen, D. Moses, and A. J. Heeger, "Increased mobility from regioregular poly(3-hexylthiophene) field-effect transistors," *J. Appl. Phys.*, vol. 93, no. 10, pp. 6137–6141, May 2003, doi: 10.1063/1.1568526.

[9] H.-I. Un, J.-Y. Wang, and J. Pei, "Recent Efforts in Understanding and Improving the Nonideal Behaviors of Organic Field-Effect Transistors," *Adv. Sci.*, vol. 6, no. 20, p. 1900375, Oct. 2019, doi: 10.1002/advs.201900375.

[10] Y. Zhou, K. Zhang, Z. Chen, and H. Zhang, "Molecular Design Concept for Enhancement Charge Carrier Mobility in OFETs: A Review," *Materials (Basel).*, vol. 16, no. 20, p. 6645, Oct. 2023, doi: 10.3390/ma16206645.

[11] J. Wang, H. Wang, X. Yan, H. Huang, and D. Yan, "Organic heterojunction and its application for double channel field-effect transistors," *Appl. Phys. Lett.*, vol. 87, no. 9, p. 93507, Aug. 2005, doi: 10.1063/1.2037204.

[12] L. Feriancová *et al.*, "Dithienylnaphthalenes and quaterthiophenes substituted with electron-withdrawing groups as n-type organic semiconductors for organic field-effect transistors," *J. Mater. Chem. C*, vol. 10, no. 27, pp. 10058–10074, 2022, doi: 10.1039/D2TC01238C.

[13] H. Jia and T. Lei, "Emerging research directions for n-type conjugated polymers," *J. Mater. Chem. C*, vol. 7, no. 41, pp. 12809–12821, 2019, doi: 10.1039/C9TC02632K.

[14] C.-H. Chen *et al.*, "Novel Photoinduced Recovery of OFET Memories Based on Ambipolar Polymer Electret for Photorecorder Application," *Adv. Funct. Mater.*, vol. 29, no. 40, p. 1902991, Oct. 2019, doi: 10.1002/adfm.201902991.

[15] T. Kimoto *et al.*, "Bis(methylthio)tetracenes: Synthesis, Crystal-Packing Structures, and OFET Properties," *J. Org. Chem.*, vol. 76, no. 12, pp. 5018–5025, Jun. 2011, doi: 10.1021/jo200696a.

[16] L. Fijahi *et al.*, “High throughput processing of dinaphtho[2,3- b :2′,3′- f]thieno[3,2- b]thiophene (DNTT) organic semiconductors,” *Nanoscale*, vol. 15, no. 1, pp. 230–236, 2023, doi: 10.1039/D2NR05625A.

[17] S. A. Shin, J.-H. Kim, J. B. Park, and D.-H. Hwang, “Semiconducting Polymers Consisting of Anthracene and Benzotriazole Units for Organic Solar Cells,” *J. Nanosci. Nanotechnol.*, vol. 15, no. 2, pp. 1515–1519, Feb. 2015, doi: 10.1166/jnn.2015.9325.

[18] M. Yi, J. Guo, W. Li, L. Xie, Q. Fan, and W. Huang, “High-mobility flexible pentacene-based organic field-effect transistors with PMMA/PVP double gate insulator layers and the investigation on their mechanical flexibility and thermal stability,” *RSC Adv.*, vol. 5, no. 115, pp. 95273–95279, 2015, doi: 10.1039/C5RA18996A.

[19] J. Smith *et al.*, “Percolation behaviour in high mobility p-channel polymer/small-molecule blend organic field-effect transistors,” *Org. Electron.*, vol. 12, no. 1, pp. 143–147, Jan. 2011, doi: 10.1016/j.orgel.2010.10.017.

[20] G. Lu *et al.*, “Synthesis, Characterization, and Transistor Response of Semiconducting Silole Polymers with Substantial Hole Mobility and Air Stability. Experiment and Theory,” *J. Am. Chem. Soc.*, vol. 130, no. 24, pp. 7670–7685, Jun. 2008, doi: 10.1021/ja800424m.

[21] T. Umeda, S. Tokito, and D. Kumaki, “High-mobility and air-stable organic thin-film transistors with highly ordered semiconducting polymer films,” *J. Appl. Phys.*, vol. 101, no. 5, p. 54517, Mar. 2007, doi: 10.1063/1.2711780.

[22] C. J. Newsome, T. Kawase, T. Shimoda, and D. J. Brennan, “Phase behavior of polymer semiconductor films and its influence on the mobility in FET devices,” Nov. 2003, p. 16, doi: 10.1117/12.504515.

[23] M. D. Ogden, C. J. Orme, and F. F. Stewart, “Effects of alkyl substitution on the physical properties and gas transport behavior in selected poly(R-phenoxyphosphazenes),” *Polymer (Guildf).*, vol. 52, no. 18, pp. 3879–3886, Aug. 2011, doi: 10.1016/j.polymer.2011.07.010.

[24] L. Fernandes, H. Gaspar, J. P. C. Tomé, F. Figueira, and G. Bernardo, “Thermal stability of low-bandgap copolymers PTB7 and PTB7-Th and their bulk heterojunction composites,” *Polym. Bull.*, vol. 75, no. 2, pp. 515–532, Feb. 2018, doi: 10.1007/s00289-017-2045-8.

[25] V. Tamilavan, M. Song, S.-H. Jin, and M. H. Hyun, “Synthesis of conjugated polymers with broad absorption bands and photovoltaic properties as bulk heterojuction solar cells,” *Polymer (Guildf).*, vol. 52, no. 11, pp. 2384–2390, May 2011, doi: 10.1016/j.polymer.2011.03.040.

[26] X. Wu *et al.*, “Hydrophobic Poly(tert -butyl acrylate) Photonic Crystals towards Robust Energy-Saving Performance,” *Angew. Chemie Int. Ed.*, vol. 58, no. 38, pp. 13556–13564, Sep. 2019, doi: 10.1002/anie.201907464.

[27] A. Demir, A. Atahan, S. Bağcı, M. Aslan, and M. Saif Islam, “Organic/inorganic interfaced field-effect transistor properties with a novel organic semiconducting material,” *Philos. Mag.*, vol. 96, no. 3, pp. 274–285, Jan. 2016, doi: 10.1080/14786435.2015.1130277.

[28] L. Herlogsson *et al.*, “Low-Voltage Polymer Field-Effect Transistors Gated via a Proton Conductor,” *Adv. Mater.*, vol. 19, no. 1, pp. 97–101, Jan. 2007, doi: 10.1002/adma.200600871.

[29] F. Bordi, C. Cametti, and R. H. Colby, “Dielectric spectroscopy and conductivity of polyelectrolyte solutions,” *J. Phys. Condens. Matter*, vol. 16, no. 49, pp. R1423–R1463, Dec. 2004, doi: 10.1088/0953-8984/16/49/R01.

[30] P. Paoprasert *et al.*, “Dipolar Chromophore Functional Layers in Organic Field Effect Transistors,” *Adv. Mater.*, vol. 20, no. 21, pp. 4180–4184, Nov. 2008, doi: 10.1002/adma.200800951.

[31] C. A. Nguyen, P. S. Lee, and S. G. Mhaisalkar, “Investigation of turn-on voltage shift in organic ferroelectric transistor with high polarity gate dielectric,” *Org. Electron.*, vol. 8, no. 4, pp. 415–422, Aug. 2007, doi: 10.1016/j.orgel.2007.01.010.

[32] X.-H. Zhang, B. Domercq, and B. Kippelen, “High-performance and electrically stable C60 organic field-effect transistors,” *Appl. Phys. Lett.*, vol. 91, no. 9, p. 92114, Aug. 2007, doi: 10.1063/1.2778472.

[33] B. Chandar Shekar, J. Lee, and S.-W. Rhee, “Organic thin film transistors: Materials, processes and devices,” *Korean J. Chem. Eng.*, vol. 21, no. 1, pp. 267–285, Jan. 2004, doi: 10.1007/BF02705409.

[34] G. Xu, Z. Bao, and J. T. Groves, “Langmuir−Blodgett Films of Regioregular Poly(3-hexylthiophene) as Field-Effect Transistors,” *Langmuir*, vol. 16, no. 4, pp. 1834–1841, Feb. 2000, doi: 10.1021/la9904455.

[35] A. Demır, S. Bağcı, S. E. San, and Z. Doğruyol, “Pentacene-Based Organic Thin Film Transistor With SiO_2 Gate Dielectric,” *Surf. Rev. Lett.*, vol. 22, no. 03, p. 1550038, Jun. 2015, doi: 10.1142/S0218625X15500389.

[36] M. Gurel, F. K. Cavus, A. Demir, E. Doganci, A. Alli, and S. Alli, “Synthesis and electrical characterization of poly[(linoleic acid)- g -(styrene)- g -(ε -caprolactone)] graft copolymers as gate insulator for OFET devices,” *Polym. Int.*, vol. 72, no. 8, pp. 727–737, Aug. 2023, doi: 10.1002/pi.6531.