Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI:10.21474/IJAR01/20847
DOI URL: http://dx.doi.org/10.21474/IJAR01/20847

ISSN NO. 2320-5407

RESEARCH ARTICLE

POLYSACCHARIDE AS ECO-FRIENDLY GATE DIELECTRIC FORORGANIC FIELD EFFECT TRANSISTORS

A. Tall[1,2], M. Manga[2], M. Toure[1], S. Haba[1], A. K. Diallo[3], M. Seck[4]and El. H. B. Ly[2]

1.Electronics Laboratory, BP: 1147, Gamal Abdel Nasser University of Conakry,Guinea.
2. Electronics, Engineering, Telecommunications and Renewable Energy Laboratory, BP: 234, Gaston Berger University of Saint-Louis, Senegal.
3. Applied Sciences Research Laboratory, Mamou Higher Institute of Technology, Guinea.
4. Atmospheric and Ocean Sciences Laboratory-Materials and Devices, BP: 234, Gaston Berger University of Saint-Louis, Senegal.

……

Manuscript Info

Manuscript History
Received: 18 February 2025
Final Accepted: 22 March 2025
Published: April 2025

Key words:-
Polysaccharides, Dielectric Materials, Natural Gums, Cellulose, Chitosan, Organic Field-Effect Transistors (OFETs)

Abstract

This article presents a comprehensive literature review on the use of polysaccharides as dielectric materials in organic field-effect transistors (OFETs). The dielectric properties of various polysaccharides-such as cellulose and its derivatives, natural gums, chitosan, and starch are thoroughly examined, with particular emphasis on their polarization behavior, relative permittivity, capacitance density, thermal stability, and film-forming ability. The article also analyses how these properties influence the electrical performance of OFETs, including charge carrier mobility, threshold voltage, operating voltage, leakage current, and hysteresis.Literature findings indicate that polysaccharide-based dielectrics, owing to their biodegradability, natural abundance, and compatibility with low-temperature processing, represent a promising alternative for the development of green, flexible, and sustainable organic electronics. Recommendations are provided to address key technical challenges such as moisture sensitivity and interfacial defects in order to further optimize device performance and support a more sustainable and environmentally friendly technological approach.

……

Introduction:

With the rapid development of semiconductor technology, computer science, and material science, significant progress has been made in the field of electronics. Indeed, over the past few decades, the evolution of electronic devices, particularly microelectronic components, has been primarily driven by innovations in the field of inorganic materials.The growing use of these devices (computers, mobile phones, chips, etc.) leads to the production of a vast quantity of them. Their short lifespan and increasing rate of obsolescence turn them into waste, known as electronic waste or e-waste.The environmental pollution resulting from this waste, due to some components that contain toxic substances such as cadmium, lead, etc., has raised significant concerns. According to forecasts,world is expected to produce around 120 million metric tons of electronic waste by 2050[1].

Corresponding Author:A. TALL
Address:1.Electronics Laboratory, BP: 1147, Gamal Abdel Nasser University of Conakry,Guinea.
2. Electronics, Engineering, Telecommunications and Renewable Energy Laboratory, BP: 234, Gaston Berger.

Nowadays, in addition to the environmental concerns associated to e-waste, numerous challenges such as device engineering, wearable sensors, and eco-friendly devices, there is a growing interest in the development of large-scale organic electronic devices, particularly organic semiconductors and polysaccharide dielectrics[2,3].Indeed, recently, several polysaccharidesdielectric from plant or animal origin have been used in organic field-effect transistors (OFETs) dueto their mechanical flexibility, biodegradability, biocompatibility, andcorrosion resistance[4]. As electrical insulators, these polysaccharide dielectrics are essential in various applications such as transistors[5,6], sensors[7,8], energy storage devices[9,10], etc. Their flexibility, potential for low-cost manufacturing, renewability, non-toxicity, abundance, and intrinsic biocompatibility make them promising candidates for additionalapplications where inorganic counterparts are unsuitable.

This paper provides a brief overview of polysaccharide-based dielectric materials for transistor applications by highlighting their properties and electrical performances in OFETs, opening a new way to promote green electronic researchin which environmentally friendly electronic devices are required.

2. Polysaccharide DielectricsProperties

Organic materials are defined as substances that contain carbon. They can be synthesized or extracted from nature. They are classified into two categories based on their molecular weight: small molecules and macromolecules, commonly referred to polymers [11]. The discovery of the conductive nature of halogen-doped polyacetylene in 1977 by Alan MacDiarmid, Alan J. Heegerand Hideki Shirakawa [12] leads to the creation of a new class of materials known as organic semiconductors. This discovery earned these pioneersNobel Prize in Chemistry in 2000, marking a recognition for opening a new field in material chemistry,the field of conductive polymers.

This discovery quickly attracted attention from researchers due to the interesting properties of these materials and their potential applications. As a result, numerous scientific studies related to these materials have led to the first electronic devices based on organic semiconductors. Accordingly, the works conducted by A. J. Heegeret al.[12]and C. W. Tanget al.[13]paved the wayforthe development of technologies based on conductive polyacetylene in transistors and circuits.

In recent years, significant progress continues to be made in the field of organic electronics. Organic light-emitting diodes (OLEDs) are now replacing conventional liquid crystal displays (LCDs), thanks to their low energy consumption, fast motion image response, and the inherent superiority of color representation[14]. Organic field-effect transistors (OFETs) have become key devices, highly versatile for the implementation of integrated circuits, sensing, and exploration of applications in various fields[15,16].This has led to the rapid expansion of demand, and the drive to produce eco-friendly devices with low operating voltage have led to a rapid evolution of research in organic materials, with the aim of producing environmentally-friendly devices. Nature is considered as a reservoir of these materials, which can be used as precursors for substrate, active layer or dielectric layer in electronic devices.

The dielectric layer is an essential component of transistors and is attracting considerable interest from researchers seeking to improve their performance. This layer electrically isolates gateelectrodefrom semiconductor channel, preventing the flow of direct current between these elements. The selection of suitable dielectric material requires careful consideration inseveral key properties, including its dielectric permittivity [17], thickness, ability to minimise leakage currents, breakdown voltage, surface roughness and surface energy, etc. among other relevant factors.Indeed, the use of a high permittivity dielectric material enables OFETs to be fabricated with reduced operating voltages [18]. In addition, obtaining a high on-state current (Ion) in OFET devices depends mainly on the use of a dielectric layer with a high gate capacitance density (C) [19]. Thus, the dielectric must be chosen to strike a balance between the nature of the dielectric material and the technology used for OFETs. Consequently, the dielectric layer in OFETs opens up possibilities for various types of materials (Fig.1). Among these materials, polysaccharide dielectrics (gums, chitin, etc.) have emerged as a promising alternative due to their biodegradability, flexibility, and eco-sustainability, which are beneficial for the fabrication of electronic devices[20], aiming to promote green electronics.

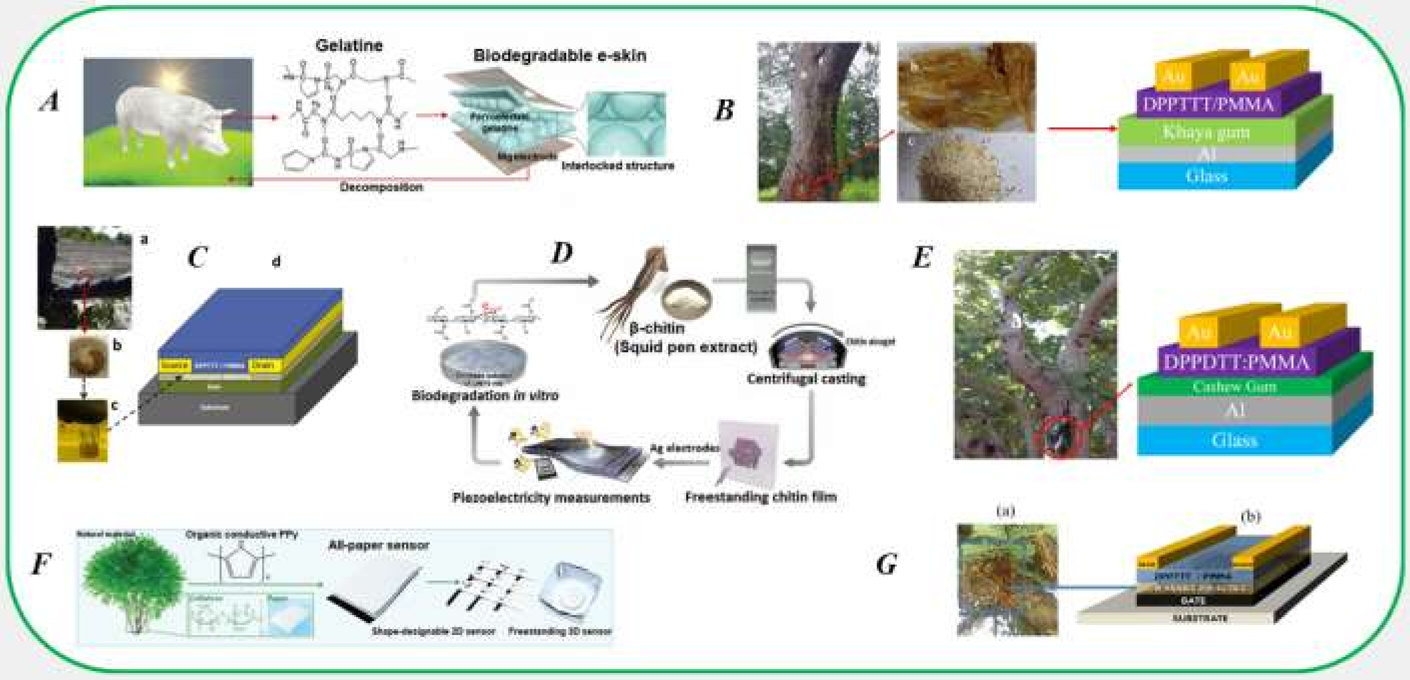

Fig.1.A: Biodegradable ferroelectric edible porcine gelatine e-skin; B: OFET using khaya gum as the gate dielectric, (a) khaya tree, (b) Unpurified khaya gum, (c) Purified khaya gum; C: (d) OFET using almond gum as the dielectric, (a) Almond tree, (b) Almond gum dried, crushed and sieved, (c) solution of Almond gum in water; D: Preparation of a thin film of biodegradable chitin; E: OFET using cashew gum, (a) western anacardium tree; F: Biodegradable capacitive sensor using cellulose; G: (b) OFET using arabic gum, (a) Acacia senegal tree. [6,18,20–22].

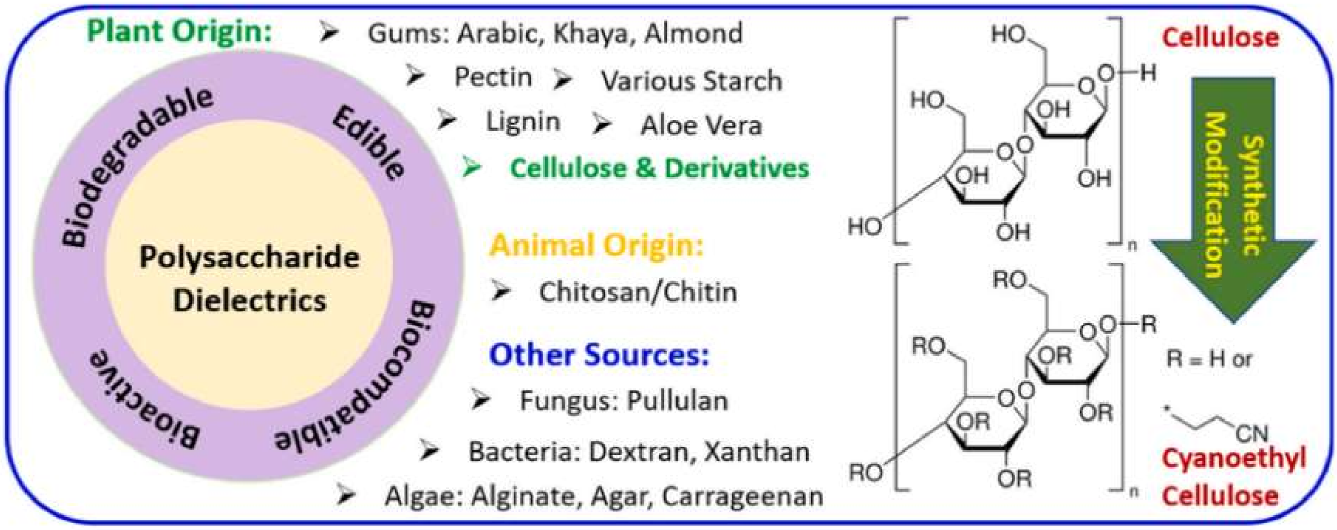

Fig. 2. Various dielectrics and the chemical structures of cellulose and cyanoethyl-cellulose[26,27].

Adielectricis a material that does not conduct current but can sustain an electric field [28].It has high resistivity ranging from 10^{17} to $10^{18}\Omega\cdot m$ and very low conductivity[29]. A dielectriccontains few free charges within them, unlike conductive materials, which have numerous free charges that can move underinfluence of an electric field. The molecules present in dielectric materials are often either polar or nonpolar. When subjected to an electric field, the nonpolar molecules present in the dielectric material become polarized and form induced dipoles. On the other hand, if the dielectric material consists of polar molecules, these molecules align along the direction of the applied field. As a result, the dielectric as a whole becomes polarized, and the positive and negative charges are referred to induced charges because they are induced by the applied electric field. The interaction between the molecules and the electric field creates dielectric polarization. This phenomenon is explained as the result of a slight oscillation of the positive and negative electric charges within the dielectric[30].

With the miniaturization of electronic devices and the increase in capacitance densities with the smallest possible area, passive components such as capacitors can be manufactured while considering technological constraints, using organic dielectric materials. These dielectric materials serve as electrical insulators in these capacitors. They help to increase the capacitance density and provide good electrical characteristics in terms of leakage current and dielectric strength.Although dielectric materials are insulators, they are not completely refractory to any form of weak electrical conduction. The low conduction phenomenon occurring in dielectric materials is due to impurities present inside, rather than their molecular structure[31]. These impurities can be free charge carriers (mobile ions) intrinsic to the dielectric material.To observe this conduction phenomenon,the arrangement of these dipoles must be disturbed by applying an electric field to the dielectric material. Thus, the electrical properties observed in the behavior of the dielectric material when subjected to a field allow the understanding of several mechanisms.

To study the dielectric properties of these materials, dielectric spectroscopy is considered the method that best describes relaxation phenomena[32]. This technique is a powerful tool for frequency analysis, effectively highlighting the molecular dynamics induced by conduction mechanisms and relaxation phenomena occurring at the microscopic level of a dielectric [33].Under influence of an electric field, the dielectric material may exhibit a response depending on the frequency. These responses can be associated with parameters such as capacitance, dielectric permittivity, etc. These parameters have made these dielectricsvery attractive as an alternative for reducing high operating voltages in electronic devices such as transistors, and addressing also the challenges in green electronics. Among these key parameters, the dielectric constant (k) should be high or low depending onthe application.The dielectric losses should be low for minimal dissipation of electromagnetic energy; and a high breakdown voltage for stability is required for electronic devices. Dielectrics are used to fabricate capacitors and thus have significant applications in capacitive sensing and organic field-effect transistors (OFETs).

To reduceoperating voltage in transistor for example, a dielectric material with high capacitance is required. Capacitance per unit area is directly proportional to k and inversely proportional to the thickness of the dielectric.Several studieson gate dielectrics have focused on dielectric polysaccharides to meet the fundamental requirements necessary to improve the performance of organic field-effect transistors (OFETs) and enable the portability of electronic devices. Furthermore, thesedielectric polysaccharides have been developed due to their intrinsic mechanical flexibility and low processing temperatures, as detailed by B. N. Yawsonet al.[34]and R. P. Ortiz et al.[35].

Various polysaccharides have been integrated as dielectrics in electronic devices. Among these, the work conducted by M. Baumgartner et al.[36]on gums has shown promising results. Many of these gums studied as dielectrics are water-soluble at low temperature, and their solutions can be deposited using cost-effective and low-temperature deposition techniques. These biopolymers exhibit interesting dielectric constants at 1 kHzfor gum mastic k = 3,9. In addition, Stadlober et al.[37]found a dielectric constant for gum arabic of k ~4.1 at 1 kHz, while M. Seck et al.[38]and P. Barik et al.[39]reported for the same biopolymer and at the same frequency dielectric constants of k ~30 and as high as 50, respectively.

The use of high-k dielectrics is a way to achieve high dielectric capacities, thus allowing for the reduction of the operating voltage of transistors. It has been demonstrated that gum arabic[22], mastic gum [40], almond gum[18], khayagum[21], and cashew gum[6]wellworkedin organicthin-film transistors. Transistors developed usinggum arabic[22], khaya gum [21], almond gum [18], and cashew gum [6]as dielectrics operated at low voltage ($V_{GS} < 3$), meeting thus a key requirement for portable applications.

Sheida Faraji et al.[6]showed the evolutions of the capacitance and dielectric losses of cashew gumdielectric layer. They fabricated a Metal-Insulator-Metal (MIM:ITO-Cashew Gum-Aluminum) structure in which the cashew gum layer was sandwiched between an ITO layer and an aluminum electrode layer deposited by thermal evaporation. Fig.3showsthe evolution of capacitance density and dielectric losses as a function of frequency, as well as capacitance as a function of voltage measured at1 kHz for the cashew gum dielectric layer.

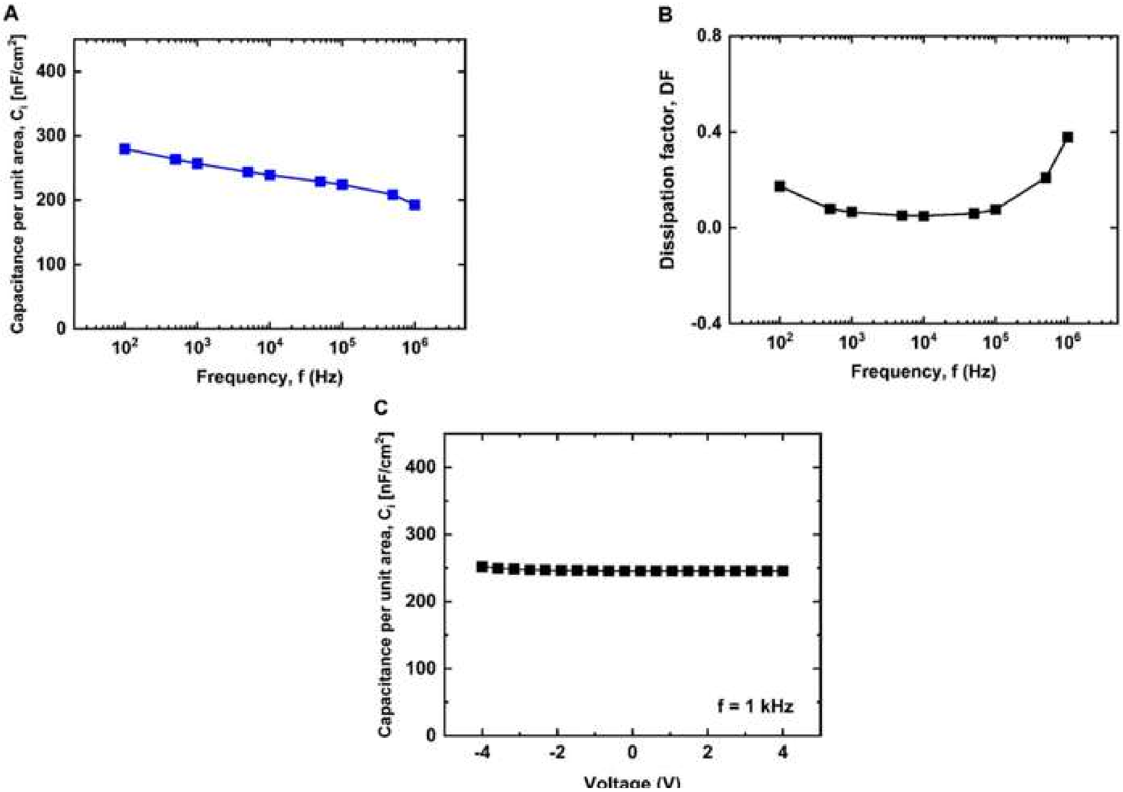

Fig.3. Capacitance density vs. frequency (A), dielectric losses vs. frequency (B), and capacitance density vs. voltage (C) of a thin layer of cashew gum [6].

Capacitance density of the thin layerof cashew gum shows a frequency-dependent behavior, similar to most of organic polymer dielectrics. It exhibits high capacitance density values at low frequencies (270 nF/cm² at 100Hz) and low dielectric losses. Then, the capacitance density decreases until 200 nF/cm² at 1 MHz.The dielectric losses remain relatively constant from 1 kHz to 100 kHz increase until 100 kHz at 1 MHz. In most organic polymer dielectrics,such behavior can be justified by the dipolar polarization phenomenon of the charges present in the dielectric[41]. The low capacitance density values at high frequencies may be caused by the fact that at this level, the high agitation of the dipoles does not allow enough time for them to follow the applied field. Such thermal agitations are also considered to be responsible of the increase in dielectric losses at high frequencies [42].

Fig.4detailed topographical informations on the surface roughness, grain size, and growth mechanism of the surface of cashew gum layer are obtained from 3D AFM images. The surface of the thin film exhibits a root mean square (RMS) roughness of 1.16 nm and a peak value of 10.2 nm, with grains having a compact pyramidal shape. A similar dendritic morphology, according to H. Seonget al.[43],represents a divergent polycrystalline growth initiated from a common nucleation point.

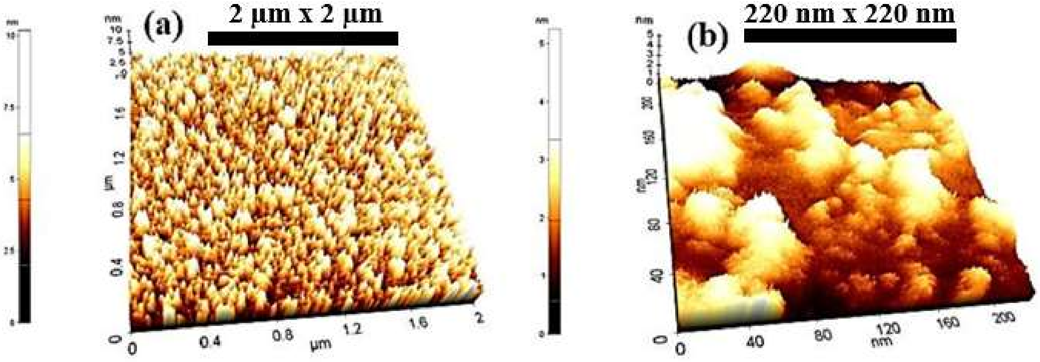

Fig.4. AFM topographical images of the surface of a thin layerof cashew gum [6].

Similar studies conducted on khaya and almond gums demonstrate the dielectric potential of these biopolymers for their use in electronic and electrical applications. For this, a study of the complex dielectric permittivity was conducted. Complex dielectric permittivity of a dielectric material can be defined as materials response to an alternating electric field. It consists of two parts, according to the following equation[44]:

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad (1)$$

ε' is the dielectric constant (real part) and ε'' represents dielectric loss (imaginary part).
Indeed,A. Tallet al.[45]andM. Secket al.[46] studies, conducted respectively on khaya gum and almond gum dielectrics, illustrate the same typical behavior of these two polymer dielectrics. Fig.5 and 6show the frequency dependence ofdielectric parameters of thin layers of khaya gum and almond gum, respectively.

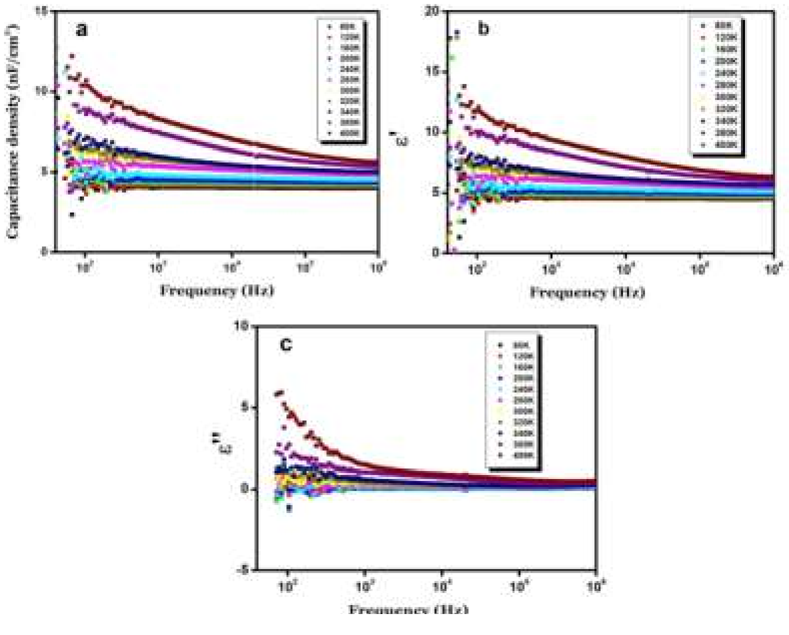

Fig.5. Capacitance density vs. frequency(a), dielectric permittivity vs.frequency (b), and dielectric loss vs.frequency of a thin layer of khaya gum [45].

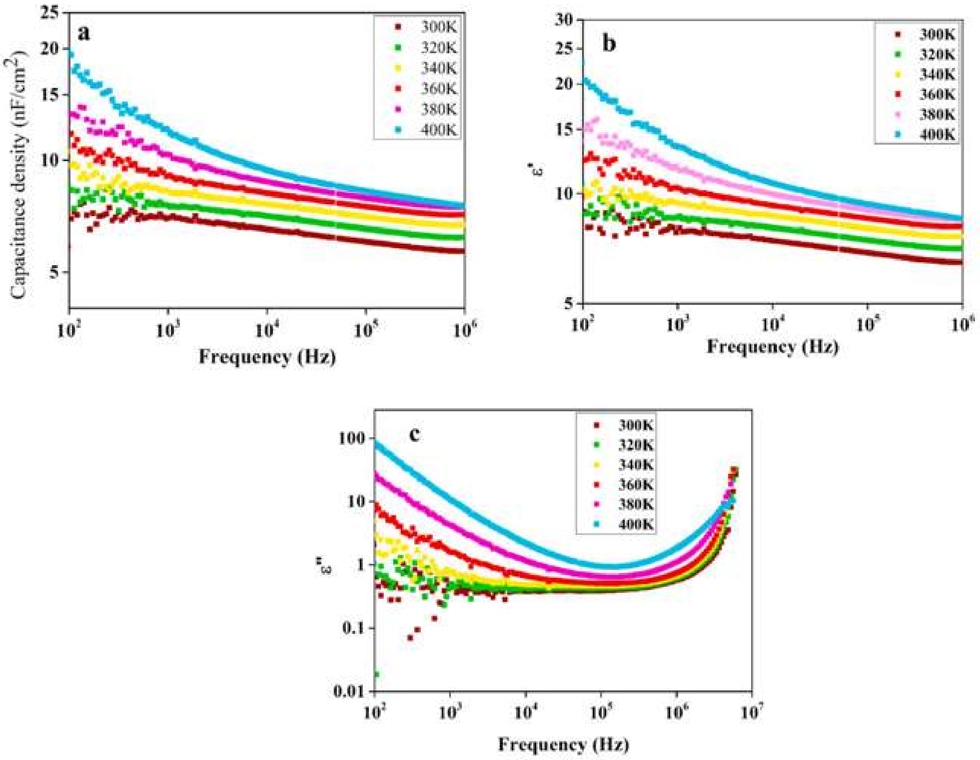

Fig.6. Capacitance density vs. frequency (a), dielectric permittivity vs.frequency (b), and dielectric loss vs.frequency(c)of a thin layer of almond gum [46].

The capacitance density (Fig.5a and 6a) and dielectric permittivity (Fig.5b and 6b) increase with temperature and decrease with frequency. According to Ramesan et al.[47], the behavior of these two parameters with the temperature is attributed to the breaking of intermolecular forces within the polymer chains due to increased thermal agitation caused by the rise in temperature. Trapped charges are released, enhancing the polarization phenomenon.

The dielectric losses of these biopolymerdielectrics (Fig.5c and 6c), display high values at low frequencies and drop to a minimum value. Then, they increase at high frequencies.This shape has been explained by the polarization phenomenon.The contribution of polarization mechanisms is enhanced at low frequencies due to the ease with which charges move, and decreases at high frequencies, which may account for the behavior of dielectric losses [47].G. Knowaretal.[48]illustrate the dielectric potential of cyanoethylcellulose (CEC), which is a derivative of cellulose. Fig.7shows the surface morphology and the variation of the capacitance density as a function of frequency (C_i-f) of a thin layer of cyanoethylcellulose. A low root mean square roughness of 2.5 (±5) nm was observedwith a scan of 10 µm x 10 µm. The C_i-f obtained with a Metal-Insulator-Semiconductor-Metal (MISM:ITO/CEC/TIPS-PEN:PS/Au) structure, over a frequency range of 1 kHz-1 MHz, displays a value of 5.8 nF/cm² at 1 kHz.

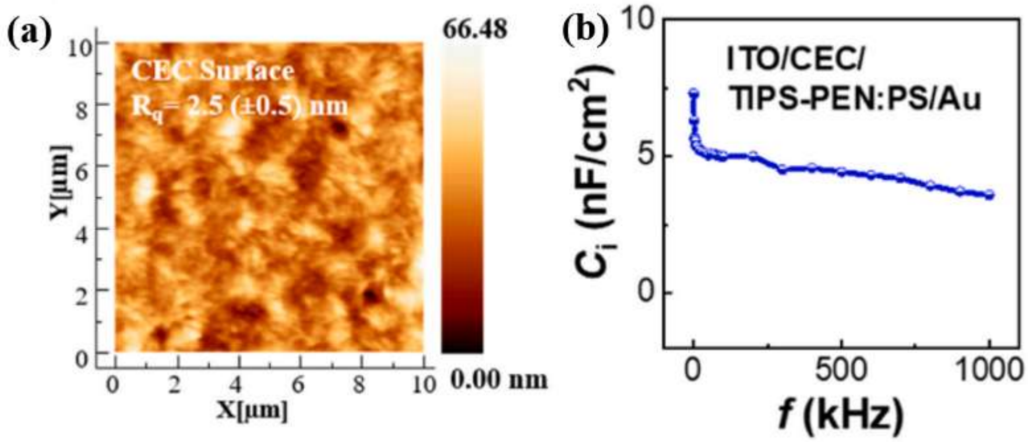

Fig.7.AFM topographical image (a) and the variation in capacitance density (b) of a thin layer of cyanoethylcellulose (CEC) [48].

The biopolymer material xanthan gum has been studied by F. Li et al.[49]. According to the authors, this polysaccharide can interact with an electric field due to its molecular structure containing hydroxylgroups.The study showed that xanthan gumhas good dielectric performance and is reliable as a dielectric layer for electric double-layer transistors. Fig.8a shows capacitance density of a thin layer of xanthan gum prepared bysolution method.From the characterization of the MIM (ITO/Xanthan Gum/ITO) structure, a capacitance density of 2 µF/cm² was obtained at 1 kHz. The thin layer of xanthan gum exhibited a uniform and dense surface with no holes, as shown by the scanning electron microscopy (SEM) image in Fig.8b.AFM image of xanthan gum thin layer shown in Fig.8c has an average root mean square (RMS) roughness of 5.44 nm. The good surface properties provide the layer an ease in electrode or semiconductor growth.

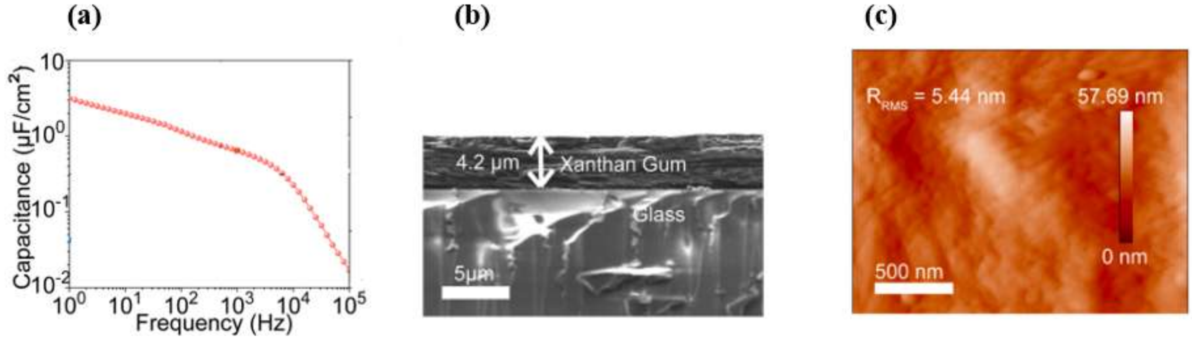

Fig.8.(a) Capacitance density as a function of frequency, (b) SEM image, and (c) AFM image of a thin layer of xanthan gum [49].

Characterizations such as frequency-dependent capacitance density and leakage current density as a function of electric field for TAC dielectric layer were measured using MIM capacitor structure. Capacitance of TAC layer did not change significantly in the range of 100 Hz to 1 MHz, with a slight disturbance of 8.1 nF/cm² and 4.57 at 1 kHz, indicating that there are few mobile impurities in TAC dielectric films [5].Furthermore, TAC layer showed a relatively stable gate leakage current density, exceeding 10^{-7} A/cm², for a breakdown field more than 1.54 MV/cm. Low leakage current density and high breakdown voltage (50 V) of TAC layer may be attributed to the acetylation effect of the hydroxyl groups in cellulose [50,51]. Since hydroxyl groups in the dielectric layer increase the gate leakage current densities [51], the chemical functionalization of the TAC layer converting the cellulose hydroxyl groups into acetyl groups should form a stable gate dielectric layer. Considering surface and dielectric properties, it is clear that thin TAC layers can be used as a good gate dielectric in BiOTFT devices. Given these surface properties, a solution of pBTTT (10 mg/ml) in 1,2-dichlorobenzene was applied by spin-coating onto TAC layer as a hole-transporting semiconductor polymer. Representative output and transfer characteristics of pBTTT-based OTFT devices on rigid ITO coated glass substrate with a cellulose triacetate gate dielectric, were recorded.

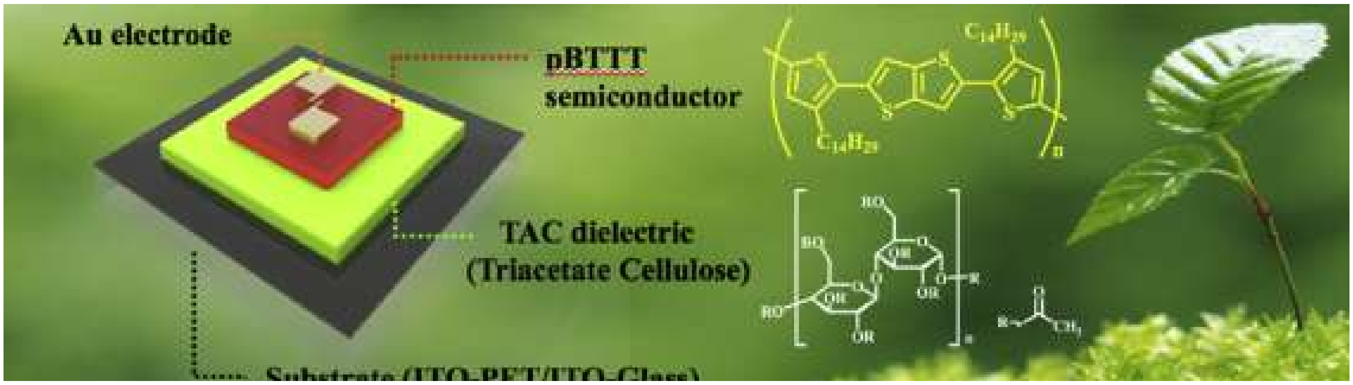

Fig.9.Structure of top-contact pBTTT-OTFT device fabricated with an eco-friendly TAC dielectric layer on an ITO glass or PET substrate. Molecular structures of TAC gate insulator andpBTTT semiconductor polymer (insert)[5].

Carboxymethyl cellulose (CMC), a water-soluble cellulose derivative, was investigated as a sustainable dielectric material for organic field-effect transistors (OFETs) by Gallegos-Rosas et al.[52]. The CMC films, fabricated via spin-coating from aqueous solutions, exhibited high optical transparency (>80%) and extremely smooth surfaces (RMS roughness <2 nm) see Fig.10.

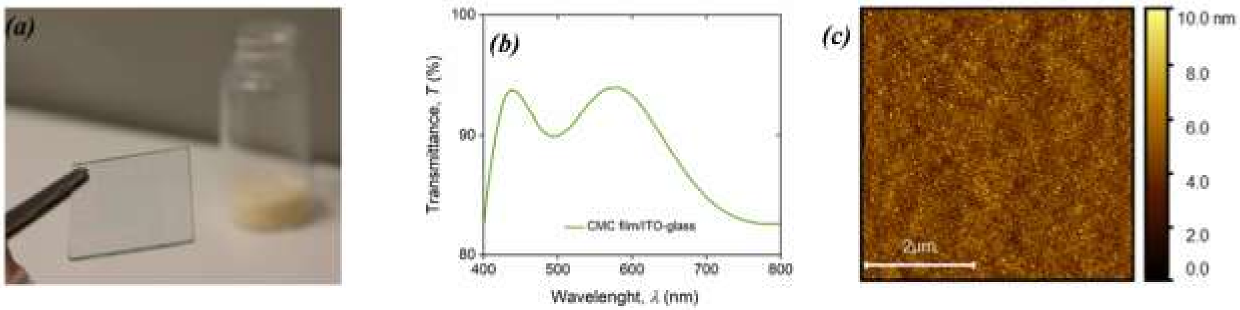

Fig.10. (a) Optical image and (b) transmittance spectrum in the visible region (400−800 nm) of a CMC film (t = 200 nm). (c) Atomic force microscope (AFM) image of the top surface of the film[52].

Dielectric characterization performed using parallel-plate capacitor structures revealed a dielectric constant (k) in the range of 5.3-5.7, notably higher than conventional polymeric dielectrics such as PMMA (k ≈ 3).Fig.11showsthe specific capacitance of the CMC films reached 24.3 nF/cm² for a 200 nm-thick film. The CMC dielectric also demonstrated a breakdown field strength of approximately 1.8 MV/cm and a leakage current density lower than 10^{-6} A/cm² at 0.2 MV/cm. Capacitance was stable up to 200 kHz, above which a decline was observed due to the onset of interfacial and dipolar polarization effects.

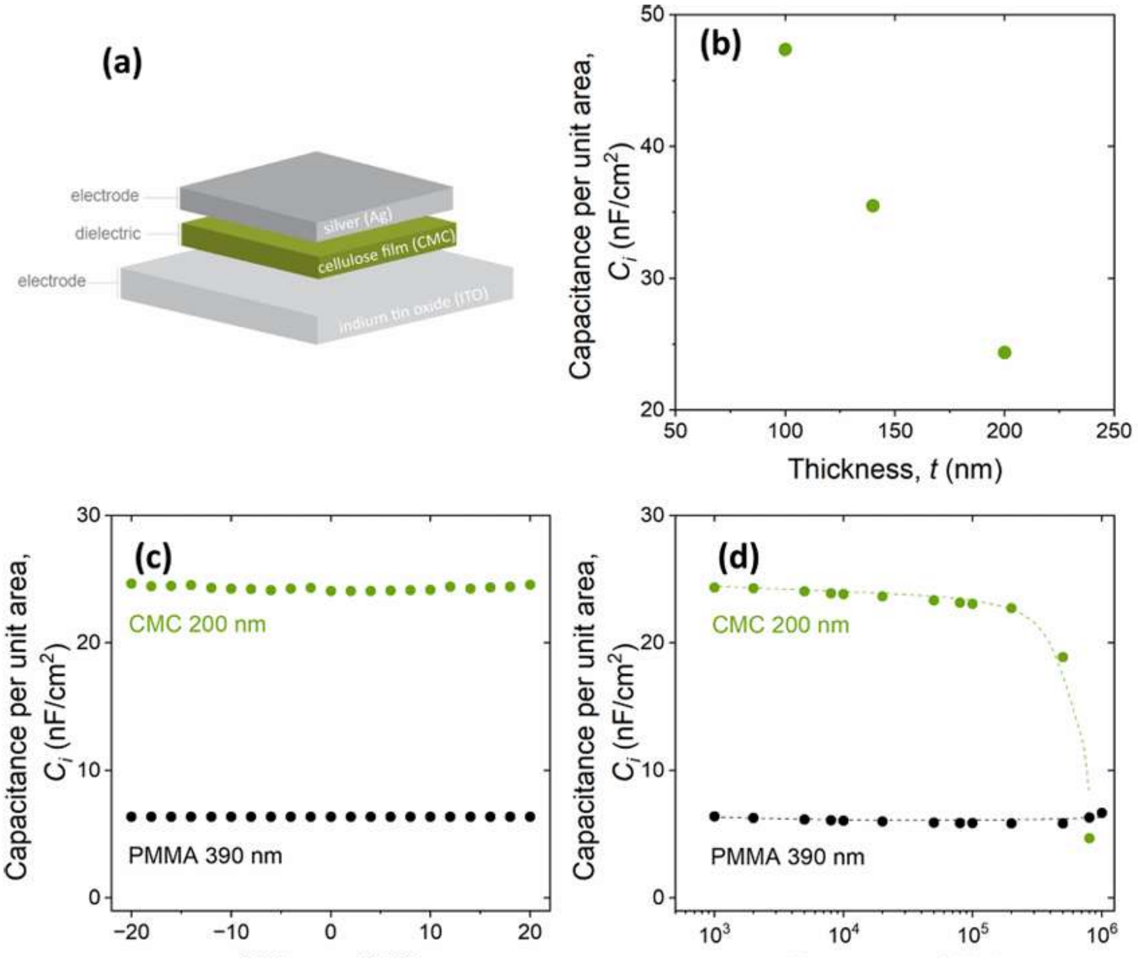

Fig.11.Dielectric response of CMC films. (a) Schematic representation of the parallel-plate capacitor-like structure (electrode/dielectric/electrode) (b) capacitance per unit area as a function of CMC film thickness. Capacitance per unit area as a function of (c) voltage and (d) frequency for CMC film (thickness of 200 nm). Corresponding values for PMMA film-based capacitors (390 nm) are also reported as a reference in panels (c, d)[52].

These results highlight the capability of CMC films to serve as effective, low-voltage, eco-friendly dielectrics in OFETs, with performance metrics competitive with or surpassing those of traditional polymer dielectrics, while offering additional benefits of biocompatibility, solution processability, and environmental sustainability.

Chitosan, a natural polysaccharide derived from chitin, is also emerging as a promising dielectric material for OFETs, due to its biocompatibility, availability and specific electrochemical properties. Sharova et al.[53], was employed as the primary dielectric layer in OFETs printed on ethyl cellulose substrates. Owing to its functional groups (hydroxyl andamine),chitosan enables the formation of an electric double layer (EDL) at the dielectric/semiconductor interface. This mechanism leads to a high specific capacitance exceeding 1 μF/cm^2, which allows for low-voltage operation (< 1 V). The dielectric layer demonstrated good ambient air stability and is particularly attractive for edible and bio-integrated electronics due to its non-toxic and biodegradable nature. In another approach Gao et al.[54]reported, chitosan was used as an interfacial smoothing layer between a cellulose paper substrate and an ion gel dielectric. In this configuration, chitosan improved the surface morphology and supported better molecular ordering of the organic semiconductor. Although the relative permittivity was not directly measured, chitosan exhibited moderate ionic conductivity and strong mechanical adhesion to the substrate, making it suitable for flexible and environmentally friendly electronic devices.

Depending on the devices architecture, chitosan can therefore serve as either an active dielectric through EDL formation or as a functional interfacial layer. In both cases, its mechanical integrity, ionic properties, and sustainability highlight its strategic potential in the development of low-voltage and eco-friendly OFET technologies.

In addition to polysaccharide-based dielectrics such as cellulose, gums, chitosan, etc. other dielectric materials such as monosaccharides (e.g., glucose), disaccharides (e.g., lactose), and nucleobases (e.g., guanine, cytosine) have also attracted attention for their potential application as dielectric layers in OFET devices. These naturally derived compounds offer complementary properties such as good film-forming ability, environmental compatibility, and favorable dielectric constants. These OFETs made with thin films of guanine and cytosine treated under vacuum have demonstrated low dielectric losses in the range of 10^{-3} to 100 mHz, with dielectric constants and breakdown voltages comparable to those of glucose [55]and lactose [55]. High capacitances per unit area at 1 kHz were notably achieved in the OFETs : 9.25 nF/cm² for guanine and 13.8 nF/cm² for cytosine [55].

3. Electrical Performance of Transistors using Polysaccharide Dielectrics

Polysaccharide-based dielectrics, such as cellulose, chitosan, and gums, etc. have demonstrated promising dielectric properties, including suitable dielectric constants, good film-forming ability, and environmental compatibility. These characteristics make them attractive candidates for application as gate dielectrics in organic electronic devices. The performance of OFET devices is closely linked to the characteristics of the dielectric layer, which directly influences charge carrier mobility, threshold voltage, and device stability. In this context, several studies have investigated the integration of polysaccharide dielectrics into OFET architectures, aiming to assess their impact on the electrical performance of the resulting devices.

Recently, studies have shown that biopolymers such as gums can be used as gate dielectrics for OFETs with low operating voltages. Indeed, Maneet al.[18,22]used gum arabic (GA) and almond gum (AG) as gate dielectrics in bottom-gate/top-contact and bottom-gate/bottom-contact OFET structures, respectively.The active layer was a mixture of the organic semi-conductor DPPTTT and the organic polymer dielectric PMMA at a ratio 70:30. They report good electrical insulation properties and OFETs operating below 3 volts with an ON/OFF ratio of 10^3 and $>10^2$ for OFETs with almond gum and arabic gum as gate dielectrics, respectively. Fig.12a and 13a show the structures of the OFETs using gum arabic and almond gum, respectively. Electrical characterizations of the OFETs using GA when the drain and gate electrodes are negatively polarized relative to the source, are recorded in Fig.12b and 12c. Those of OFETs based on AG are shown in Fig.13b and 13c. Fig.12b and Fig.13b representoutput characteristics of OFETs operating in accumulation mode, measured by applying a drain voltage (V_{DS}) and a gate voltage (V_{GS}) varying from 0 V down to -3 V.

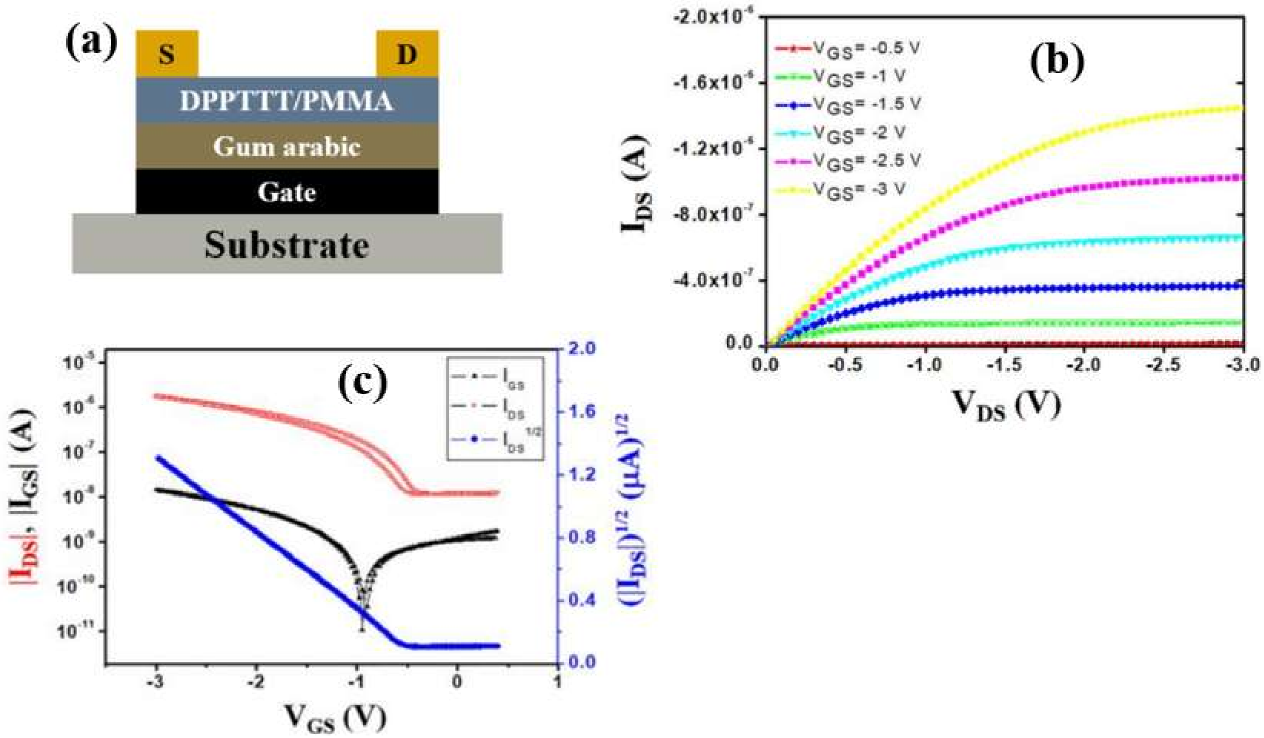

Fig.12. (a) Structure of the OFETs with Gum Arabic dielectric, Output(b) and Transfer(c) characteristics of a representative OFET [22].

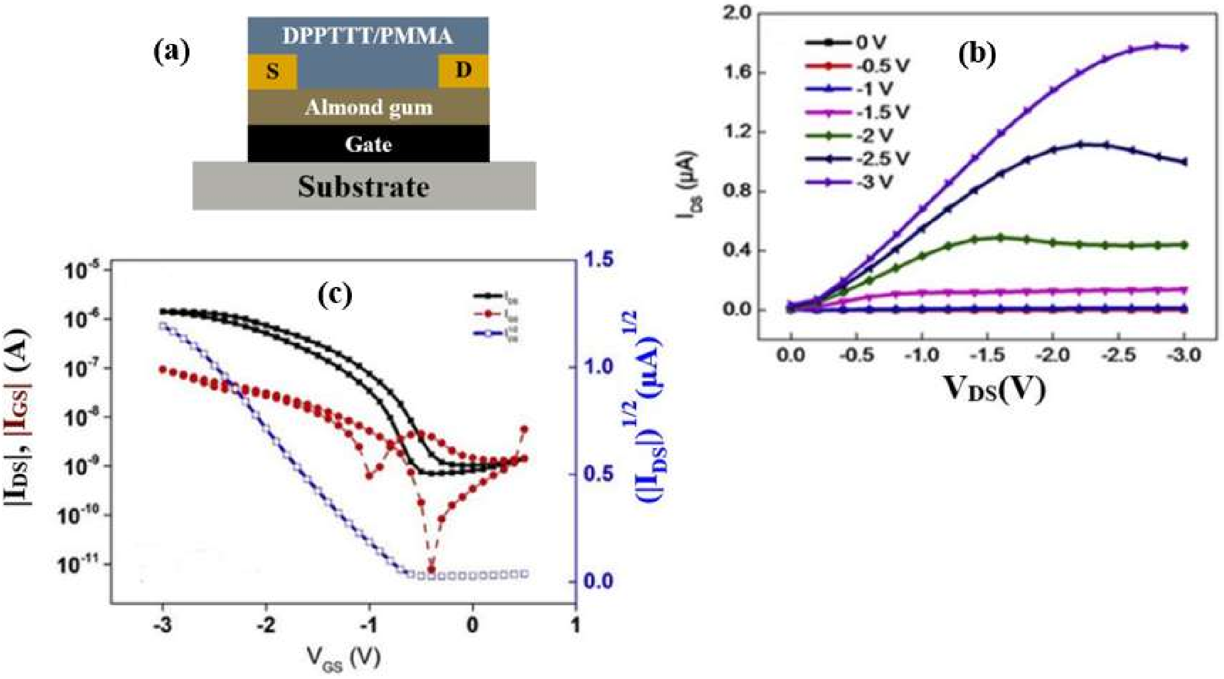

Fig.13.(a) Structure of the OFETs with Almond Gum dielectric, (b) Output and (c) Transfer characteristics of a representative OFET [18].

The electrical parameters of these OFETs were measured in the saturated regime and are listed in Table 1 below. Khaya and cashew gums have also been demonstrated as gate dielectrics in OFETs byA. Tallet al.[6,21]. These transistors were fabricated in the bottom-gate/top-contact configuration with DPPTTT-PMMA as active layer. They are p-channel with a length of 30 µm and a width of 1000 µm (Fig. 14a and Fig.15a).Fabricated OFETs were all characterized under ambient conditions. Electrical measurements were conducted by applying a drain voltage (V_{DS}) and a gate voltage (V_{GS}), both varying identically from -3 V to 0 V. These measurements revealed an output characteristic (Fig.14b and Fig.15b) exhibiting transistor behavior. For the transfer characteristics (Fig.14c and Fig. 15c), the curves were obtained by applying a constant drain voltage (V_{DS} = -3 V) and a gate voltage varying from -3 V to 0 V. Similar to their dielectric counterparts, gum arabic and almond gum, all electrical parameters were measured in the saturated regime and are presented in the same table (Table 1 below).

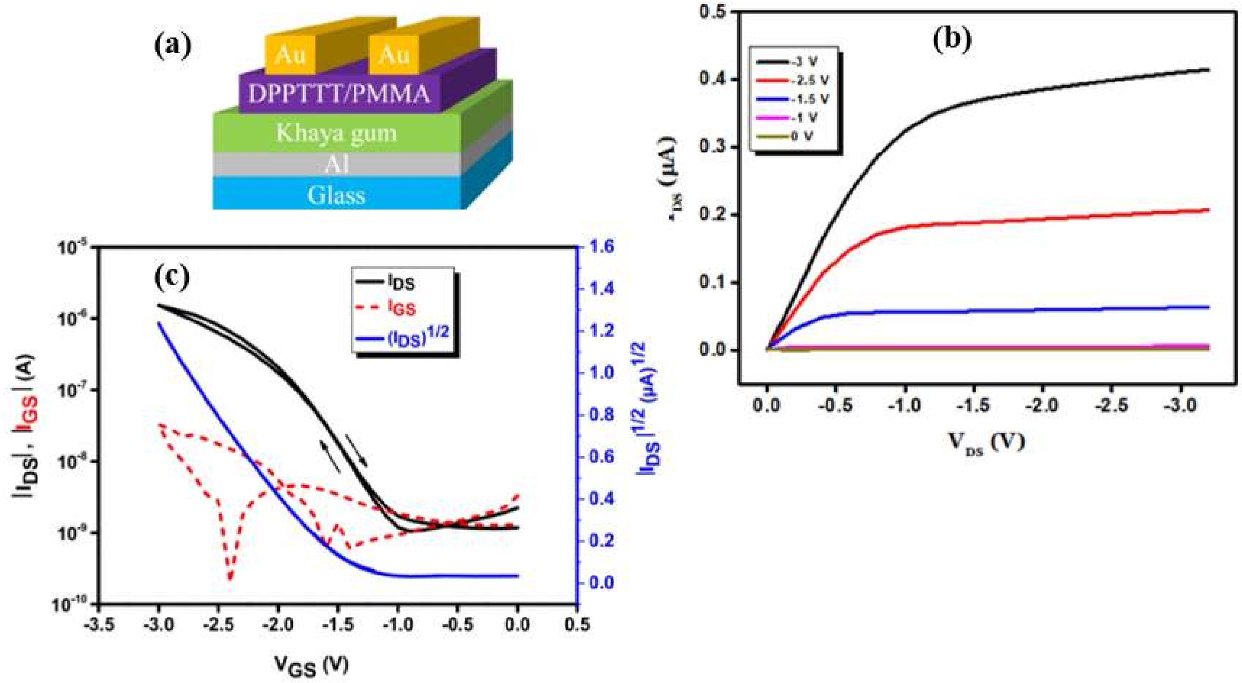

Fig.14. (a) Structure of the OFET with Khaya Gum dielectric, (b) Output and (c) Transfer characteristics of a representative OFET [21].

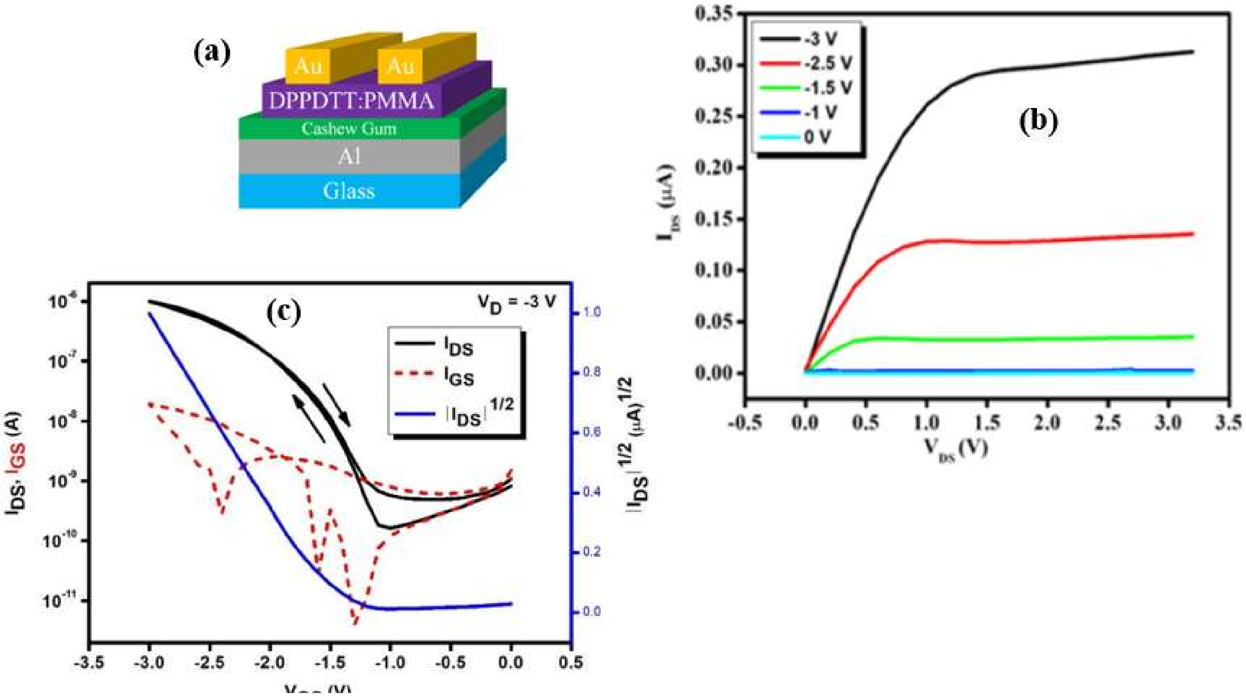

Fig.15. (a) Structure of the OFET with Cashew Gum dielectric, (b) Output and (c) Transfer characteristics of the OFET[6].

Characteristic parameters ofOFETs using these gums: Gum Arabic, Almond Gum, Khaya Gum, and Cashew Gum, and those of other organic dielectrics, as shown in Table 1, demonstrate acceptable OFET performances. Field-effect mobilities (μ_{sat}) of these OFETs were calculated using capacitance density measured at 100 Hz. Their threshold voltages (V_{th}) were relatively low, which is a guarantee of reducing energy consumption for portable electronic devices. The quality of the dielectric/semiconductor interface can be evaluated with the subthreshold slope (SS). A high SS can limit the performance of the device for integrated circuits[56].

Table 1. Performancesof OFETs with Gum Arabic, Almond Gum, Khaya Gum, Cashew Gum, Cyanoethylcellulose and Xanthan Gum dielectrics.

Dielectrics	Active Layers	μ_{sat} (cm^2/Vs)	V_{th} (V)	SS	ON/OFF	References
Arabic Gum	DPPTTT-PMMA	0,6	-0,35	350	$> 10^2$	[22]
Almond Gum	DPPTTT-PMMA	0,75	-0,8	266	$> 10^3$	[18]
Khaya Gum	DPPTTT-PMMA	0,3	-1,3	450	$> 10^3$	[21]
Cashew Gum	DPPTTT-PMMA	0,2	-1,4	250	$> 10^3$	[6]
Cyanoethylcellulose	DPPTTT-PMMA	0,6	-1,3	145	$\sim 10^4$	[57]
Xanthan Gum	-	14	0,67	102	$> 10^5$	[49]

Recent studies have also been conducted in other areas [14,58–60]highlighting the dielectric potential of polysaccharides-based dielectrics from plant or animal sources. R. D'Orsiet al.[61]present OFETs with pentacene as active layer, fabricated by thermal evaporation, operating at a voltage of -6 V, using lignin as the dielectric. Dielectric potential of C-dextran[62]and cyanoethylcellulose[48] have been demonstrated in OFETs. These transistors operated at -30 V and -5 V, respectivelywith threshold voltages of -10.34 V and -0.4 V.

In term of temperature processability, organic materials can be processed at much lower temperatures compared to inorganic materials, which require much higher temperatures. This provides the advantage of using substrates such as paper and plastic for printed electronics.

C. S. Bugaet al.[63], J. H. Kwon et al.[64], and D. Kimet al.[65]have explored technological advances, demonstrating greater adaptability and the potential to create flexible, portable, and innovative organic electronic devices. They use modern manufacturing techniques, such as screen printing and inkjet printing.Bae et al.[5]focused on organic thin-film transistors (OTFTs) with a triacetate cellulose gate dielectric. These transistors are fully solution processable and top contact.Output characteristic curve of the pBTTTBiOTFT exhibited good pinch-off and saturation regime. Saturated mobility value obtained from the transfer characteristic and the electrical performance of the pBTTT OTFT devices with the triacetate cellulose gate dielectric fabricated on each ITO (or ITO-PET) coated glass were evaluated in an ambient atmosphere and summarized in Table 2. Average field-effect mobility of the pBTTTBiOTFTs with TAC gate insulators on rigid ITO coated glass was 0.031 ± 0.007 cm²/V.s, which is comparable to those of an OTFT device with an untreated silicon oxide gate dielectric[66,67].

To obtain the flexible pBTTTbased BiOTFT,TAC dielectric layer was applied onto ITO-coated PETflexible substrate. The study of the flexing of the device was performed using a custom-built bending device with a 15 mm radius. The bending inward and outward were repeated 100 times, as shown inFig.16a and 16b. These flexible devices exhibited excellent performance with no significant difference compared to the rigid devices (Table 2). Therefore, the results show hydrophobic and solution-processable thin layer of TAC, as a gate dielectric layer, even when bent (flexible), plays an important role inobtaining stableandhigh valueof mobility, reliable performance offlexible BiOTFT devices without significant hysteresis.

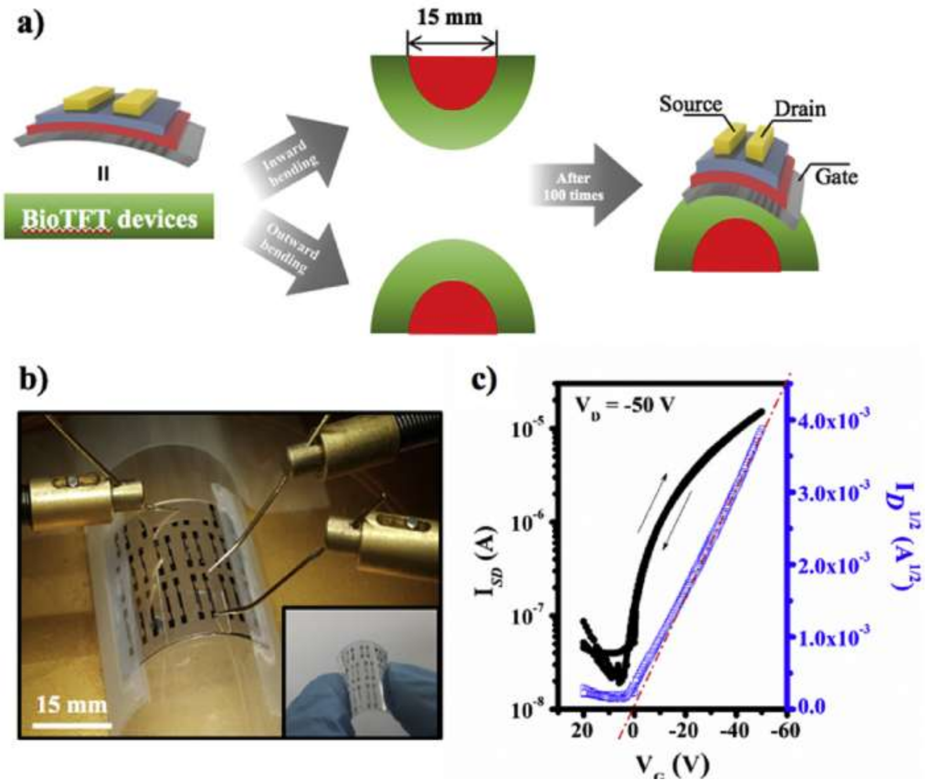

Fig.16. (a) Schematic diagram ofprocedure for bending stimulation of the flexible BiOTFT device arrays using a custom-built bending apparatus with a 15 mm radius. After inward and outward bending was repeated 100 times, (b) represent a photo and (c) the transfer characteristic of the flexible pBTTT-based OTFT device usingTAC gate dielectric measured in the outward bending state. The transfer curve was repeated 10 times[5].

Table 2. Electrical characteristics of pBTTT based OTFT using triacetate cellulose as gate dielectric. The devices were fabricated onto different substrates[5].

Substrates type	μ_{avg}[a] (cm^2/Vs)	I_{on}/I_{off}	V_{th} (V)
ITO-glass (uncurved state)	0.031 ± 0.007	1.2E+03	0.15
ITO-PET (curved state)	0.027 ± 0.004	1.2E+03	0.12

[a] Average field-effect mobilities and standard deviations are calculated from 60 individual BiOTFT devices.

Gallegos-Rosas et al.[52] introduced carboxymethyl cellulose (CMC) as a sustainable gate dielectric for OFET applications (Fig.17). The CMC-based dielectric exhibited a surface capacitance four times higher than that of polymethyl methacrylate (PMMA) and a threshold voltage reduction by a factor of seven. OFETs fabricated with this dielectric operated at low voltages (<10 V) while maintaining excellent electrical stability. In addition to its eco-friendly nature, the material displayed high optical transparency and low surface roughness, positioning it as a promising alternative to conventional polymer dielectrics for next-generation bio-sourced organic electronics.

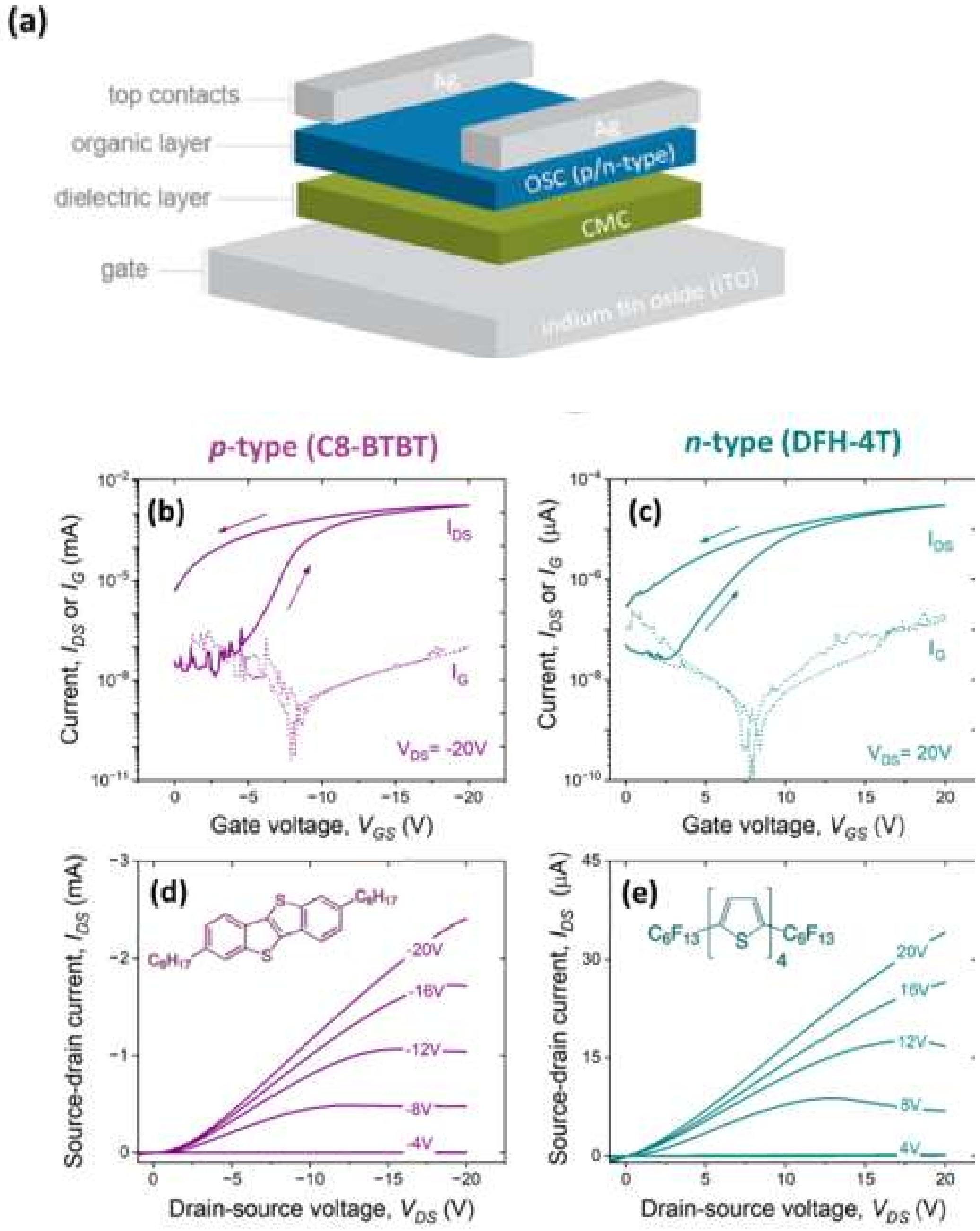

Fig.17. Organic field-effect transistor with a CMC dielectric film. (a) Device schematic of the bottom-gate top-contacts OFET configuration using CMC film as gate dielectric layer. (b, c) Saturation transfer and (d, e) multiple output curves for (left column) p- and (right column) n-type OFET. Chemical structures of the organic semiconductors are also reported in panels (d, e)[52].

In the context of the growing development of green electronics, natural polysaccharides such as cellulose and its derivatives, chitin, gums and other bio-based materials have emerged as promising alternatives to conventional synthetic dielectrics. Owing to their biodegradability, biocompatibility, abundance, and low cost, these biopolymers align with sustainable strategies for the fabrication of environmentally friendly electronic devices.

The use of polysaccharides-based dielectrics paves the way for the development of flexible, biodegradable, and potentially compostable electronic devices, particularly suited for transient or disposable applications such as environmental sensors, biomedical devices, and wearable electronics.Their integration into OFET architectures represents a practical andenvironmentally responsible strategy for minimizing the ecological footprint of organic electronics and contributing to the advancement of sustainable electronic systems.

4.Conclusion:-

This review highlights the potential of polysaccharide-based dielectrics in green and sustainable electronics. Polysaccharides offer excellent dielectric properties, including the ability to form layers stables and double layers when combined with. These results in high specific capacitances suitable for low-voltage applications, make them ideal for organic field-effect transistors (OFETs) operating at reduced voltages.Thesepolysaccharide dielectrics offer numerous opportunities for the development of green and sustainable electronics. Although their use faces challenges, current and future research aims to overcome these barriers and fully exploit the potential of these materials.

Improving thermal stability, adopting sustainable green chemistry practices, promoting and green electronics could be key aspects for fully developing the potential of dielectrics polysaccharides.If we succeed in combining these advancements and challenges with innovative manufacturing techniques, we can expect significant improvements in the functionality and durability of biomaterials. Furthermore, this will promote the development of electronics in a sustainable and environmentally responsible approach.

References:-

[1] Uhrich K E, Cannizzaro S M, Langer R S and Shakesheff K M 1999 Polymeric Systems for Controlled Drug Release Chem. Rev.99 3181–98

[2] Meier T, Yoon Y, Teuerle L, Solgi A, Leo K and Kleemann H 2023 A Hybrid Process for Integration of Organic Electrochemical Transistors for High Uniformity & Reliability MRS Communications14 149–57

[3] Quinton C, Sicard L, Vanthuyne N, Jeannin O and Poriel C 2018 Confining Nitrogen Inversion to Yield Enantiopure Quinolino[3,2,1-k]Phenothiazine Derivatives Adv Funct Materials28 1803140

[4] Nair L S and Laurencin C T 2007 Biodegradable polymers as biomaterials Progress in Polymer Science32 762–98

[5] Bae J W, Jang H-S, Park W-H and Kim S-Y 2017 Triacetate cellulose gate dielectric organic thin-film transistors Organic Electronics41 186–9

[6] Faraji S, Tall A, Mohammadian N, Seck M, Saadi M, Tavasli A, Erouel M, Khirouni K, Diallo A K and Majewski L A 2023 Towards sustainable, solution-processed organic field-effect transistors using cashew gum as the gate dielectric Front. Mater.10 1280543

[7] Azeman N H, Arsad N and A Bakar A A 2020 Polysaccharides as the Sensing Material for Metal Ion Detection-Based Optical Sensor Applications Sensors20 3924

[8] Bibi F, Guillaume C, Sorli B and Gontard N 2016 Plant polymer as sensing material: Exploring environmental sensitivity of dielectric properties using interdigital capacitors at ultra high frequency Sensors and Actuators B: Chemical230 212–22

[9] Schlemmer W, Selinger J, Hobisch M A and Spirk S 2021 Polysaccharides for sustainable energy storage – A review Carbohydrate Polymers265 118063

[10] Pandurangan P 2023 Recent Progression and Opportunities of Polysaccharide Assisted Bio-Electrolyte Membranes for Rechargeable Charge Storage and Conversion Devices Electrochem4 212–38

[11] Sirringhaus H, Sakanoue T and Chang J 2012 Charge-transport physics of high-mobility molecular semiconductors Physica Status Solidi (b)249 1655–76

[12] Shirakawa H, Louis E J, MacDiarmid A g, Chiang C K and Heeger A J Synthesis of Electrically-Conducting Organic Polymers: Halogen Derivatives of Polyacetylene, (CH)(X).

[13] Tang C W, VanSlyke S A and Chen C H 1989 Electroluminescence of doped organic thin films Journal of Applied Physics65 3610–6

[14] Chen H-W, Lee J-H, Lin B-Y, Chen S and Wu S-T 2017 Liquid crystal display and organic light-emitting diode display: present status and future perspectives Light Sci Appl7 17168–17168

[15] Wang J, Xu S, Zhang C, Yin A, Sun M, Yang H, Hu C and Liu H 2023 Field effect transistor-based tactile sensors: From sensor configurations to advanced applications InfoMat5 e12376

[16] Shen Y, Liang L, Zhang S, Huang D, Zhang J, Xu S, Liang C and Xu W 2018 Organelle-targeting surface-enhanced Raman scattering (SERS) nanosensors for subcellular pH sensing Nanoscale10 1622–30

[17] Louis E J and Macdiarmid A Synthesis of Electrically Conducting Organic Polymers : Halogen Derivatives of Polyacetylene, (CH),

[18] Seck M, Mohammadian N, Diallo A K, Faraji S, Erouel M, Bouguila N, Ndiaye D, Khirouni K and Majewski L A 2020 Organic FETs using biodegradable almond gum as gate dielectric: A promising way towards green electronics Organic Electronics83 105735

[19] Wang Y, Huang X, Li T, Li L, Guo X and Jiang P 2019 Polymer-Based Gate Dielectrics for Organic Field-Effect Transistors Chem. Mater.31 2212–40

[20] Zarei M, Lee G, Lee S G and Cho K 2023 Advances in Biodegradable Electronic Skin: Material Progress and Recent Applications in Sensing, Robotics, and Human–Machine Interfaces Advanced Materials35 2203193

[21] Tall A, Faraji S, Diallo A K, Mohammadian N, Erouel M, Seck M, Saadi M, Khirouni K and Majewski L A 2022 Khaya gum – a natural and eco-friendly biopolymer dielectric for low-cost organic field-effect transistors (OFETs) J Mater Sci: Mater Electron33 15283–95

[22] Seck M, Mohammadian N, Diallo A K, Faraji S, Saadi M, Erouel M, Ly E H B, Khirouni K and Majewski L A 2020 Low voltage organic transistors with water-processed gum arabic dielectric Synthetic Metals267 116447

[23] Klemm D, Heublein B, Fink H and Bohn A 2005 Cellulose: Fascinating Biopolymer and Sustainable Raw Material Angew Chem Int Ed44 3358–93

[24] Rinaudo M 2006 Chitin and chitosan: Properties and applications Progress in Polymer Science31 603–32

[25] Li, Bin., Xu, Wenyang., Kronlund, Dennis., Maattanen, Anni., Liu, Jun., Smatt, Jan-Henrik., Peltonen, Jouko., Willfddotor, Stefan., Mu, Xindong., & Xu, Chunlin., 2015 Cellulose nanocrystals prepared via formic acid hydrolysis followed by TEMPO-mediated oxidation.Carbohydrate Polymers

[26] Konwar G and Tiwari S P 2024 Flexible devices for eco-sustainable electronics: Natural polysaccharide as gate dielectric in organic transistors Memories - Materials, Devices, Circuits and Systems7 100102

[27] Gao D, Lv J and Lee P S 2022 Natural Polymer in Soft Electronics: Opportunities, Challenges, and Future Prospects Advanced Materials34 2105020

[28] Khan M N 2017 Principles of Engineering Physics 2 (Cambridge: Cambridge University Press)

[29] O. O. N. Dine (2026). Detection of partial charges in dielectrics, Guelma University, Algeria

[30] Lee H M, Kim Y W, Go E M, Revadekar C, Choi K H, Cho Y, Kwak S K and Park B J 2023 Direct measurements of the colloidal Debye force Nat Commun14 3838

[31] Gajula G R, Buddiga L R, Chidambara Kumar K N and Dasari M 2020 Study on electric modulus, complex modulus and conductivity properties of Nb/Sm, Gd doped barium titanate-lithium ferrite ceramic composites Results in Physics17 103076

[32] Raïssi T, Ibos L, Ramdani N and Candau Y 2005 Analyse de spectres de relaxation diélectrique par inversion ensembliste. Une première approche Revue internationale de génie électrique8 97–117

[33]Macdonald J R 1974 Binary electrolyte small-signal frequency response Journal of Electroanalytical Chemistry and Interfacial Electrochemistry53 1–55

[34]Nketia-Yawson B and Noh Y 2018 Recent Progress on High-Capacitance Polymer Gate Dielectrics for Flexible Low-Voltage Transistors Adv Funct Materials28 1802201

[35]Ortiz R P, Facchetti A and Marks T J 2010 High- k Organic, Inorganic, and Hybrid Dielectrics for Low-Voltage Organic Field-Effect Transistors Chem. Rev.110 205–39

[36]Irimia-Vladu M, D. Glowacki E, S. Sariciftci N and Bauer S 2017 Green Materials for Electronics (Wiley)

[37]Stadlober B, Karner E, Petritz A, Fian A and Irimia-Vladu M Nature as Microelectronic Fab

[38] Seck M, Diallo A K, Erouel M, Saadi M, Tiss B, Wederni M A, Tall A, Babacar Ly E H, Kobor D, Bouguila N and Khirouni K 2021 Dielectric investigation and material properties of almond gum thin films deposited by spray pyrolysis Materials Chemistry and Physics272 124917

[39] Barik P, Bhattacharjee A and Roy M 2016 Characterization of dielectric properties of developed CdS-gum arabic composites in low frequency region Polymer Composites37 108–14

[40] Awasthi A K, Li J, Koh L and Ogunseitan O A 2019 Circular economy and electronic waste Nat Electron2 86–9

[41] Farris S, Introzzi L, Biagioni P, Holz T, Schiraldi A and Piergiovanni L 2011 Wetting of Biopolymer Coatings: Contact Angle Kinetics and Image Analysis Investigation Langmuir27 7563–74

[42] Ramesan M T and Surya K 2016 Synthesis, characterization, and properties of cashew gum graft poly(acrylamide)/magnetite nanocomposites J of Applied Polymer Sci133 app.43496

[43] Seong H, Baek J, Pak K and Im S G 2015 A Surface Tailoring Method of Ultrathin Polymer Gate Dielectrics for Organic Transistors: Improved Device Performance and the Thermal Stability Thereof Adv Funct Materials25 4462–9

[44] Barik P, Bhattacharjee A and Roy M 2015 Preparation, characterization and electrical study of gum arabic/ZnO nanocomposites Bull Mater Sci38 1609–16

[45] Tall A, Diallo A K, Erouel M, Seck M, Chouiref L, Saadi M, Wederni M A, Ly E H B, Diallo A, Bouguila N, Kobor D and Khirouni K 2022 Electrical and Dielectrical Properties of Khaya Gum Biopolymer Thin Filmcoated by Spray Pyrolysis Technique J Sol-Gel Sci Technol104 401–11

[46] Seck M, Diallo A K, Erouel M, Saadi M, Tiss B, Wederni M A, Tall A, Babacar Ly E H, Kobor D, Bouguila N and Khirouni K 2021 Dielectric investigation and material properties of almond gum thin films deposited by spray pyrolysis Materials Chemistry and Physics272 124917

[47] Ramesan M T and Surya K 2016 Synthesis, characterization, and properties of cashew gum graft poly(acrylamide)/magnetite nanocomposites J of Applied Polymer Sci133 app.43496

[48] Konwar G and Tiwari S P 2024 Flexible devices for eco-sustainable electronics: Natural polysaccharide as gate dielectric in organic transistors Memories - Materials, Devices, Circuits and Systems7 100102

[49] Li F, Liang L, Liu K, Liu N and Liu Y 2022 Xanthan gum-gated flexible thin-film transistor for realizing inverter functions Thin Solid Films763 139591

[50] Ukah N B, Granstrom J, Sanganna Gari R R, King G M and Guha S 2011 Low-operating voltage and stable organic field-effect transistors with poly (methyl methacrylate) gate dielectric solution deposited from a high dipole moment solvent Applied Physics Letters99 243302

[51] Kim S H, Yun W M, Kwon O-K, Hong K, Yang C, Choi W-S and Park C E 2010 Hysteresis behaviour of low-voltage organic field-effect transistors employing high dielectric constant polymer gate dielectrics J. Phys. D: Appl. Phys.43 465102

[52] Gallegos-Rosas K, Azari A and Soldano C 2025 Carboxymethyl Cellulose as a Sustainable Dielectric Material for Organic Field-Effect Transistors ACS Appl. Electron. Mater.7 1274–82

[53] Shen Y, Liang L, Zhang S, Huang D, Zhang J, Xu S, Liang C and Xu W 2018 Organelle-targeting surface-enhanced Raman scattering (SERS) nanosensors for subcellular pH sensing Nanoscale10 1622–30

[54] Qian C, Sun J, Yang J and Gao Y 2015 Flexible organic field-effect transistors on biodegradable cellulose paper with efficient reusable ion gel dielectrics RSC Adv.5 14567–74

[55] Irimia-Vladu M, Troshin P A, Reisinger M, Shmygleva L, Kanbur Y, Schwabegger G, Bodea M, Schwödiauer R, Mumyatov A, Fergus J W, Razumov V F, Sitter H, Sariciftci N S and Bauer S 2010 Biocompatible and Biodegradable Materials for Organic Field-Effect Transistors Adv Funct Materials20 4069–76

[56] Rahmouni H, Smari M, Cherif B, Dhahri E and Khirouni K 2015 Conduction mechanism, impedance spectroscopic investigation and dielectric behavior of $La_{0.5}$ $Ca_{0.5-x}$ Ag_x MnO_3 manganites with compositions below the concentration limit of silver solubility in perovskites ($0 \leq x \leq 0.2$) Dalton Trans.44 10457–66

[57] Faraji S, Danesh E, Tate D J, Turner M L and Majewski L A 2016 Cyanoethyl cellulose-based nanocomposite dielectric for low-voltage, solution-processed organic field-effect transistors (OFETs) J. Phys. D: Appl. Phys.49 185102

[58] Chang J, Wang C, Huang C, Tsai T, Guo T and Wen T 2011 Chicken Albumen Dielectrics in Organic Field-Effect Transistors Advanced Materials23 4077–81

[59] Feig V R, Tran H and Bao Z 2018 Biodegradable Polymeric Materials in Degradable Electronic Devices ACS Cent. Sci.4 337–48

[60] Singh A K, Ghosh S, Roy B and Tiwari D K Application of Radio Frequency Identification (RFID) Technology in Dairy Herd Management 4

[61] D'Orsi R, Irimia C V, Lucejko J J, Kahraman B, Kanbur Y, Yumusak C, Bednorz M, Babudri F, Irimia-Vladu M and Operamolla A 2022 Kraft Lignin: From Pulping Waste to Bio-Based Dielectric Polymer for Organic Field-Effect Transistors Advanced Sustainable Systems6 2200285

[62]Yang Y, Sun H, Zhao X, Xian D, Han X, Wang B, Wang S, Zhang M, Zhang C, Ye X, Ni Y, Tong Y, Tang Q and Liu Y 2022 High-Mobility Fungus-Triggered Biodegradable Ultraflexible Organic Transistors Advanced Science9 2105125

[63] Buga C S and Viana J C 2021 A Review on Materials and Technologies for Organic Large-Area Electronics Adv Materials Technologies6 2001016

[64] Gross S and Bauer M 2010 EXAFS as Powerful Analytical Tool for the Investigation of Organic–Inorganic Hybrid Materials Adv Funct Materials20 4026–47

[65] Admane D C and Karadbhajne S V 2019 Advances in Low Temperature Processing IJETT67 100–12
[66] Bae J W and Song K 2016 Anisotropic charge-carrier mobilities of liquid crystalline conjugated polymers on photo-aligned PVCN dielectric insulators Organic Electronics30 143–8
[67] Operamolla A and Farinola G M 2011 Molecular and Supramolecular Architectures of Organic Semiconductors for Field-Effect Transistor Devices and Sensors: A Synthetic Chemical Perspective Eur J Org Chem2011 423–50