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Synthesis and characterization of a new organic semiconductor material

Imane Tiffour [a, b], Abdelkader Dehbi [a], Abdel-Hamid I. Mourad [c, *, 1], Abdelkader Belfedal [b, d]

[a] Laboratoire de Génie Physique, Département de Physique, Université de Tiaret, Tiaret 14000, Algeria
[b] Faculté des Sciences et Technologies, Université Mustapha Stambouli, Mascara 29000, Algeria
[c] Mechanical Engineering Department, Faculty of Engineering, United Arab Emirates University, Al-Ain, P.O. Box 15551, United Arab Emirates
[d] LPCMME, Département de Physique, Université d'Oran Es-sénia, 3100 Oran, Algeria

HIGHLIGHTS

- Development of a new organic acetaminophen/Curcumin semiconductor material.
- The developed material has characteristics of an organic semiconductor.
- It has electrical conductivity comparable to available organic semiconductors.
- It has high optical transmittance and low permittivity/dielectric constant.

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ABSTRACT

The objective of this study is to create an ideal mixture of Acetaminophen/Curcumin leading to a new and improved semiconductor material, by a study of the electrical, thermal and optical properties. This new material will be compared with existing semiconductor technology to discuss its viability within the industry. The electrical properties were investigated using complex impedance spectroscopy and optical properties were studied by means of UV-Vis spectrophotometry. The electric conductivity σ, the dielectric constant ε_r, the activation energy E_a, the optical transmittance T and the gap energy E_g have been investigated in order to characterize our organic material. The electrical conductivity of the material is approximately 10^{-5} S/m at room temperature, increasing the temperature causes σ to increase exponentially to approximately 10^{-4} S/m. The activation energy obtained for the material is equal to 0.49 ± 0.02 ev. The optical absorption spectra show that the investigating material has absorbance in the visible range with a maximum wavelength (λ_{max}) 424 nm. From analysis, the absorption spectra it was found the optical band gap equal to 2.6 ± 0.02 eV and 2.46 ± 0.02 eV for the direct and indirect transition, respectively. In general, the study shows that the developed material has characteristics of organic semiconductor material that has a promising future in the field of organic electronics and their potential applications, e.g., photovoltaic cells.

1. Introduction

Conducting organics (CO) are an exciting new class of electronic materials which have garnered increasing interest since Shirakawa's report in 1977 [1] due to the fact that they combine both metal and organic properties. These conducting organics will establish themselves as key low-cost electronic materials. The structural and electrical properties of organic compound semiconductor (OCS) materials have been intensively investigated in the recent years due to their wide range of potential applications in light-emitting diodes, solar cells, organic transistors, battery materials [2], electrochromic devices [3,4], electromagnetic shielding [5], sensor technology [6], nonlinear optics [7], molecular electronics [8] and enzyme immobilization matrices [9,10]. The Organic semiconductor materials carry a potential for development in the

* Corresponding author.
E-mail address: ahmourad@uaeu.ac.ae (A.-H.I. Mourad).
[1] On leave from the Mechanical Design Department, Faculty of Engineering, Mataria, Helwan University, Cairo, Egypt.

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search for relatively low cost photovoltaic modules for the production of domestic electricity. Unlike silicon cells, they can be easily manufactured on flexible substrates, allowing them to be easily integrated in to everyday objects. Several studies on the use of semiconducting polymers have been published in recent years [4]. In contrast to polymers, small molecules have the advantage that they can be deposited by evaporation or vacuum distillation without solvent and under high vacuum; this method allows obtaining a film of high purity. Many unsubstituted conducting organic systems have limited solubility as a result, they exhibit intractable and infusible properties. This is primarily due to the rigid rod nature of COs, arising from their extended-delocalization. Several approaches have been considered to improve the processability of conducting polymers [11]. The most effective method is the introduction of insulating organic matrices into them [12–18]. Organic semiconductors have certain advantages such as light weight and simplicity of design since the molecules are assembled together, and their biggest strength hallowing greater manipulation. In terms of manufacturing conditions and financial cost, unlike crystalline silicon whose production requires very high temperatures, their manufacture involves low energy costs and low environmental impact. They are evolving more and more into the world of electronics and information technology. They also are useful elements to replace silicon inorganic electronics.

Our attention was to limit the hepatotoxicity of Acetaminophen by adding Curcumin, and to increase the bioavailability of Curcumin. On this basis, it was thought to study certain physical properties, in order to find a relationship between physical and biological properties of the mixture. But coincidentally and after measuring the absorbance λ and the electrical conductivity σ of the blend it has been discovered that the blend may have semiconductor characteristics. Since Acetaminophen and Curcumin are widely used in the biological applications and of limited applications in electronics fields, the work has been directed and focused on such interesting research area of the organic semiconductors. In this paper, a new approach is introduced to produce a new organic semiconductor material from Acetaminophen (synthesized) mixed with powdered Curcumin (commercial) [50 wt%–50 wt%]. The new compounds were characterized by using complex impedance, UV–vis spectroscopy, thermogravimetric analysis (TGA) and X-ray diffraction.

2. Material and experimental

2.1. Material and sample preparation

The sample was prepared by mixing 01 g of powdered Curcumin (commercial) with 01 g of Acetaminophen (the commercial name is paracetamol) (synthesized) [50%–50%]. The chemical structures of the organic compounds are shown in Fig. 1. An amount of 7 ml of distilled water was added to each sample and was thoroughly mixed. This was placed into a microwave oven at 300 W for 10 min to get a homogenous semiconductor material. Finally, using a mortar, the mixture was crushed until a fine powder was obtained. The melting temperature was then measured using the powder and found to be 493 K. Discs samples of 13 mm diameter and 1 mm thickness have been prepared by compaction technique and used for the measurements of the electrical properties. Fig. 2 shows the disc samples that has been used.

2.2. Structural characterization

The structural characterization of Acetaminophen/Curcumin samples was performed by the XRD technique. The structural changes were analysed using Cu K_α radiation of wavelength

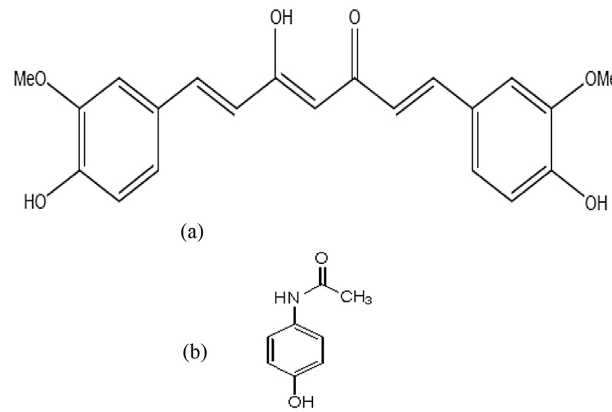

Fig. 1. The chemical structures of the organic compounds: (a) Curcumin and (b) Acetaminophen.

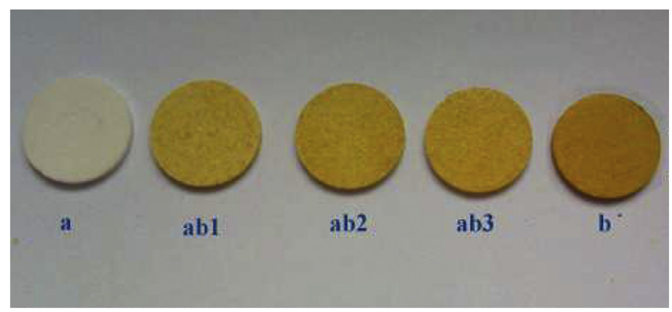

Fig. 2. Disc samples for electrical properties measurements. (a) Acetaminophen (100%); (ab1) Acetaminophen (75%)/Curcumin (25%); (ab2) Acetaminophen (50%)/Curcumin (50%); (ab3) Acetaminophen (25%)/Curcumin (75%); (b) Curcumin (100%).

λ = 1.5406 Å, produced by Bruker AXS D8 focus advance X-ray diffraction meter (Rigaku, Japan, Tokyo) with 'Ni-filtered'. The scans were taken in the 2θ range from 10° to 80° with a scanning speed and step size of 1°/mm and 0.01° respectively.

2.3. Optical absorption characterization

The UV–visible spectrum of the developed organic semiconductor was obtained by using Shimazdu UV-1600 PC,UV–vis spectro-photometer of the range of 200–900 nm. The optical absorption of the prepared Acetaminophen/Curcumin samples was measured over the range of 300–800 nm and the energy band gap has been obtained.

2.4. Thermal performance characterization

Differential scanning calorimetry (DSC) experiment was performed by using TA instrument Q20-2487, for thermal characterization of the organic semiconductor. The sample for DSC analysis was cut into small pieces of 10 mg weight from the. Acetaminophen/Curcumin samples. All the experiments were carried out at 200 °C with heating rate of 10 °C min^{-1} in N_2 gas.

The thermogravimetric analysis (TGA, TA Instrument Q50-1555) of compounds were performed using an instrument equipped with a platinum pan. The sample was heated from 40 °C to 600 °C at a heating rate of 10 °C/min, while the chamber was purged continuously with N_2 gas at a rate of 100 ml/min. More details about the procedure and purpose of thermal tests are available in the work of Mourad and his group [19–26].

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