Semnan University

Progress in Physics of Applied Materials

journal homepage: https://ppam.semnan.ac.ir/

Nonferritic Metallic Oxide / Polyvinyl Alcohol Polymer Nanocomposite as a Biocompatible Dielectric Material for Future Generations of Clean Energy Systems

Ali Bahari [a*], Vaheed Fallah Hamidabadi [b], Abbas Farhadi Koutenaei [a], Nasrin Moradbeigi [a]

[a] *Department of Solid State Physics, Faculty of Sciences, University of Mazandaran, Babolsar, Iran*

[b] *Department of Physics Education, Farhangian University, Tehran, Iran*

ARTICLE INFO

Article history:
Received: 11 June 2025
Revised: 23 July 2025
Accepted: 23 July 2025
Published online: 2 September 2025

Keywords:
Clean energy systems;
Nonferritic material oxide;
Polyvinyl Alcohol Polymer (PVA);
Eco-friendly.

ABSTRACT

In the last decades, there has been much research in the manufacture of clean energy systems such as display components and chips due to the large-scale production and economical synthesis conditions. For getting low dependence on fossil fuel consumption, it has led researchers to use, as an example of organic field effect transistors (OFETs), eco-friendly gate dielectric materials which are bio-compatible with nature. For this reason, among a large number of metal oxides, polymers and organic materials, as a novelty of the present work, the electrical and dielectric characteristics of nonferritic metallic- lithium oxide ($NFLiO_x$) an eco-friendly metal oxide and polyvinyl alcohol polymer (PVA) are investigated and tested as a possible alternative biocompatible dielectric material for the next OFET generations.

1. Introduction

In recent years, various energy devices such as supercapacitors, energy storage, and especially field effect transistors, have been the focus of attention of engineers in the optoelectronic, and medical application industries [1-3]. With the advancements in technology, the demand for these electronic chips has increased significantly. Traditional energy devices are mainly composed of non-biodegradable materials, which lead to destructive environmental issues. The indestructibility of these energy devices after burying leads to environmental pollution. In addition, these devices often lead to wastage of valuable metal resources [1]. Thereby, the use of polymers in various industries and energy devices seems inevitable. It means that people should find a solution route for these environmental concerns and the challenges of electronic chip. The Intergovernmental Panel on Climate Change has stated that the temperature of the earth's climate has reached a level of 1.09 degrees Celsius (in 1850-2020 years) [1].

The main reasons for Climate change are the emission of greenhouse gases, atomic waste and electronic chips. In fact, in these years, the global average concentration of carbon dioxide in the atmosphere has increased to about 419 ppm (a polluting particle out of a metallic particle in the earth's atmosphere) [2, 3]. In particular, according to this report, 72% of greenhouse gas emissions in the world were caused by the production of electricity and energy systems in total [4]. These data clearly indicate the need to reverse this trend. Many studies have been done to determine a strategy and a new approach in reducing this alarming trend.

* Corresponding author.
E-mail address: a.bahari@umz.ac.ir

Cite this article as:

Bahari, A., Fallah Hamidabadi, V., Farhadi Koutenaei, A., and Moradbeigi, N., 2026. Nonferritic Metallic Oxide / Polyvinyl Alcohol Polymer Nanocomposite as a Biocompatible Dielectric Material for Future Generations of Clean Energy Systems. *Progress in Physics of Applied Materials*, *6*(1), pp.27-34. DOI: **10.22075/ppam.2025.38068.1150**

However, a sustainable process must be taken so that the next generations should have the least negative impact on the environment and nature [5-8]. Therefore, to discover and implement innovative and sustainable materials and production methods, one needs to conduct fundamental research and develop new strategies.

On the other hand, the use of polymers and conjugated polymers in flexible electronic industries, fuel cells and transistors due to their mass production and large scale, simple and economical synthesis conditions should be considered with these concerns. To reduce the negative environmental effects of these materials, it is necessary to go for materials that are friendly to nature and include in the field of green synthesis [8-15]. The fact is that biodegradable polymers can be regenerated into hydrogels, fibers, foams, films, tubes, particles, and other forms [14]. Polymers generally originate from renewable or biological sources such as animals, plants, marine organisms, and microorganisms, while synthetic polymers are chemically synthesized [15].

First polymers include polysaccharides such as starch, cellulose, chitosan, and chitosan derivatives, as drain as protein-based polymers such as silk fibroin, collagen, and silk. Biodegradable synthetic polymers usually contain ester, amide or ether linkages and include polylactic acid, polycaprolactone, polyurethane, polyethylene glycol, poly (lactic-co-glycolic acid), polybutylene, and polyvinyl alcohol [15-22]. There are two ways to solve the problems and challenges related to environmental issues and greenhouse effects: in the first way, one can use biocompatible solutions such as water, hybrids, precursors and ligands. They are not going to use toxic solvents, non-removable and non-degradable pollutants, and the best solvent for them is water solvent. In the second way; Biodegradable polymers should be used that both maintain the stability of their characteristics during operation conditions. It means that they should be easily destroyed using chemical reactions or environmental microorganisms into carbon dioxide [23-32]. In addition, electronic chips, and here OFETs, can meet the demand for versatility, efficiency in energy supply [12] and electrical devices [13], metamaterials [10] and smart wearables [9].

For this purpose, lithium metal oxide was synthesized from lithium nitride with the help of a water solvent and under environmental conditions with PVA polymer as a possible gate dielectric of OFET transistors. By measuring the electrical transfer and output characteristics of OFETs; such as carrier mobility (there is a direct relationship between carrier mobility and the output current density), threshold voltage (lower threshold voltage, lower electricity consumption) and higher on-off current ratio and lower subthreshold voltage (SS) for faster OFET operations, compared to the current dielectric gate materials of chips and electronic components, NFLiOx/PVA nano composite is a more desirable gate dielectric and is also promised to be used in the future production of environmentally friendly electronic and optoelectronic chips.

2. Experimental Procedures and Details

It is known that there are at least four configurations of OFETs in the field of electronic industries, depending on the purpose of the manufacturers, they choose a specific configuration. The configuration is depicted in Figure 1. Firstly, the aluminum metal gate is placed under the silicon substrate. Then 2 ml nonferritic metallic; lithium oxide (which produced from 1 g lithium nitride in 1000 ml pure water) and 2 ml polyvinyl alcohol (which produced from 2 g PVA in 1000 ml pure water) with purity: 99.94% from Merck company, mixed together and poured dropwise on the P-type Si (100) substrate. Silicon (Si) wafer has 1× 1×0.2 cm^3 dimensions, resistivity of 5 ohm-cm, was rinsed in sulfuric acid and then in acetone on the ultrasonic bath at room temperature. It has been transferred in the furnace for 2 more hours of drying time. Finally, NFLiOx/PVA gate dielectric with 5 nm thickness could be formed on the silicon substrate and on top of gate dielectric material, two source and drain aluminum electrodes with w= 500 μm are placed at a distance of 500 μm from each other. Such a configuration where the gate is placed at the bottom of substrate and the two source- drain electrodes are on top of gate dielectric for Prova probe's contacting, is known bottom-gate top- contact (BGTC) configuration (which is shown in Figure 1 along with the composition of the chemical structure of the materials used).

As shown in Figure 1 one of the materials used in this research is lithium which cannot be found freely in nature. Monovalent lithium, is one of the lightest metals that easily dissolves in water, due to its high reactivity.

At the same time, the electron of Li last layer is easily released and becomes a cation. This feature makes this material a good conductor of electricity and suitable analyte for biosensors in medical instruments. In addition, lithium is widely used in various industries, including rechargeable batteries, mobile phones, electronic chips, rectifiers, and smart coatings. Moreover, it does not have a destructive greenhouse effect. It also can form lithium hydroxide in reaction with water and steam. In addition, when lithium nitrate dissolves in water, nonferritic metallic; lithium oxide is formed, which is capable of being a good electrical conductor, and due to electrostatic forces, it is weak and fragile and is not able to hold ions in its network. In other words, the ions are easily mobile in its structure and transfer electric charge.

Another material used is polyvinyl alcohol (PVA), which is made from polyvinyl acetate by hydrolysis method and is easily destroyed by biological organisms. This polymer can be decomposed in water in conducting electrical and ionic charges and characterized by biodegradation in a green synthesis route [32-35]. It is therefore a biodegradable polymer in a wide range of combinations with other polymer compounds such as biopolymers and other hydrophilic polymers, and its degradability increases through hydrolysis due to the presence of hydroxy groups in carbon atoms. In addition, the crystal structure of PVA, is connected by modifying the chemical composition of the control groups (OH) and with the atoms (H) between the hydroxyl groups and connects the hydrogen atoms together.

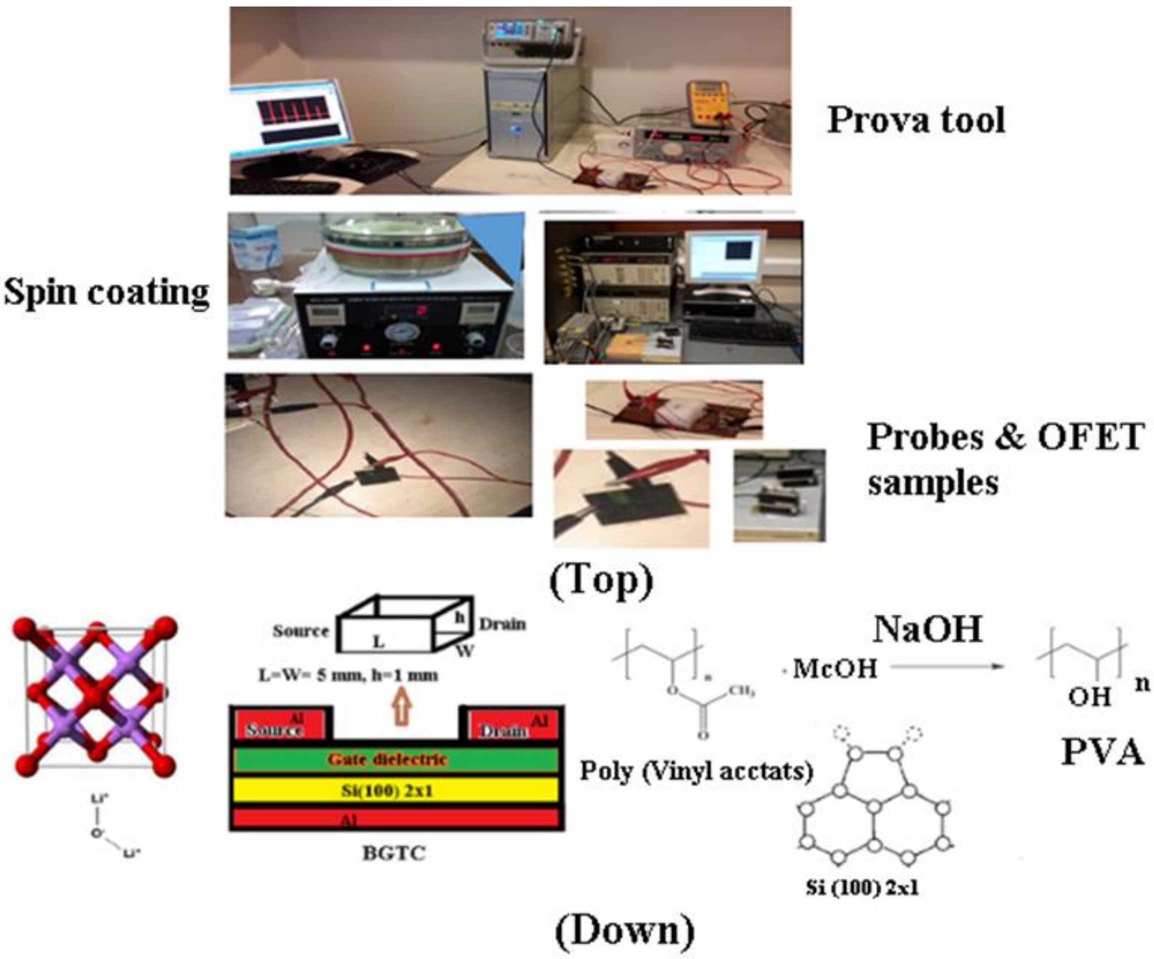

Fig. 1. (Up): Equipment (Prova, Spin coating and fabricated OFETs); (Down) Schematic view of an OFET with Al gate on the bottom and the source-drain electrodes on top of p- type Si(100) 2×1, known as BGTC transistors.

Table 1. Some characteristics of nonferritic metallic; lithium oxide and polyvinyl alcohol (PVA) [7,8].

"**Properties**"	"**PVA (Purity: 99.94%)**"	"**Nonferritic metallic; lithium oxide**" "**(Purity: 99.9%)**"
"Molecular formula"	$C_4 H_6O_2C_2H_4 O_2$	$NFLi_2O$
"Average molecular (g/mole)"	Wight: 44.05	Molar mass: 29.88
"Degree of polymerization"	1.400	N/A
"Degree of hydrolysis"	88%	N/A
"Density (g/cm^3)"	1.19	2.01

The chemical structure of the materials used in the present work, includes non-ferritic metallic (NF)- Lithium oxide (LiO_x), labelled as $NFLiO_x$), PVA and silicon 2×1. Table 1 shows some specifications of cited samples.

3. Results and Discussion

Here, by referring to our previous works [6-10, 35] and also from Figures 1 and 2, after applying voltage to the gate-source electrodes (V_{GS}), the hole carriers are excited and then drawn from the electrodes into the gate dielectric channel of the composite material, where with the increase of ($-V_{GS}$) , the output voltage (I_{DS}) increases, until it reaches the saturation regime, where V_{GS}-V_{th} = V_{DS} (the threshold voltage was indicated by V_{th}.). In this context, several relationships between the output current (I_{DS}) and the applied gate voltage (VGS) assist us in plotting electrical transfer characteristic curves. For example, by replacing the charge relationship with the dielectric capacity in the form of the below relationship, we can find carrier charges in stated capacitor (Q):

$$Q = C_i \frac{V_{DS} - V_{th}}{WL} \tag{1}$$

where C_i is the capacitance per unit area (W: Width, L: Length of the channel between source and drain electrodes).

To obtain the mobility of carriers (μ) in the linear regime before the saturation regime, the following relationship can be used [8]:

$$I_{DS} = \mu_{Linear} \frac{WC}{L} (V_{DS} - V_{th})^2 \tag{2}$$

$$\mu = \frac{I_{DS}L}{WQV_{DS}} = \frac{I_{DS}L^2}{C(V_{DS} - V_{th})V_{DS}} \quad (3)$$

and/or in a saturated regime:

$$\mu_{sat} = \frac{2l}{wC}\left(\frac{\partial\sqrt{I_{DS}}}{\partial V_{Gs}}\right)^2 \quad (4)$$

Therefore, by drawing the slope of the $\sqrt{I_{DS}} - V_{GS}$ curves, the carrier mobility can be determined. And finally subthreshold voltage can be estimated from slopping of V_{GS} $-\mathrm{Log}\, I_{DS}$ curves and Eq. (5):

$$SS = \frac{dV_{GS}}{d\, LogI_{DS}} \quad (5)$$

C_i (which is measured with GPS132A tool) in equations (1-3), shows that there is an inverse relation between C_i and carrier mobility.

In Figures 3-5, the square root of the source-drain current ($\sqrt{I_{DS}}$) at a constant drain voltage (V_{DS}= 20 V) of the OFET transistor for $NFLiO_x$, PVA and composite gate dielectrics, give us carrier mobility and the threshold voltage. The logarithm of the output current (Log I_{DS}) determined subthreshold voltage (SS). SS suggesting that how the rate of transition from OFF state to the ON state of the device can be improved with gate dielectric material.

The measured with the help of Prova IV measuring device and plotting the measurement results; I_{DS}-V_{GS}, $(I_{DS})^{1/2}$-V_{GS}, Log I_{DS}-V_{GS} and shown in Figures 2-5. It specified the transition and output characteristics of OFET.

In addition to the above parameters, the ratio of ON to OFF current (I_{on}/I_{off}) or the ability of the transistor to change from ON to OFF current values has been estimated by considering the maximum output current, $(I_{DS})_{Max}$ in the accumulated layer to its minimum in the not accumulated layer, of- current, $(I_{DS})_{Min}$ in the I_{DS} $-V_{GS}$ curve.

Figs. 3-5 display the findings, and Table 2 lists them. By comparing the findings of the present work and the findings of other researchers in this area, presented in the Table 3, it is clear that NFLiOx/PVA nano composite has not only acceptable and desirable values for being gate dielectric material of OFET devices, but also it is biocompatible due to the use of water solvent.

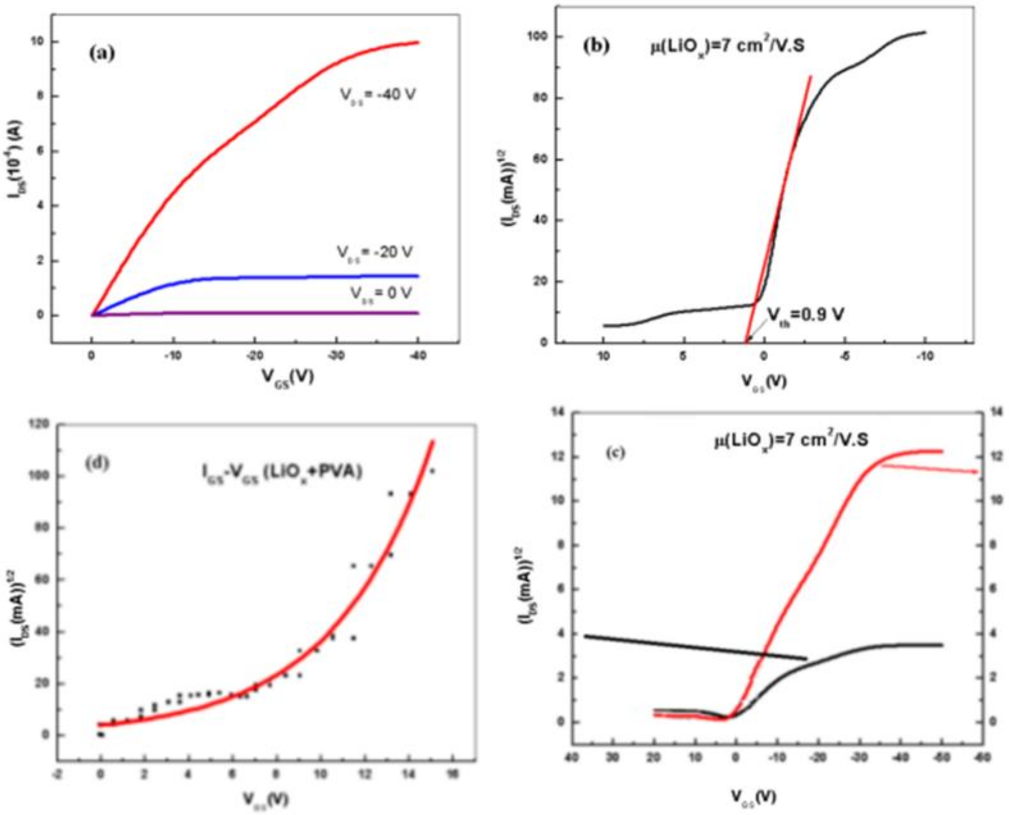

Fig. 2. (a) exhibits the effect of applied voltages of V_{DS}= 0, 20, 40 V on the electrical transfer characteristics. (b) shows the carrier mobility and threshold voltage. (c) The output electric current (I_{DS}) and $\sqrt{I_{DS}}$ in terms of applied voltage to the aluminum gate (V_{GS}) of the OFET transistor. (d) shows the effect of applied voltage on the source-drain (at a constant voltage of V_{DS}= 20 V), for the $NFLiO_x$ gate dielectric.

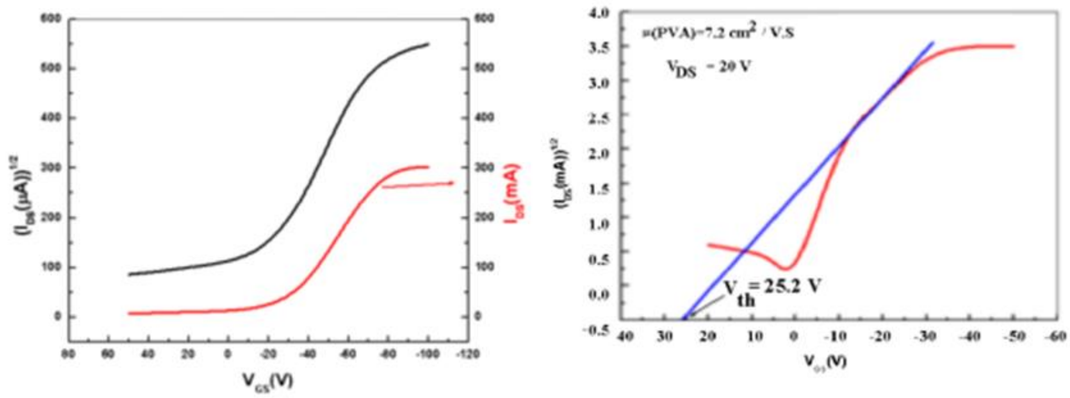

Fig. 3. (Left): The output electric current and its root in terms of applied voltage to the aluminum gate of the OFET transistor. (Right): The curve shows the carrier mobility and threshold voltage for the PVA gate dielectric.

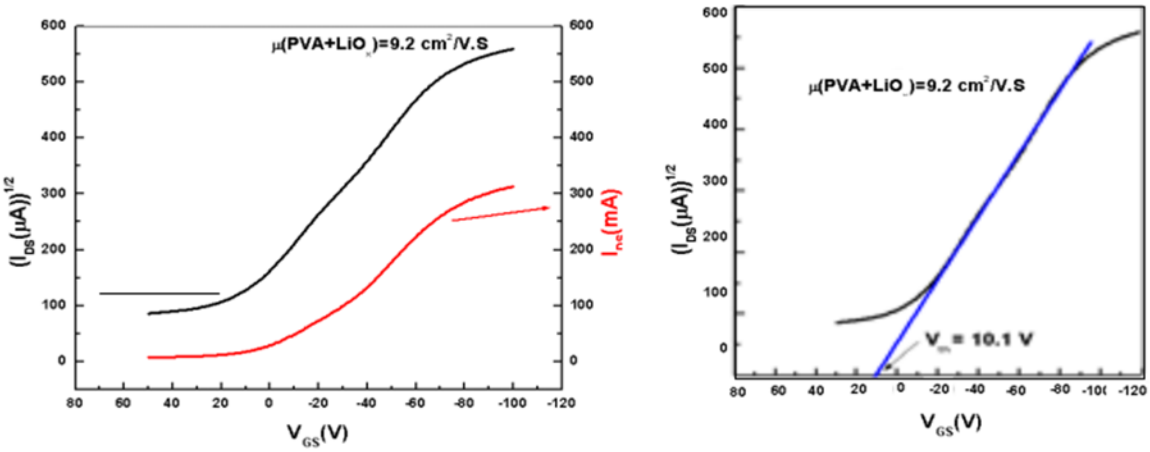

Fig. 4. (Left): The output electric current and its root in terms of applied voltage to the aluminum gate of the OFET transistor. (Right): The curve shows the electrical transfer characteristic of the carrier mobility and the threshold voltage for the gate dielectric of the PVA+ NFLiO$_x$ nanocomposite.

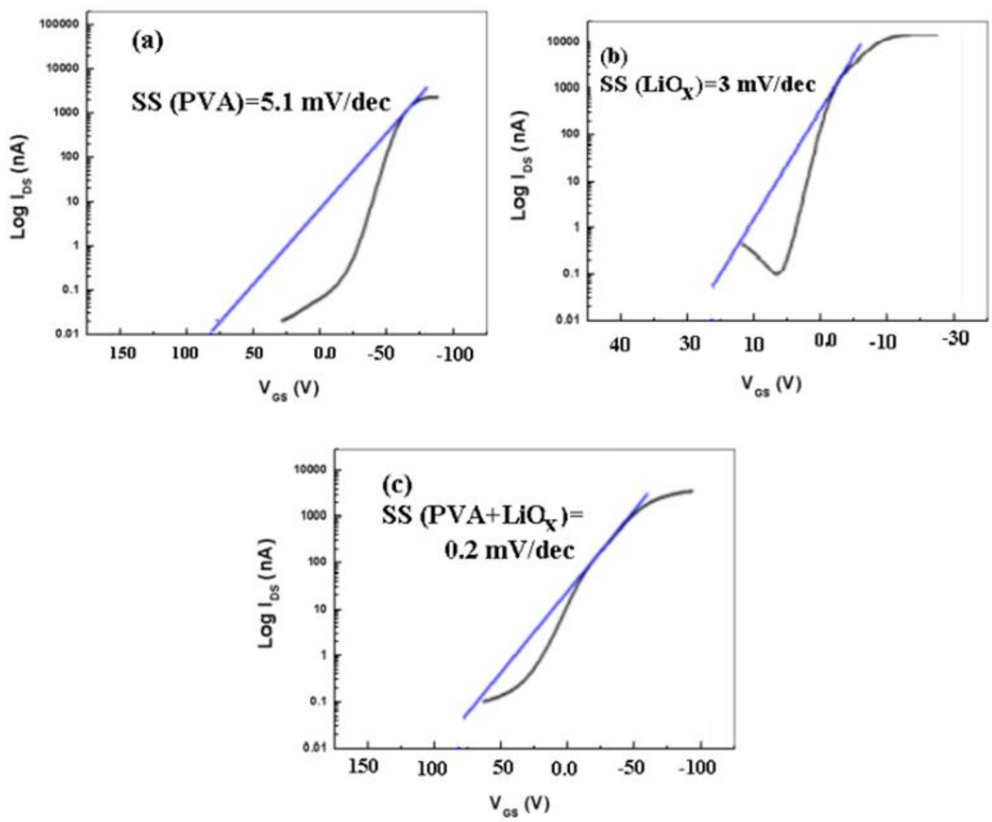

Fig. 5. The logarithm of the output electric current in terms of the applied voltage to the aluminum gate (at a source-drain voltage of 20 V) of the OFET transistor gives the SS in terms of mV/decade (mV/dec.) of (a): PVA, (b): NFLiO$_x$, and (c): NFLiO$_x$+PVA according to equation (3).

Table 2. Measured values of carrier mobility, threshold and subthreshold voltage, ratio of ON to OFF current with 300 μm length and width of OFET transistor channel.

Gate dielectric	C_i (F/m^2)	μ ($cm^2/V.s$)	SS (mV/dec.)	V_{th} (V)	I_{on}/I_{off} (10^5)
$NFLiO_x$	17	7.0	3.0	0.9	1.2
PVA	52	7.2	5.1	25	0.3
$NFLiO_x$+PVA	22	9.2	0. 2	10.1	32.0

Table 3. Comparing the findings related to OFET electrical characteristics of other researchers with the findings of the present work.

Device	Dielectric	μ ($cm^2/V.s$)	V_{th} (V)	SS (mV/dec.)	I_{ON}/I_{OFF}	Ref.
BCBG	SiO_2	0.0094				25
BCBG	TiO_2	0.013	-1			26
BCTG*	PEO:EV$(ClO_4)_2$	8	-1.87	177	10^7	34
BGTC	$In_2O_3/NFLiO_x$	2.64	-0.16	220	10^4	32
TGTC	Ge (Sn)			72	3×10^6	32
BGTC	DPP-DTT**	0.184	1.12	186	10^4	20
BGTC	InAs/GaSb			60	10^7	31
BGTC	povidone/silica	34	0.4		2.2×10^3	21
BGTC	$NFLiO_x$	7	0.9	3	1.2×10^5	Present work
BGTC	PVA	7.2	25	5.1	3×10^4	Present work
BGTC	$NFLiO_x$/ PVA	9.2	10.1	0.2	3.2×10^6	Present work

*BCTG: Bottom-contact Top gated, BCBG: Bottom- contact Bottom- gated.
BGTC: Bottom- gate Top –contacted.
** DPP-DTT: self-assembled poly [2,5-(2-octyldodecyl)-3,6-diketopyrrolopyrrole-alt-5,5-(2,5di (thien-2-yl)thieno [3,2-b]-thiophene)].

4. Conclusions

In the present work, by fabricating three devices of OFET with NFLiOx, PVA, and NFLiOx/PVA gate dielectric materials and measuring their electrical characteristic parameters, a suitable gate dielectric and eco-friendly material for OFET transistors is found in a biocompatible synthesis method without using any toxic materials. According to the curves and comparing the findings of other researchers with the present work, it has been determined that the NFLiOx/PVA gate dielectric material has favorable electrical characteristics: higher carrier mobility (μ) of 9.2 $cm^2/V^{-1}S^{-1}$, higher carrier mobility (μ) 9.2 $cm^2/V^{-1}S^{-1}$, higher on-off current ratio 2.3×10^6, minimum threshold voltage (V_{th}) equal to 10.1 V and with lower subthreshold swing (SS) around 0.2 mV/dc and also with eco friend characteristic, which can be considered for future OFET devices.

Acknowledgements

This research was financed by a research grant from the university of Mazandaran.

Funding Statement

This research received no specific grant from any funding agency.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors Contribution Statement

Ali Bahari: Conceptualization, Methodology, Writing–original draft, Formal analysis, Validation, Project administration, Funding acquisition, Investigation, Writing–original draft, Supervision.
Vaheed Falah Hamidabadi: Methodology, Investigation,
Abbas Farhadi: Investigation,
Nasrin Moradbeigi: Investigation, Formal analysis.

References

[1] Tang, W., Huang, Y., Han, L., Liu, R., Su, Y., Guo, X. and Yan, F., 2019. Recent progress in printable organic field effect transistors. *Journal of Materials Chemistry C*, *7*(4), pp.790-808.

[2] Bahari, A., Robenhagen, U., Morgen, P. and Li, Z.S., 2005. Growth of ultrathin silicon nitride on Si (111) at low temperatures. *Physical Review B—Condensed Matter and Materials Physics*, *72*(20), p.205323.

[3] Hallani, R.K., Moser, M., Bristow, H., Jenart, M.V., Faber, H., Neophytou, M., Yarali, E., Paterson, A.F., Anthopoulos, T.D. and McCulloch, I., 2019. Low-temperature cross-linking benzocyclobutene based polymer dielectric for organic thin film transistors on plastic substrates. *The Journal of Organic Chemistry*, *85*(1), pp.277-283.

[4] Zhang, L., Yang, D., Yang, S. and Zou, B., 2014. Solution-processed P3HT-based photodetector with field-effect transistor configuration. *Applied Physics A*, *116*(3), pp.1511-1516.
[5] Kim, J.H., Jo, I.Y., Baek, S., Cho, H.R., Park, S., Lee, J., Kim, C.H. and Yoon, M.H., 2024. Investigating versatile capabilities of organic field-effect transistors incorporated with vacuum-deposited metal nanoparticles. *Journal of Materials Chemistry C*, *12*(16), pp.5941-5950.
[6] Soltani, B., Babaeipour, M. and Bahari, A., 2017. Studying electrical characteristics of Al_2O_3/PVP nano-hybrid composites as OFET gate dielectric. *Journal of Materials Science: Materials in Electronics*, *28*(5), pp.4378-4387.
[7] Hashemi, A. and Bahari, A., 2018. Synthesis and characterization of silanized-SiO_2/povidone nanocomposite as a gate insulator: The influence of Si semiconductor film type on the interface traps by deconvolution of Si_{2s}. *Current Applied Physics*, *18*(12), pp.1546-1552.
[8] Bahari, A., 2024. Eco-friendly water-induced lithium oxide/polyethyleneimine ethoxylated as a possible gate dielectric of the organic field effect transistor. *Journal of Materials Science: Materials in Electronics*, *35*(26), p.1709.
[9] Gholipur, R. and Bahari, A., 2017. Tunability of negative permittivity and permeability of Ag/Zr0.9Ni0.1Oy nanocomposites with morphology. *Electronic Materials Letters*, *13*(2), pp.179-183.
[10] Shahbazi, M., Bahari, A. and Ghasemi, S., 2016. Structural and frequency-dependent dielectric properties of PVP-SiO_2-TMSPM hybrid thin films. *Organic Electronics*, *32*, pp.100-108.
[11] Aziz, J., Kim, H., Hussain, T., Lee, H., Choi, T., Rehman, S., Khan, M.F., Kadam, K.D., Patil, H., Mehdi, S.M.Z. and Lee, M.J., 2022. Power efficient transistors with low subthreshold swing using abrupt switching devices. *Nano Energy*, *95*, p.107060.
[12] Bahari, A., Delkhosh, F. and Gholipur, R., 2025. Ni-Doped Cu10%/YIG Nanoparticle-Based Metamaterials: Synthesis and Electromagnetic Property Investigation at Terahertz Frequencies. *Progress in Physics of Applied Materials*, *5*(1), pp.31-38.
[13] Abouk, Y., Bahari, A. and Gholipur, R., 2023. Synthesis and characterization of Cu/YIG nanoparticles-Terahertz material. *Optical materials*, *142*, p.113992.
[14] Li, J., Tamayo, A., Quintana, A., Riera-Galindo, S., Pfattner, R., Gong, Y. and Mas-Torrent, M., 2023. Binder polymer influence on the electrical and UV response of organic field-effect transistors. *Journal of Materials Chemistry C*, *11*(24), pp.8178-8185.
[15] Guo, Y., Deng, J., Niu, J., Duan, C., Long, S., Li, M. and Li, L., 2023. observation of large threshold voltage shift induced by pre-applied voltage to SiO_2 gate dielectric in organic field-effect transistors. *Electronics*, *12*(3), p.540.
[16] Ajayan, J., Sreejith, S., Manikandan, M., Sreenivasulu, V.B., Kumari, N.A. and Ravindran, A., 2024. An intensive study on organic thin film transistors (OTFTs) for future flexible/wearable electronics applications. *Micro and Nanostructures*, *187*, p.207766.
[17] Xie, P., Liu, T., Sun, J., Jiang, J., Yuan, Y., Gao, Y., Zhou, J. and Yang, J., 2020. Solution-processed ultra-flexible C8-BTBT organic thin-film transistors with the corrected mobility over 18 cm2/(V s). *Sci. Bull.*, *65*(10), pp.791-795.
[18] Hu, Z., Li, D., Lu, W., Qin, Z., Ran, Y., Wang, X. and Lu, G., 2023. In situ tuning of the performance of polymer field-effect transistors by soft plasma etching. *Materials Advances*, *4*(13), pp.2811-2820.
[19] Kim, G., Fuentes-Hernandez, C., Jia, X. and Kippelen, B., 2020. Organic thin-film transistors with a bottom bilayer gate dielectric having a low operating voltage and high operational stability. *ACS Applied Electronic Materials*, *2*(9), pp.2813-2818.
[20] Hashemi, A., Bahari, A. and Ghasemi, S., 2017. The low threshold voltage n-type silicon transistors based on a polymer/silica nanocomposite gate dielectric: The effect of annealing temperatures on their operation. *Applied Surface Science*, *416*, pp.234-240.
[21] Paterson, A.F., Mottram, A.D., Faber, H., Niazi, M.R., Fei, Z., Heeney, M. and Anthopoulos, T.D., 2019. Impact of the gate dielectric on contact resistance in high-mobility organic transistors. *Advanced Electronic Materials*, *5*(5), p.1800723.
[22] FarhadiKoutenaei, A., Ali Mahdi, M., Bahari, A. and Al-Jelif, A., 2024. Different behavior of Nano sheet and Bulk of the hexagonal boron nitride with first principal calculation approach. *Progress in Physics of Applied Materials*, *4*(1), pp.13-19.
[23] Lee, J.H., Seo, Y., Park, Y.D., Anthony, J.E., Kwak, D.H., Lim, J.A., Ko, S., Jang, H.W., Cho, K. and Lee, W.H., 2019. Effect of crystallization modes in TIPS-pentacene/insulating polymer blends on the gas sensing properties of organic field-effect transistors. *Scientific reports*, *9*(1), p.21.
[24] Shin, E., Yoo, J., Yoo, G., Kim, Y.J. and Kim, Y.S., 2019. Eco-friendly cross-linked polymeric dielectric material based on natural tannic acid. *Chemical Engineering Journal*, *358*, pp.170-175.
[25] Nketia-Yawson, B. and Noh, Y.Y., 2018. Recent progress on high-capacitance polymer gate dielectrics for flexible low-voltage transistors. *Advanced Functional Materials*, *28*(42), p.1802201.
[26] Li, P., Cai, L., Wang, G., Zhou, D.C., Xiang, J., Zhang, Y.J., Ding, B.F., Alameh, K. and Song, Q.L., 2015. PEIE capped ZnO as cathode buffer layer with enhanced charge transfer ability for high efficiency polymer solar cells. *Synthetic Metals*, *203*, pp.243-248.
[27] Rullyani, C., Ramesh, M., Sung, C.F., Lin, H.C. and Chu, C.W., 2018. Natural polymers for disposable organic thin film transistors. *Organic Electronics*, *54*, pp.154-160.
[28] Hashemi, A., Bahari, A. and Ghasemi, S., 2017. Reduction the leakage current through povidone-SiO_2 nano-composite as a promising gate dielectric of FETs. *Journal of Materials Science: Materials in Electronics*, *28*(18), pp.13313-13319.
[29] Shahbazi, M., Bahari, A. and Ghasemi, S., 2016. Studying saturation mobility, threshold voltage, and stability of PMMA-SiO2-TMSPM nano-hybrid as OFET gate dielectric. *Synthetic Metals*, *221*, pp.332-339.
[30] Alavisadr, S.M., 2025. Structural, Electronic, and Magnetic Properties of Mn2NbAl1-xSix (x= 0.0–1.0) Alloys. *Progress in Physics of Applied Materials*, *5*(2), pp.73-82.
[31] Chen, X., Guo, J., Peng, L., Wang, Q.,, Jiang, S., and Li, Y., 2023. Charge transport in organic field-effect transistors, *Materials Today Electronics*, 6, PP. 100077-100088.
[32] Kumar, P., Mishra, V.N. and Prakash, R., 2023. Low voltage operable eco-friendly water-induced LiO x dielectric based organic field effect transistor. *IEEE Electron Device Letters*, *44*(4), pp.638-641.

[33] Gillan, L., Li, S., Lahtinen, J., Chang, C.H., Alastalo, A. and Leppäniemi, J., 2021. Inkjet-Printed Ternary Oxide Dielectric and Doped Interface Layer for Metal-Oxide Thin-Film Transistors with Low Voltage Operation. *Advanced Materials Interfaces*, *8*(12), p.2100728.

[34] Bahari, A., Ahmady-Asbchin, S., Naeij, M., Farhadikoutenaei, A. and Al-Jilef, A., 2023. Green synthesis and study of structural properties of Copper nanocrystallites from hawthorn plant extract and study of its antibacterial activities. *International Journal of Nano Dimension*, *14*(2 (April 2023)), PP. 138-144.

[35] Mazaheri, E., Bahari, A. and Ghasemi, S., 2024. GO/Co-MOF/NiMnCu nanocomposite as a possible candidate for the future of the supercapacitor generations. *Progress in Physics of Applied Materials*, *4*(2), pp.135-144.