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Fabrication of Cobalt Phthalocyanine Based OFETs and its Application in Voltage Converters

Lekshmi Vijayan[1], K. Shreekrishna Kumar[2]

[1]Research Scholar, School of Technology and Applied Sciences, Pullarikunnu Campus, Mahatma Gandhi University, Kottayam, Kerala
[2]Professor, School of Technology and Applied Sciences, Pullarikunnu Campus, Mahatma Gandhi University, Kottayam, Kerala

Abstract: ***Organic electronic devices are nowadays emerging technologies for future applications. Recently, organic thin film transistors have attracted significant attention due to its potential of realizing large area deposition, mechanical flexibility, light weight and low cost devices. The lower material and fabrication costs of organic FETs are attracting extensive interest for their potential application in organic electronics. In this work a top gate bottom contact organic field effect transistor was fabricated as a voltage converter. Here we report a simple and inexpensive way for the preparation of organic FET and their application as active element in voltage converters. Samples were fabricated using thin film vapor deposition technique. The aim of this work was to investigate the gate source voltage versus drain source voltage characteristics of an OFET and used to voltage converting applications.***

Keywords: Organic field effect transistors, Cobalt Phthalocyanine, Thermal evaporation, Spin coating

1. Introduction

Voltage converters have application in several electronic devices. There is a growing need for miniaturized voltage converter as well as easy interfacing with electronic circuits. However most of the voltage converters are large in size due to their external components. The organic FET uses no external components and is recommended for applications where the space of the device is critical [1]. Besides the increase of the input voltage in the electronic devices is an outstanding problem. Solving these problems might open new opportunities for OFETs and its applications. That is single Organic FET is used to solve this problem. The objective of this work is to evaluate the gate-source voltage versus drain-source voltage characteristics of an OFET so as to design a voltage converter. Organic semiconductors exhibit interesting properties which can be exploited for the fabrication of organic FETs. In particular, they possess excellent mechanical flexibility, thermal stability etc.

Organic semiconductors are a very important class of materials having wide range of properties. The characterization of organic semiconductors is receiving great attention because of the increased activity in their synthesis and potential use in a wide range of large area flexible, disposable, electric, electronic, and photonic devices, such as rechargeable batteries, junction diodes, organic field effect transistor, memory, solar cells, organic light emitting diodes and sensors. The chemical variety in semiconducting materials allows us to apply them in active layers of thin film transistors with a high selectivity. The electronic conductivity of these materials lies between that of metals and insulators. Organic semiconductors are advantageous for the fabrication of electronic devices because of the ease of processing at low temperature, architectural flexibility, material variety, and environmental safety [2].

In 1947, John Bardeen, William Shockley, and Walter Brattain invented the transistor bringing to history one of the major discoveries of the last century. Actually, their invention marked the birth of modern electronics, the transistor being its principal component [3]. An organic field-effect transistor is a field-effect transistor using an organic semiconductor in its channel. Field effect transistors are the basis for all electronic circuits and processors, and the ability to create FETs from organic materials raise exciting possibilities for low cost disposable electronics. OFETs can be prepared either by vacuum evaporation of small molecules or by mechanical transfer of a peeled single-crystalline organic layer onto a substrate [4].

Phthalocyanine (Pc) is an organic semiconductor has excellent stability against heat, light, moisture and oxygen. The phthalocyanines have been become one of the most studied of all organic functional materials and have recently attracted considerable interest due to their high thermal and chemical stability. Phthalocyanines are organic semiconductors receiving considerable attention because of their suitability as an active layer for organic electronic devices. Metal phthalocyanine is one of the promising organic semiconductors due to the possibility of applications in electro-optic devices; photo conducting agents, photovoltaic cell elements, nonlinear optics, electro catalysis, and other photo electronic devices. Among the classes of materials, the Cobalt Phthalocyanine (CoPc) based OFETs exhibit excellent electrical properties. β-form of CoPc is thermodynamically stable and its structure is reported to be monoclinic.

Cobalt phthalocyanine, whose chemical formula is $C_{32}H_{16}CoN_8$, is an organic semiconductor with excellent chemical stability against heat, light, moisture and oxygen, low heat conduction, and diversity of optical properties. In this paper the gate-source voltage versus drain-source voltage characteristics of CoPc based thin film transistors deposited at room temperature are studied to investigate the changes in the electrical properties [6]. Figure 1 shows the molecular structure of a phthalocyanine molecule used as an active material. Here the molecule is planar and the space within the four central nitrogen atoms are occupied either by hydrogen atoms in metal free phthalocyanine or by a metal atom in metal substituted Pcs.

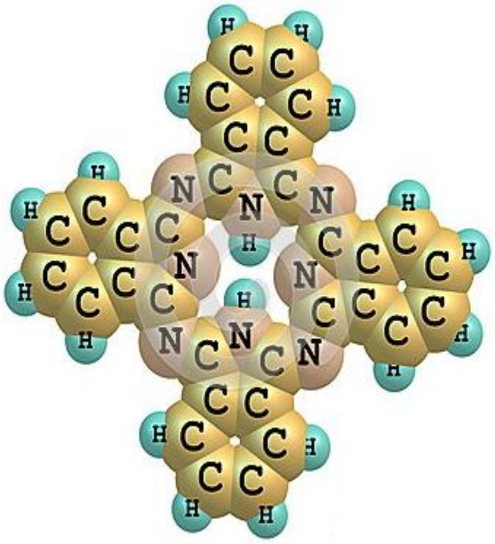

Figure 1: Molecular structure of Phthalocyanine

In this study we describe the working principles of organic field effect transistors for voltage converters. A common use of the voltage converter is for a device that allows appliances made for the mains voltage of one geographical region to operate in an area with different voltage. When we want to interconnect two devices, one of which works over high voltage and the other over low voltage, we need to convert the high into low. Here we show that a voltage converter can be replaced by a single organic FET.

2. Experiment

2.1 Device Fabrication

Three terminal OFETs were used for performing the experiments, using the bottom contact configuration [5]. One advantage of top gate geometry is the auto encapsulation effect created by over coating the gate dielectric and gate layer. The top gate bottom contact p-type OFETs were fabricated on a glass substrate with cobalt phthalocyanine as the organic semiconductor as shown in figure 2. Before starting the deposition, the glass substrate was cleaned in an ultrasonic bath for 10 min using acetone followed by rinsing in deionized water. The substrate was dried in open air in a cleaned room. A molybdenum boat was used as a heating source. The source material is evaporated on to glass substrates from a molybdenum boat of dimension 25mm X 23mm x 1.1mm by resistive heating method. During deposition, the pressure in the vacuum chamber was kept constant at about 10^{-5} mbar and the deposition rates of all the films were at about 10 nm/min. Also the substrate is placed at a distance of 10cm from the molybdenum boat. Thickness of the film is measured from the crystal monitor [9].

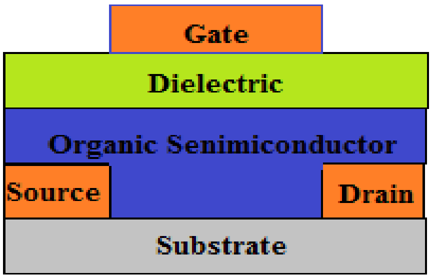

Figure 2: Schematic representation of a OFET structure

To form source/drain electrodes, a 100nm thick silver layer was deposited by a vacuum thermal evaporation process with shadow mask [10]. Also the interdigited source/drain electrodes of silver were patterned using the shadow masking technique. After that the Powdered Cobalt Phthalocyanine from Zigma Aldrich Chemical is used as active channel material. Then as a gate insulator, polyvinyl alcohol (PVA) was dissolved in de-ionized water to obtain 150mg/ml solutions. These solutions were then filtered before the deposition by spin coating. After coating, the film was thermally annealed at 60°C for 10 minutes [8]. PVA has a higher surface energy and dielectric constant in comparison to other polymers. This results in a stronger interaction between the dielectric surface and the organic semiconducting molecules during evaporation [7]. The OFET device fabrication was completed by depositing the silver gate electrode with a thickness of 100nm via vacuum thermal evaporation using a shadow mask.

2.2 Device Characterization

The research into the behavior of the organic semiconducting materials is normally carried out in two ways, optically and electrically. In optical method usually optical absorption measurements are performed. While the conductivity properties are explored in electrical method. The electrical characterizations of the OFET based voltage converters were done in air at room temperature by means of a Keithley sourcemeter and a LCR meter. The fundamental OFET electrical characteristics were measured using a Keithley 2400 Semiconductor characterization system. In this paper V_{gs} versus V_{ds} characteristics of an OFET was recorded for a standard source/drain and an interdigitated source/drain patterns.

3. Working Principle

In an organic field effect transistor, including, on a substrate having an insulating surface, at least a gate electrode, a gate insulating film formed in contact with the gate electrode, an organic semiconductor film formed in contact with the gate insulating film, and at least a pair of source-drain electrodes formed in contact with the organic semiconductor film, a carrier generating electrode to which carriers can be injected in response to a gate signal is implanted within the organic semiconductor film. Three essential components of field effect transistors are the source, the drain and the gate [11].

Field effect transistors usually operate as a capacitor. They are composed of two plates. One plate works as a conducting channel between two ohmic contacts, which are called the source and the drain contacts. The other plate works to control the charge induced into the channel, and it is called the gate. The direction of the movement of the carriers in the channel is from the source to the drain. Hence the relationship between these three components is that the gate controls the carrier movement from the source to the drain. When this capacitor concept is applied to the device design, various devices can be built up based on the difference in the controller. Figure 3 shows the working of an OFET.

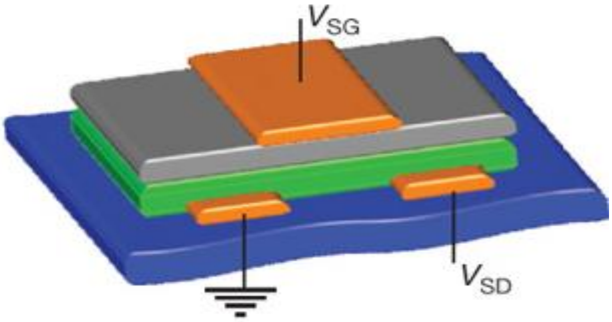

Figure 3: Working of OFET

A voltage is applied to the gate to control the amount of current flow between the source and drain. In a p-type OFET, which is the most common variety of OFET due to the relatively high hole mobility in OSCs, a negative voltage greater in magnitude than the threshold voltage of the semiconductor material is applied between the gate and the source. This voltage causes a p-type channel to form at the semiconductor-insulator interface. A negative voltage is also applied between the drain and the source, causing a hole to flow from the source to the drain. This behavior is equivalent to a negative current owing from the drain to the source. As the magnitude of the drain-source voltage is increased, the magnitude of the drain-source current also increases until pinch-off, at which point the p-channel pinches closed on one side and the drain current saturates at its maximum value. The magnitude of the saturation current depends on the applied gate-source voltage.

4. Results and Discussions

The aim of this study was to fabricate a voltage converter using a single organic FET by thermal evaporation technique. Figure 4 shows the plots of V_{gs} versus V_{ds} switching characteristics, that were recorded for a standard source/drain and an interdigitated source/drain patterns with top gate bottom contact structure. Here the characteristics are indicated by different colours, such as black and red. The black line to be used for the interdigitated source/drain pattern and the red line for standard source/drain pattern. The voltage is varied from 0 to 14 V in steps of 2 V. It is seen that the input gate-source voltage stepped down to the output drain-source region.

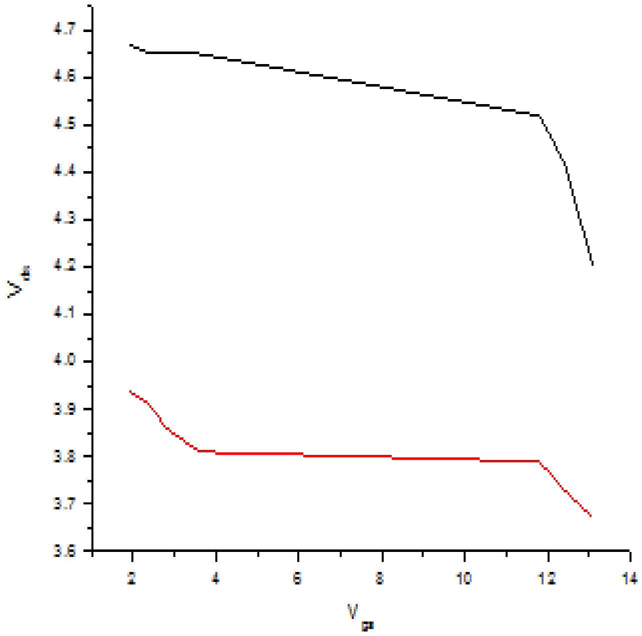

Figure 4: V_{gs} versus V_{ds}

5. Conclusion

In this paper we have presented an organic field effect transistor based voltage converter. That is we have explored the use of organic semiconductor based transistor for converting a high voltage into a low voltage. Besides that organic FETs will have all the advantages of organic electronics such as large area coverage, mechanical flexibility and simpler processing resulting in a low production cost. This paper focuses on the fabrication of an OFET for step down the voltage using thermal evaporation technique. Organic field effect transistors were realized using cobalt phthalocyanine as the organic active layer and PVA as the dielectric. Here the films, except dielectric were fabricated using thermal deposition technique.

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