Organic Field Effect Transistor with Silk Dielectric Layer

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ABSTRACT:

We present a study of organic semi-conducting field effect transistors (FETs) made with diF-TESADT and a Bombyx Mori silk dielectric insulating layer. The FETs made are humidity dependent showing changes in properties such as switching speed and mobility at different humidity levels. Annealing at 95% humidity for 12 hours and further retesting at 50% humidity improved the switching speed and no longer showed a hysteresis in the I_{DS} vs V_{DS} curves.

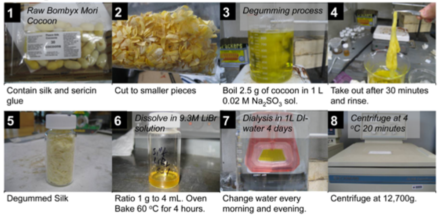
INTRODUCTION:

DiF-TESADT is an organic semiconductor similar to Pentacene which is regularly used to make organic field effect transistors (FET). FETs are generally made with a silicon dioxide (SiO_2) insulating layer. A sophisticated and costly fabrication processes is required to make scientifically precise SiO_2. SiO_2 is also non-biocompatible which makes it less than ideal for biomedical applications.

Bombyx Mori silk is a very cost effective, biocompatible, and biodegradable material. Bombyx Mori silk also works as a dielectric insulating layer in FETs. Using Bombyx Mori silk as a dielectric insulating layer and diF-TESADT as an organic semi-conductor, we have fabricated humidity dependent transistors with moderately high mobility.

EXPERIMENTAL METHOD:

In order to make a Bombyx Mori silk insulation layer, a spin-castable solution must first be made. The process of how the silk solution is made is shown on figure 1.



1. Contain silk and sericin glue
2. Cut to smaller pieces
3. Boil 2.5 g of cocoon in 1 L 0.02 M Na_2SO_3 sol.
4. Take out after 30 minutes and rinse.
5. Degummed Silk
6. Ratio 1 g to 4 mL. Oven Bake 60 °C for 4 hours.
7. Change water every morning and evening.
8. Centrifuge at 12,700g.

Figure 1. Process of making Bombyx Mori silk solution from raw Bombyx Mori cocoons.[1]

The silk solution is then spin-casted twice at 4000 rpm for 30 seconds onto a pre-made glass slide. The pre-made glass slides are roughly 7x7 mm with evaporated 5 nm of chromium and 25 nm of gold. After the silk solution is spin-casted onto the glass slides, they are left to dry for at least 12 hours. DiF-TESADT is then deposited by one of two methods: spin-casting or drop-casting. If the sample is spin-casted, 2 wt% of diF-TESADT in toluene is spun at 1200 rpm for 60 seconds.[2] If the sample is drop-casted, a 0.1μL drop is deposited without spinning. A 30 nm thick gold source and drain electrode is then evaporated on the sample. A schematic of the transistor is shown on figure 2 for clarification.

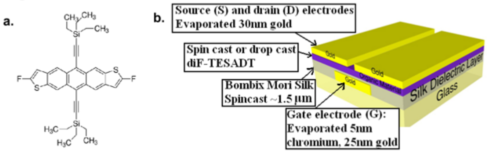


Figure 2. a. Schematic of organic semiconductor diF-TESADT. b.Schematic of the device in top contact configuration.

RESULT AND ANALYSIS:

1. Capacitor Data: Capacitance measurements were made to calculate the dielectric constant of the silk layer

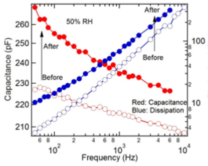


Figure 4. Log-log plot of frequency dependent capacitance and dissipation

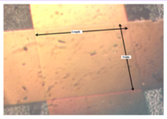


Figure 3. Capacitor, length and width was used to calculate area

To calculate the dielectric constant ε_r of the silk layer:

$$\varepsilon_r = \frac{Cd}{\varepsilon_0 A}$$

Where C is the capacitance at 50Hz
A~2x2mm which is the area of the transistor

The dielectric constant of silk (ε_r) was found to be ~12 before annealing and ~14 after annealing

2. Spin-Casted diF-TESADT

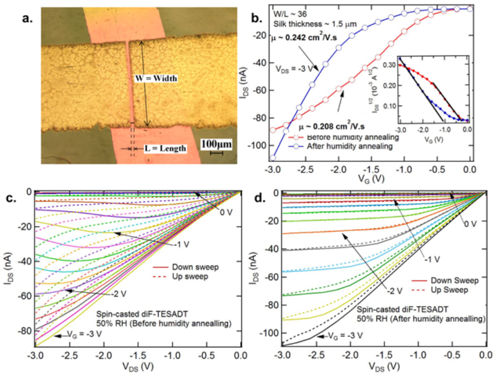


Figure 5. a. Spin-casted diF-TESADT sample with shown length and width used in calculations. b. transfer characteristic of sample. Mobility is slightly increased after annealing. c. I_{DS} vs V_{DS} curves before annealing. d. I_{DS} vs V_{DS} curves after annealing. There is little hysteresis shown after annealing.

$$I_{DS} = \mu \frac{\varepsilon_0 * \varepsilon_r}{d} \frac{W}{L} \frac{V_G^2}{2}$$

Where $\varepsilon_0 = 8.854*10^{-12}$ F*m^{-1} which is the vacuum electric permittivity
ε_r is the dielectric constant of silk
d~1.5μm which is the thickness of the silk layer
W is the width (figure 5.a)
L is the length (figure 5.a)
V_G is the gate voltage
I_{DS} is the current from drain to source
μ is the mobility

Derivation of mobility (μ):

$$\sqrt{I_D} = V_G \sqrt{\frac{\mu \varepsilon_0 \varepsilon_r W}{2dL}} \qquad m = \sqrt{\frac{\mu \varepsilon_0 \varepsilon_r W}{2dL}}$$

$$\sqrt{I_D} = m * V_G \qquad \mu = \frac{2dLm^2}{\varepsilon_0 \varepsilon_r W}$$

Where m is the slope of the characteristic graph (figure 5.b)

3. Drop-Casted diF-TESADT

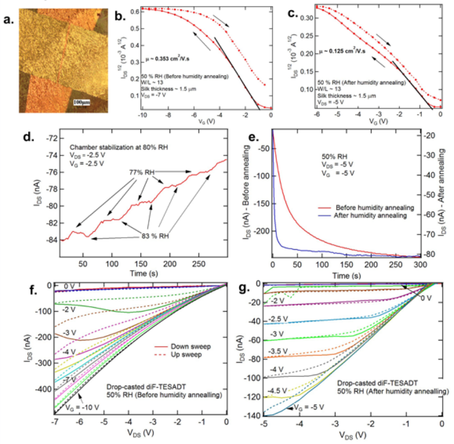


Figure 6. a. Drop-casted diF-TESADT sample. b. c. Transfer characteristics before and after annealing. Mobility is lowered by ~300 % after annealing. d. Humidity monitoring using the FET during chamber stabilization. e. Switch-on time graph. Before annealing the switch-on time is ~300 seconds which is reduced to ~20 seconds after annealing. f. I_{DS} vs V_{DS} curves before annealing. g. I_{DS} vs V_{DS} curves after annealing. There is lowered hysteresis after annealing.

CONCLUSION:

We have fabricated humidity dependent FETs made of diF-TESADT and Bombyx Mori silk dielectric insulating layer. It has been shown that after annealing the samples at high humidity, the hysteresis lowers considerably in the I_{DS} vs V_{DS} curves. After the annealing process the switch on speed increased by ~93%. However, in some devices the mobility was lowered considerably.

FUTURE PLANS:

So far, data has only been collected for spin cast and drop cast samples of diF-TESADT. We would like to compare this data to samples with evaporated diF-TESADT in the future as this method should give the highest mobility. We would also like to anneal the silk layer before depositing the sample to avoid possible degradation of the diF-TESADT at high humidity.

Underlying variables related to the silk layer humidity content and its influence to the physical and dielectric properties require further investigation. Understanding the effects of humidity on hysteresis at the molecular level would advance our research.

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REFERENCES:

[1] D.N.Rockwood et. al., Nature Protocols. Vol 6, No10. 1612 (2011).
[2] S.K.Park et. al., Appl. Phys. Lett. 93, 043301 (2008).