Supramolecular Dielectric for Low Voltage Organic Electronics

Hei-Chit Leo Tsui*, Joachim Steinke*, Nikolay Vaklev** and Alasdair Campbell**

*Department of Chemistry, Imperial College London, London SW7 2AZ, United Kingdom, leo.tsui10@imperial.ac.uk, j.steinke@imperial.ac.uk

** Department of Physics, Imperial College London, London SW7 2AZ, United Kingdom, nikolay.vaklev09@imperial.ac.uk, alasdair.campbell@imperial.ac.uk

ABSTRACT

The interest in organic thin film transistor (OTFT) has been rising rapidly in recent years because of its potentially low cost fabrication process on flexible substrates. Engineering the dielectric layer is one approach to generate performance enhancement. This work will present a new dielectric material based on a self-assembly strategy. This study aims to investigate the potential of a lipid bilayer in order to obtain ultrathin dielectric layer and reduce the operation voltage for OTFT. We also suggest that self assembly strategies could be useful for large area and high throughput OTFT production with relatively low cost.

Keywords: dielectric, lipid bilayer, self-assembly

1 INTRODUCTION

The transistor is the key components in today electronic devices like microprocessors and integrated circuits, acting as an amplifier or a switch in the device. Conventionally, this device is made of silicon due to its semiconducting property and these silicon-based devices shows high performance and stability during operation. However, silicon-based materials have very limited flexibility and are produced by expensive top-down fabrication methods. Therefore, the interest in organic transistor is rising rapidly in recent years as it shows many attractive advantages, such as being flexible, light weight, potentially low cost and low temperature solution processibility. [1]

The current challenges of OTFT development include lowering operation voltage and enhancing charge mobility. There has been a vast body of work reporting improvements in organic semiconductors materials in particular in regards to performance and fabrication aspects [2,3]; however, this is not the only approach to achieve higher performing OTFTs. As the dielectric layer is an important component affecting the device properties, it can be optimised by modifying present dielectric materials or employing new insulators. [4]

Self-assembled monolayers and bilayers are interesting for dielectric materials because they are able to form thin layered films in the nanometer ranges by self-organisation. Due to their nanometer thickness, they are likely to possess high capacitance, which help reducing the operating voltage of the OTFT. Kauffman and Procarione for example have investigated the electrical properties of phospholipid bilayer film prepared by Langmuir-Blodgett technique. The measured resistance of the film was 10^9 Ω and the capacitance was in the range of 10^{-6} Fcm^{-2}. [5,6] Their results imply that lipid bilayers is a potential candidate to be employed as dielectric layer for OTFTs.

2 EXPERIMENTAL

A capacitor with metal-insulator-metal (MIM) structure is employed to investigate the insulating properties of the lipid dielectric.

PC-IZO foil substrates are sonicated in ethanol for 5 min. The IZO layer of the foil is removed by immersing in 6M HCl for 30 s and then washed in deionized water bath followed by nitrogen jet drying. A solution containing a lipid dissolved in an organic solvent was prepared and the lipid concentration varied.

50 nm Aluminium electrodes are evaporated on the cleaned PC substrate at a rate of 0.03-0.06 nm/s through a shadow mask of 1mm width bar. The lipid solution is then spin coated on top of it. The top electrodes are also evaporated at the same rate through the same mask to form a cross-bar junction with 1 mm^2 area.

The electrical properties are investigated by an IV analyser and an impedance spectroscopy in nitrogen environment and AFM is employed for surface characterisation.

3 RESULTS

3.1 Effect of Solvents

The choice of solvent is important to ensure that the lipid is molecularly dispersed as otherwise complication can arise from existing aggregates during spin coating. This phase separation is not desirable because it leads to higher surface roughness, which is not beneficial for depositing semiconductor films on top. A bilayer structure is able to give a roughness of approx. 4 nm according to Jurak et al. study. [7]

The results show that the ethanol/hexane mixed solvent gives lipid films with better insulating properties at higher voltages, a parameter which we will study further. (Figure 1a)

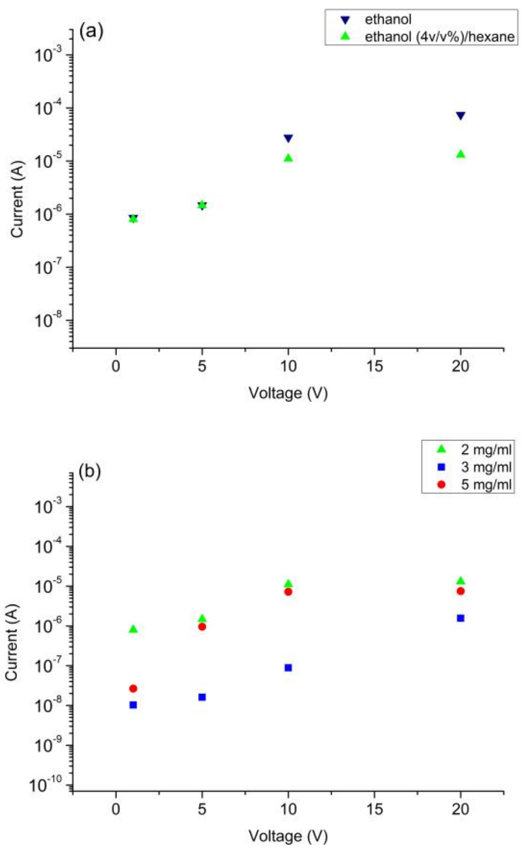

Figure 1: Average current flow through junctions under different voltages (a) different solvents (b) differnet lipid concentrations

3.2 Effect of lipid concentrations

Comparing the performance of different lipid concentrations (Figure 1b), the current passing through the junctions with 2mg/ml and 5mg/ml are in the same range, while there is a 2 order of magnitude lower current passing through the junction with 3mg/ml lipid concentration under all biases except for 1V, which we did not expect and may suggest a subtle balance between film forming properties and lipid preorganisation in solution.

Considering the result of 5mg/ml, a big step up of current from 1V to 5V was found. A possible explanation for this phenomenon is that there are more defects at the junction area. The surface roughness of the electrodes and substrate is one of the factors affecting the number of defects. Besides, since the lipid layer is spin coated on the substrate, the lipid molecules may not form a well organised layer during the process. For instance, some molecules may stack on top of an already formed layer, which may lead to a variation of thickness throughout the junction area. This result suggests that a higher lipid concentration does not necessarily results in an insulating layer with less defects.

The best insulating properties we demonstrate in the present work are 10^{-8}Acm^{-2} at 1V (See Figure 2), while the state-of-the-art leakage current of Self-assembled Monolayer (SAM) dielectrics empolyed in OTFT is 10^{-10}Acm^{-2}.

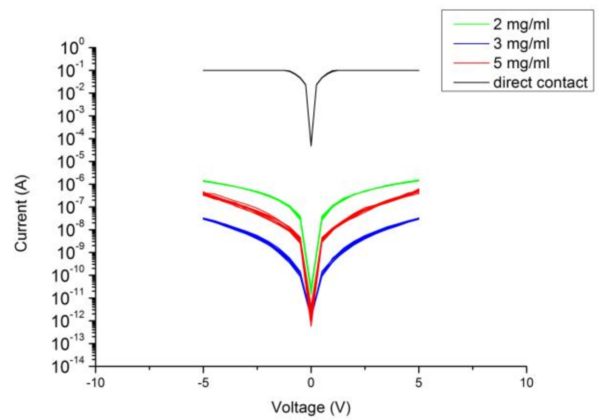

Figure 2: Current-voltage curves of the junctions with different lipid concentrations at 5V

4 CONCLUSION

This work confirms the insulating properties lipid bilayer. The use of spin coating shows that lipid bilayer could be formed via a simpler process compared to Langmuir-Blodget technique and indicates the possibility for printing.

REFERENCES

[1] Colin Reese, Mark Roberts, Mang-mang Ling, and Zhenan Bao, "Organic thin film transistors" MaterialsToday, 21-27, September 2004.

[2] Hagen Klauk, "Organic thin-film transistors", Chem. Soc. Rev., 39, 2643-2666, 2010.

[3] Yoshiro Yamashita, "Organic semiconductors for organic field-effect transistors", Sci. Technol. Adv. Mater. 10, 024313, 2009

[4] Rocio Ponce Ortiz, Antonio Facchetti, and Tobin J. Marks, "High-k Organic, Inorganic, and Hybrid Dielectrics for Low-Voltage Organic Field-Effect Transistors", Chem. Rev., 110, 205-239, 2010.

[5] W.L. Procarione and J.W. Kauffman, "The Electrical Properties of Phospholipid Bilayer Langmuir

Films", Chemistry and Physics of Lipid, 12, 251-260, 1974.
[6] W.L. Procarione and J.W. Kauffman, "Capacitance Studies of Synthetic Phospholipid Langmuir Films", Chemistry and Physics of Lipids, 18, 49-61, 1977.
[7] Malgorzata Jurak, Emil Chibowski, "Surface free energy and topography of mixed lipid layers on mica", Colloids and Surafces B: Biointeraces, 75, 165-174, 2010.