Tuning the Conductivity Of Neurochemical Sensors

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INTRODUCTION

▪ The purpose of this project is to design a neurochemical sensor which will aid in the detection of early signs of mental disease.

▪ The sensor will measure neurotransmitter levels in the brain, which, when imbalanced, may indicate the presence of illness. Neurotransmitters are chemicals that convey signals between neurons in the brain.

a) b)

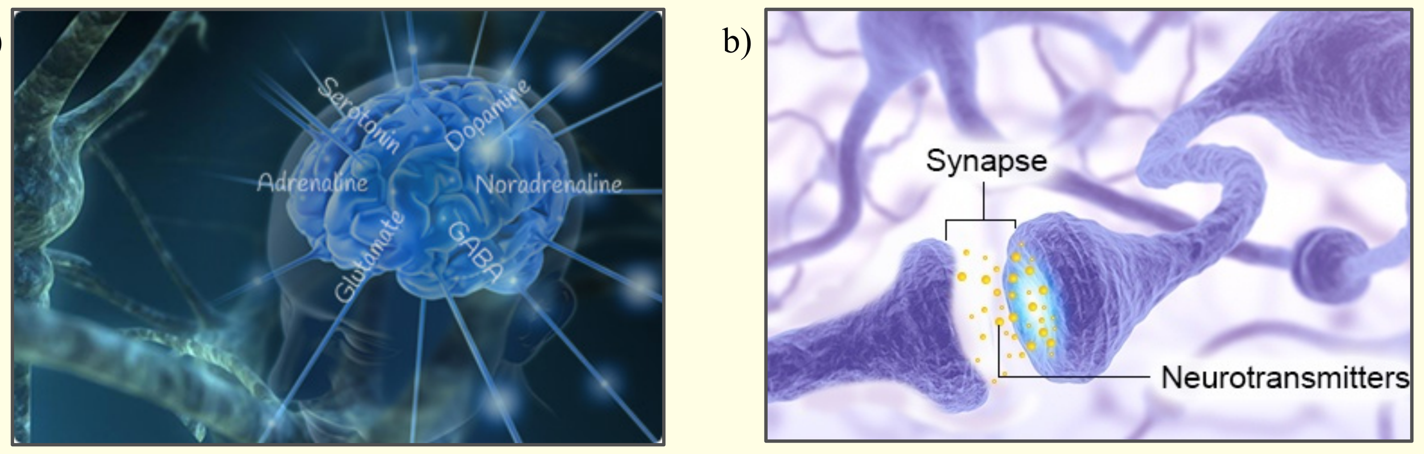

Fig. 1- a) Model of brain and neurotransmitters b) Portrayal of synapse and neurotransmitters [1,2].

▪Examples of neurotransmitters:

- **Dopamine**: Regulates motor function , motivation, and emotional arousal. When imbalanced, may cause Parkinson's disease or schizophrenia.
- **Glutamate**: Essential to proper function of excitatory neurons. Plays a role in illnesses such as epilepsy, stroke, and Alzheimer's disease.
- **Serotonin**: Controls appetite, sleep cycles, learning ability, temperature regulation, mood, and other important functions. Low levels of serotonin may be a cause of depression.

▪ Pre-existing models of neurochemical sensors are in the form of probes which enter into the brain. This method is very invasive and potentially damaging to the patient's brain function. Our sensor is designed to be film-like and flexible, capable of resting on the surface of the brain rather than entering it.

▪ The key component of our sensor is an Organic Electrochemical Transistor (OECT) [3], which uses, in this case, an organic semiconductor called PEDOT:PSS as its primary sensing element (OECT channel- see Fig. 2 and 3).

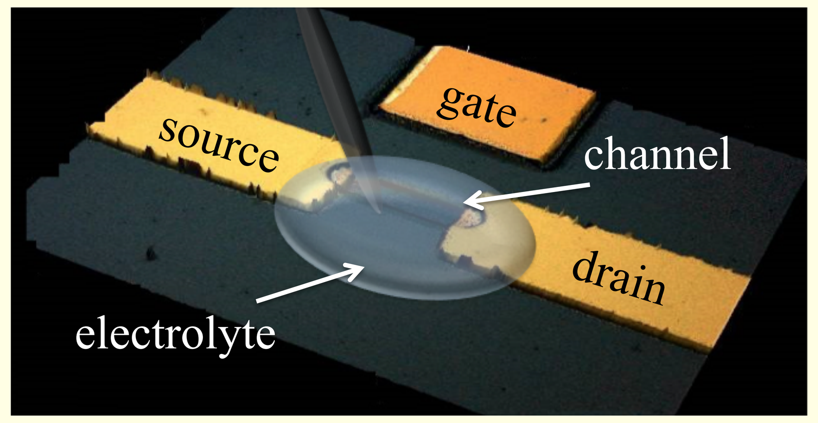

Fig. 2- Confocal image of PEDOT:PSS OECT [4]

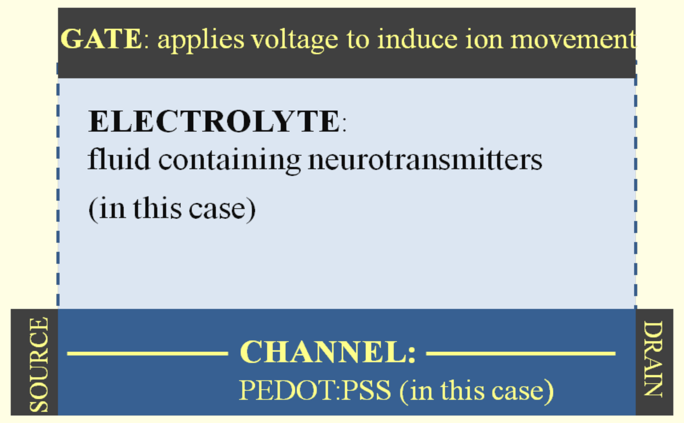

Fig. 3- Basic structure of OECT.

▪PEDOT:PSS is chemically stable, porous, conductive, and biocompatible, making it ideal for our purposes.

PEDOT → poly(3,4- ethylenedioxythiophene)

PSS → poly(styrenesulfonate)

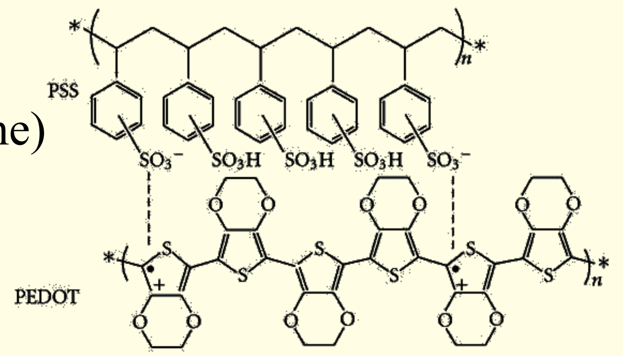

Fig. 4- Structure of PEDOT:PSS [5]

OBJECTIVE

To optimize PEDOT:PSS conductive properties and improve device sensitivity through the addition of silver nanoparticles.

METHODOLOGY

▪PEDOT:PSS' properties were initially tuned by mixing the following additions (Fig. 5a)

- Ethylene Glycol, to enhance conductivity
- Dodecyl benzene sulfonic acid (DBSA), to adjust surface tension
- (3-Glycidyloxypropyl) trimethoxysilane (GOPS), as a cross-linker

▪Glass slides were used as the substrate for our samples.

- They were first cleaned ultrasonically in acetone, rinsed with isopropanol alcohol, and dried.

▪ The slides were coated with the PEDOT:PSS mixture using the spin-coater (Fig. 5b) at different spin-rates (600rpm - 3000rpm). The samples were then cured on the hot-plate at 130°C for 15 minutes.

- **Spin-Coater** utilizes centripetal force to uniformly spread a solution over a substrate.

a) b)

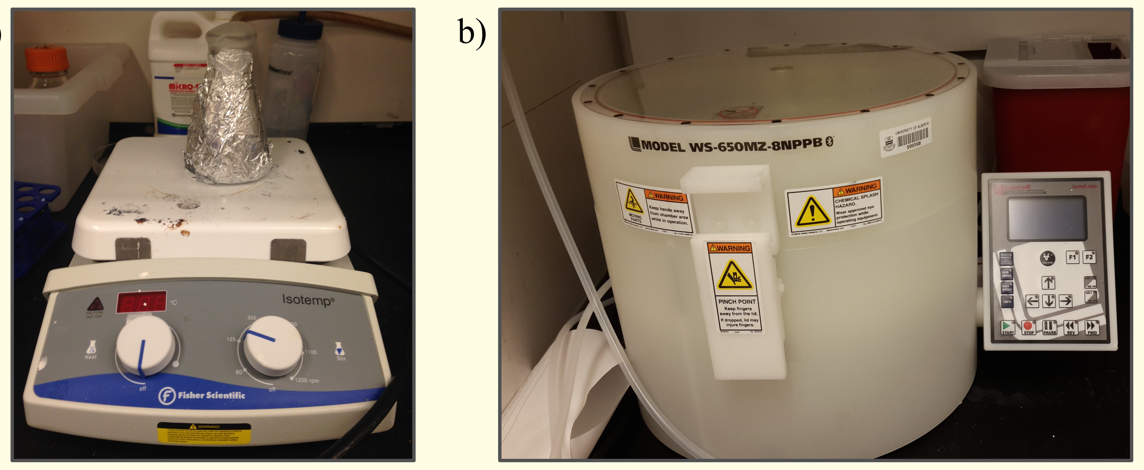

Fig. 5-Experimental Setup- a) Mixing chemicals b) Spin-coater

▪The thickness of the PEDOT:PSS films was measured using ellipsometry (Fig. 6a), and resistance was measured with the four-point probe (Fig. 6b).

- **Ellipsometry** is an optical technique used to determine properties of thin films, such as the thickness. It involves the measurement of change in phase and intensity of reflected light from an incident beam.
- **Four-Point Probe** is a device in which four evenly-spaced probes are brought into contact with a sample. The two outer probes apply current, while the inner probes measure the voltage difference created by the resistance of the surface.

a) b)

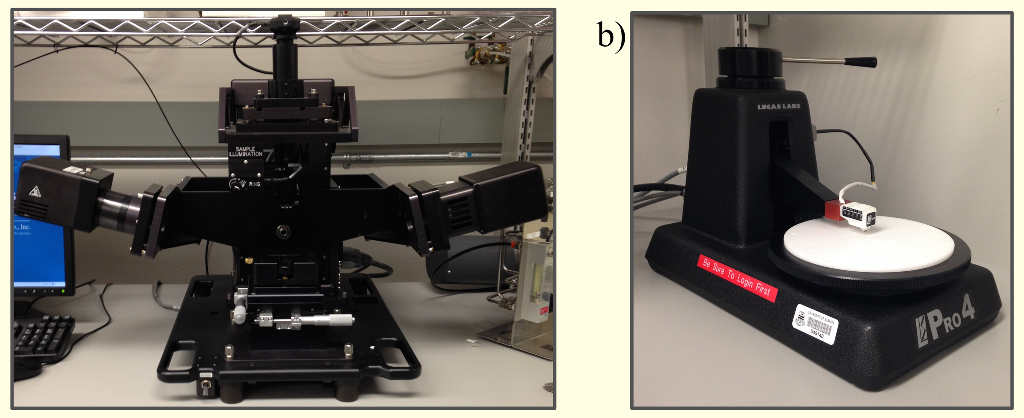

Fig. 6- Characterization tools a) Ellipsometry b) Four-point probe

Addition of Silver Nanoparticles

▪ Varying concentrations (1 - 25 % weight) of 100nm silver particles were added to 1mL portions of PEDOT:PSS solution in order to improve overall conductivity.

RESULTS

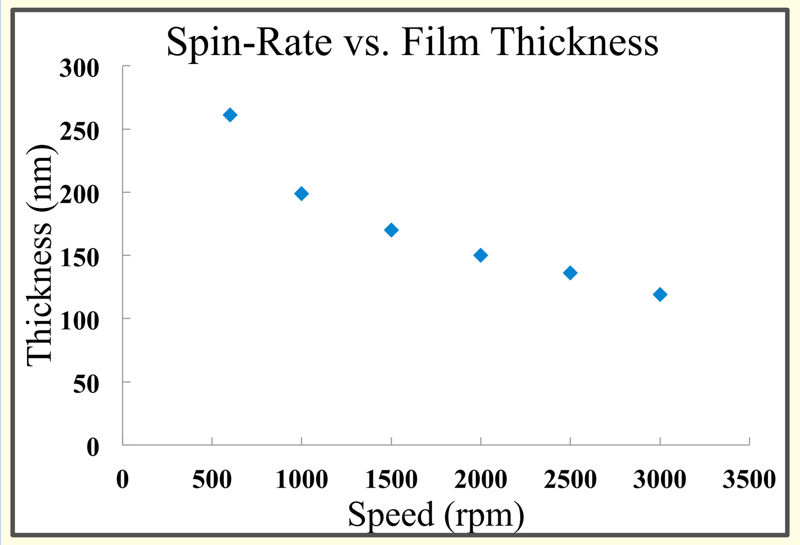

Fig. 7- Spin-rate vs. thickness

▪ Figure 7 shows the change in thickness of the PEDOT:PSS film (in nanometers) with respect to spin-rate (600-3000rpm)

▪ The spin-coater (see Fig. 5b) was used to apply the coatings uniformly, and ellipsometry to measure their thickness. (see Fig. 6a).

▪ The data suggests that faster speeds result in thinner films, and vice versa, which is logical based on the nature of centripetal force.

▪ Figure 8 demonstrates a linear relationship between spin-rate (in rpm) and the resistance (in Ohms).

▪ The data shown here was obtained using the four-point probe (see Fig. 6b).

▪ The trend illustrated by the graph is that higher spin-rates result in greater resistance, and therefore lower conductivity.

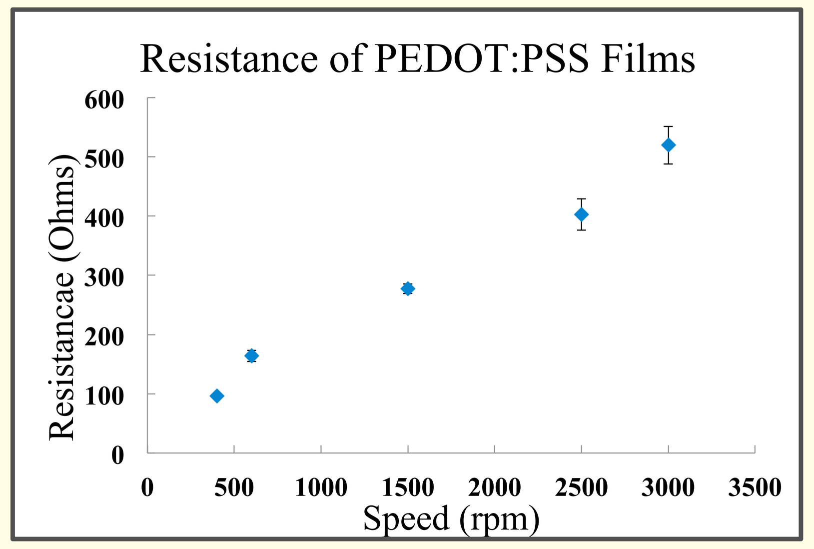

Fig. 8- Spin-rate vs. resistance

▪ Figures 7 and 8 show that spin-rate, thickness of coating, and resistance are interconnected factors.

▪For our sensor, thicker coatings of PEDOT:PSS to maximize conductivity are desirable, in order to improve sensitivity. However, response-time of the sensor must be taken into account, which decreases as thickness increases (inner components have farther to travel). A balance must therefore be reached for optimum functionality.

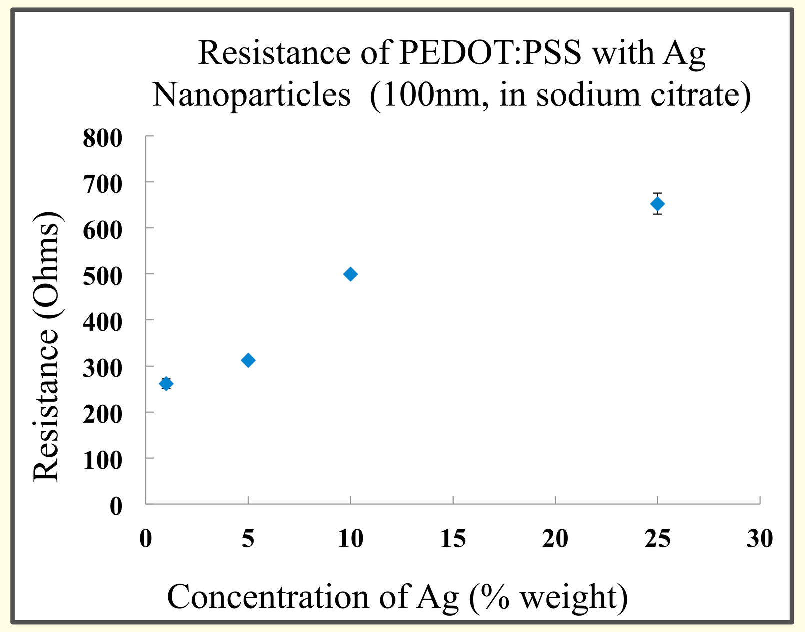

Fig. 9- Concentration of Ag (in sodium citrate) vs. Resistance

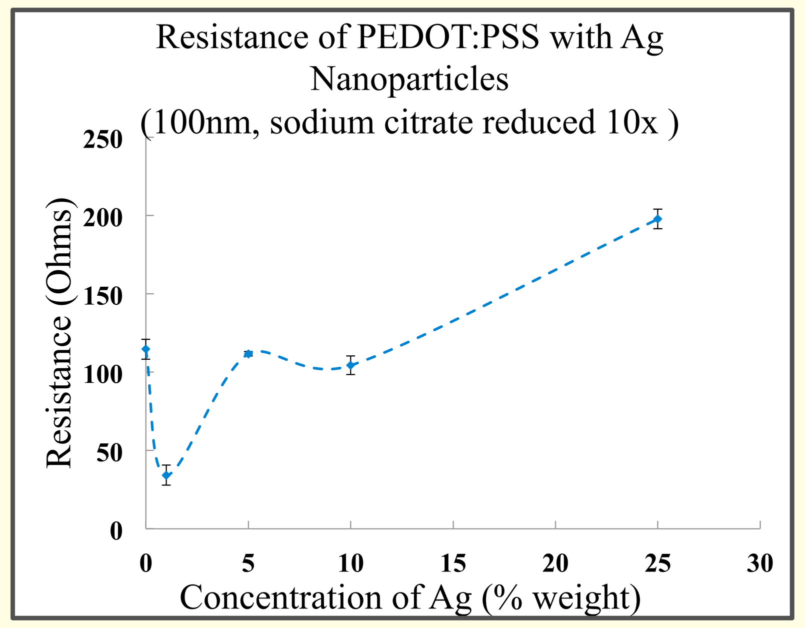

Fig. 10- Concentration of diluted Ag vs. Resistance

- Figure 9 represents the relationship between the concentration of silver nanoparticles added to PEDOT:PSS and resistance.
- It is showing that higher concentrations of silver lead to more resistance, which is unexpected. We discovered that it is due to the fact that the silver nanoparticles were suspended in a non-conductive solution of sodium citrate (to prevent aggregation), which dominated the conductance of PEDOT:PSS.
- To decrease the amount of sodium citrate, we centrifuged the silver nanoparticle solution at 20000rpm and reduced it by 10 times.
- Figure 10 portrays the resistance of the reduced-sodium citrate silver samples. At 1% silver concentration, conductivity increased significantly (as shown by the dip in the graph). But at higher concentrations of silver (5%, 10%, 25%), the sodium citrate still had an effect.

CONCLUSIONS

- Higher spin-rates result in thinner PEDOT:PSS films, and therefore decrease conductivity.
- A balance of PEDOT:PSS coating thickness must be attained in order to optimize sensitivity and response-time.
- The addition of silver nanoparticles improves the overall conductivity of PEDOT:PSS films only when the concentration of the sodium citrate suspension is low.

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