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Characterization of Parylene as a Water Barrier via Buried-in Pentacene Moisture Sensors for Soaking Tests

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Abstract- **We present a simple method to characterize parylene as a water barrier for soaking tests. The key component is the buried-in pentacene moisture sensor, which is a thin-film transistor sandwiched between two layers of parylene C. This pentacene thin-film transistor takes bottom contact configuration and uses parylene C as the gate dielectric material. Parylene films containing pentacene moisture sensors are soaked in saline at room temperature and the saturation drain current of pentacene thin film transistors is monitored. Hole mobility of pentacene is extracted via linearization of the square root of the drain current of the transistor versus gate voltages. We can determine the capability of parylene as a water permeation barrier by the changes of pentacene mobility.**

Keywords-pentacene; thin-film transistor; parylene

I. INTRODUCTION

Poly (chloro-p-xylylene), parylene C, is a widely-used MEMS material. Besides serving as a structural material, parylene C can also serve as a good encapsulation material, since parylene C can achieve conformal and pin-hole free coating. With the emergence of bio-implantable technology, lots of bio-implantable devices employ parylene C as a hermetic packaging material [1]. The intensive and extensive studies of parylene C as a hermetic packaging material are needed.

A good hermetic packaging material has to stop at least the penetration of water. The water and gas permeability of parylene C has been studied in 1990's [2] [3]. However, further characterization of parylene C as a water stopping barrier has to be performed to answer more intensive questions, such as "how thick parylene should be", "could metal parylene composite layers serve as better barriers". In [2] and [3], measurements were done with the time lag method, which requires complex apparatus and precise moisture control and calibration, and have little use for extensive and large-amount measurement. Also, in [2] and [3], the measurements were meant for permeation measurements of gas and water vapor in air. However, for devices for implantation use, there is need to characterize permeation while the whole device is soaked in the liquid.

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Organic thin film transistors (OTFTs) based on pentacene as active layer have received considerable interest. One advantage of organic TFTs is that they can be fabricated on almost all kinds of substrates. Pentacene TFTs have been fabricated on a variety of substrates, such as silicon, glass, polyimide, polyethylene naphthalate (PEN), polyethylene terephthalate (PET), and polycarbonate [4][5][6][7][8]. Recently we have successfully developed a process for the fabrication of pentacene TFTs on the parylene substrate [9]. Also, the hole mobility of pentacene is very sensitive to water and oxygen. Based on this fact, humidity sensors based on pentacene TFTs have been fabricated [10][11].

In short, we can directly fabrication parylene films containing pentacene TFTs as buried-in moisture sensors. By monitoring the hole mobility of pentacene, we can obtain information of the amount of water penetrating into parylene films. Therefore, no complex apparatus nor precise humidity control and calibration are needed.

II. EXPERIMENTAL

Fabrication of the parylene film containing pentacene TFTs can be divided into 3 parts, fabrication of the bottom parylene film, fabrication of pentacene TFTs, and fabrication of top parylene film. So that parylene films with pentacene TFTs sandwiched in between are fabricated. The pentacene TFTs take bottom-contact configuration (Fig.1). The fabrication process starts with photoresist-coated wafers. Parylene C of desired thickness was first deposited in a room temperature CVD process. To define gate electrodes of pentacene TFTs, 1,500-angstron Au with 100-angstron Cr was thermally deposited under the vacuum of 1e-6 Torr and patterned by photolithography and wet etching. 150nm parylene-C was then deposited as the gate dielectric. To create vias for interconnects, the parylene-C gate dielectric was patterned by photolithography and oxygen plasma etching. To define source and drain contacts, 500-angstron Au was deposited by thermal evaporation and patterned by photolithography and wet etching. Pentacene (as purchased from Sigma-Aldrich) was deposited by thermal evaporation under high vacuum to create an organic active TFT layer with average thickness of 30 nm.

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Parylene C of desired thickness was deposited as the top layer. Finally, the whole parylene film with pentacene TFTs sandwiched inside was liftoff from the wafer in a flexible MEMS form, shown in Fig. 2. The simplified fabrication process is illustrated in Fig. 3.

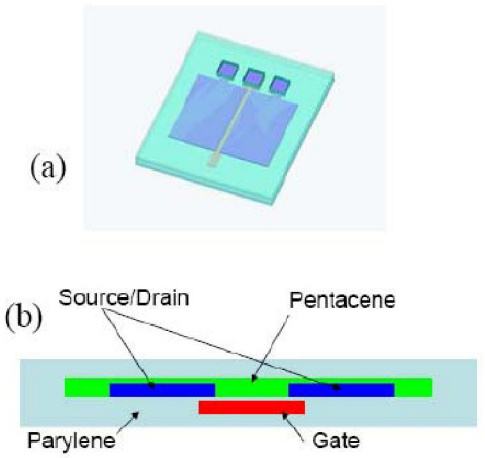

Figure 1. Isometric (a) and cross-section (b) views of bottom-contact configuration of parylene films containing pentacene TFTs

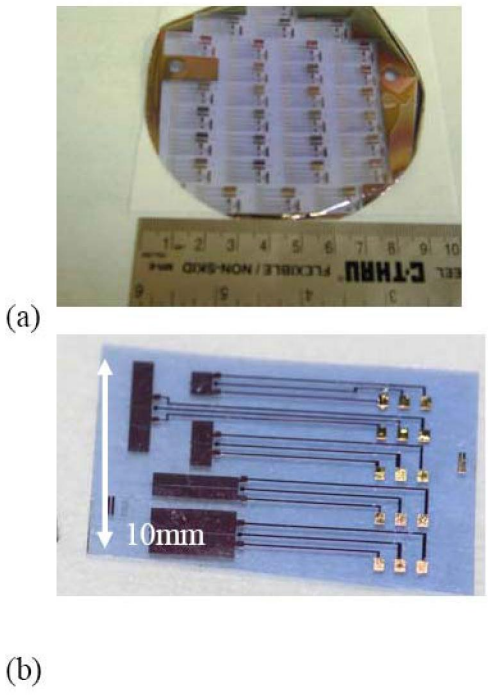

Figure 2. Fabricated Parylene film containing pentacene thin-film transistors. (a) Released film (b) Closer view

III. Results and Discussion

A. *Hole mobility of pentacene thin-film transistors*

We obtained the drain and gate characteristics of the thin-film transistor with a probe station and the HP4145B semiconductor parameter analyzer. The transistor was measured at room temperature. The mobility of charge carrier (μ) in the saturation regime can be calculated from the drain current given by the equation.

$$I_D = \frac{1}{2}\mu C_i \frac{W}{L}(V_{GS} - V_T)^2 \quad (1)$$

Take square root of both sides.

$$\sqrt{I_D} = \sqrt{\frac{C_i W}{2L}}\mu(V_{GS} - V_T) \quad (2)$$

Solving this equation and use a definition of "k" as

$$k = \sqrt{\frac{C_i W}{2L}}\mu \quad (3)$$

$$\mu = \frac{2L}{WC_i}k^2 \quad (4)$$

Equating the slope of the plot $\sqrt{I_D}$ versus V_{GS} to "k" determines the μ in the saturation regime. Fig. 4 shows the drain and gate characteristics of a "fresh" pentacene TFT right after the fabrication finished. This transistor shown has the channel length of 20μm, channel width of 1000μm, mobility of 0.0193 cm^2/V-s, on/off ratio of 500. Though this mobility and on/off ration are not high enough for circuit application, they are good enough for this application.

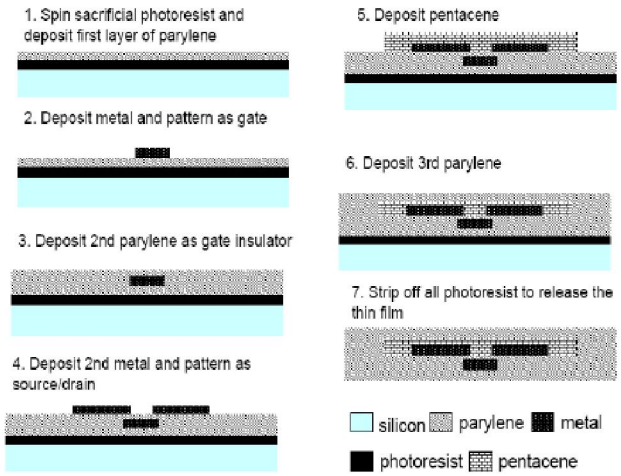

Figure 3. Simplified process flow.

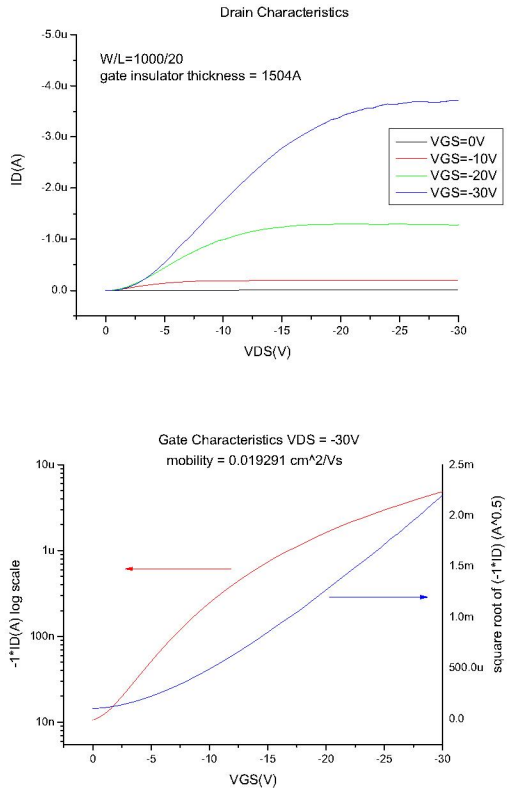

Figure 4. Drain (Up) and gate (Down) characteristics of the fresh pentacene thin film transistors.

B. *Soaking tests*

The objective of this work is to determine parylene's capability of protecting electronics in physiological environments. Therefore, we mimic the physiological environment with saline. For preliminary tests, we soaked the fabricated parylene films in saline at room temperature, as shown in Fig. 5, and monitored the change of mobility of pentacene over time. To find out the relationship of mobility decrease and thickness of parylene film, we fabricated three kinds of parylene films. They are 10μm-1μm (bottom-top), 10μm-10μm (bottom-top), and 20μm-20μm (bottom-top). Due to handling issues, the bottom parylene has to be at least 10μm. Too thin parylene is hard to handle during later testing.

Fig. 6, Fig. 7, and Fig. 8 show the mobility change over a long period of time. As expected, The 3 parylene films show different decreasing slopes. The mobility of the 10μm -1μm film dropped fastest and that of the 20μm-20μm film slowest. From these initial data, we can see 1μm parylene film can hardly protect the pentacene TFTs.

And, even though 20μm parylene film shows the slowest decay, the mobility of the pentacene TFT in the 20μm parylene film still drops. That showed that parylene film along may not stop water penetration. Of course, thicker parylene will have better water stopping ability. But thicker parylene might have worse mechanical properties, such as flexibility. Further analysis on these data and modeling of water diffusion through parylene film are underway.

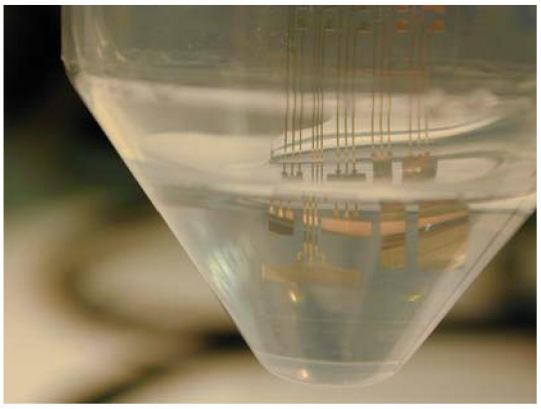

Figure 5. Parylene film soaked in saline.

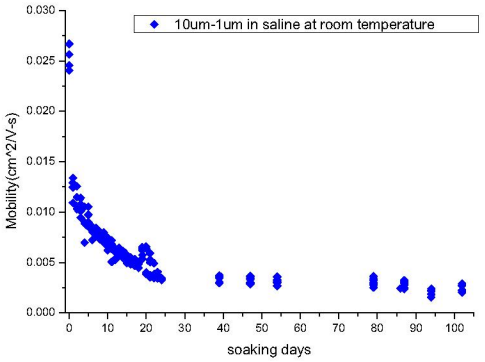

Figure 6. Mobility of 10μm-1μm parylene films in saline

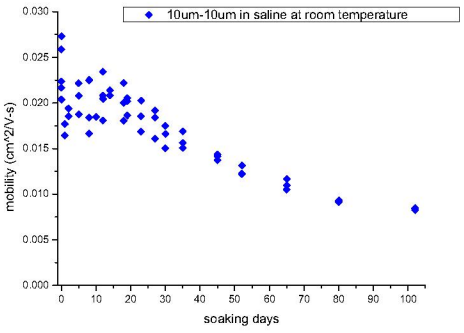

Figure 7. Mobility of 10μm-10μm parylene films in saline

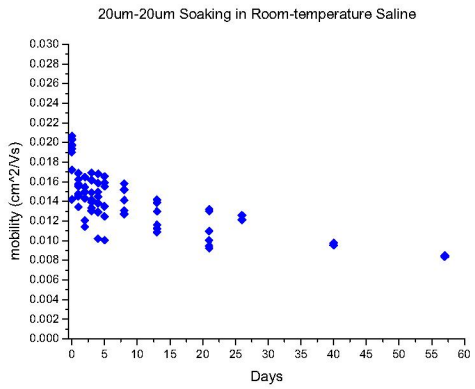

Figure 8. Mobility of 20μm-20μm parylene films in saline

IV. Conclusion

We fabricated parylene films with pentacene thin-film transistors sandwiched inside by fully MEMS-compatible parylene thin-film technology. The pentacene thin-film transistors work as humidity sensors. The fabricated parylene films are soaked in saline at room temperature. Mobility change of pentacene is monitored to determine the water stopping ability of parylene with different thickness. Further analysis and modeling are underway.

Acknowledgements

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