Fabrication of Organic Transistors Using Inkjet Printing

Michelle Pillers
Chemistry, Southern Methodist University

NNIN iREU Site: Centre Microélectronique de Provence, Ecole Nationale Supérieure des Mines de Saint Etienne, France
NNIN iREU Principal Investigator: Professor George Malliaras, Biological Electronics Lab, Centre Microélectronique de Provence
NNIN iREU Mentor: Dr. Sébastien Sanaur, Biological Electronics Laboratory, Centre Microélectronique de Provence
Contact: mpillers@smu.edu, malliaras@emse.fr, sanaur@emse.fr

Abstract and Introduction:

Inkjet printing is being explored as an alternative technique for device fabrication. This cost effective method is a direct-write, non-contact process that avoids the use of masks, excessive chemical treatments, and cumbersome fabrication steps. In this project, a Dimatix Materials Printer was used; this printer utilizes user-fillable piezocrystal-based jetting cartridges to jet specifically formulated inks to print a predesigned pattern. The jetting of the inks is achieved by the application of a voltage. The voltage pulses cause mechanical deformation (contraction or expansion) of the piezocrystals, resulting in jetting of ink for printing.

This project focused on the use of the Dimatix Materals Printer for fabrication of biocompatible organic electro-chemical transistors (OECTs) for use as biosensors. The project was separated into two phases.

The first phase of the project focused on the optimization of printing parameters for successful printing of three specifically formulated inks: silver nanoparticle ink, polyimide (PI) ink, and poly(3,4-ethylenedioxythiophene)-poly(4-styrenesulfonate) (PEDOT:PSS) ink. The parameters included drop spacing (the distance between the center of each printed drop), waveform (the pattern of electrical stimulation of the piezocrystal that causes ink jetting), and substrate temperature.

The second phase of the experiment consisted of the design and fabrication of two types of OECTs: a multilayered OECT incorporating the three optimized inks and a planar all-PEDOT:PSS OECT. All designs and devices were printed on Parylene-C-coated glass slides. Parylene-C is a biocompatible polymer that can be peeled off of the slide to make the device flexible and more easily used as a biosensor.

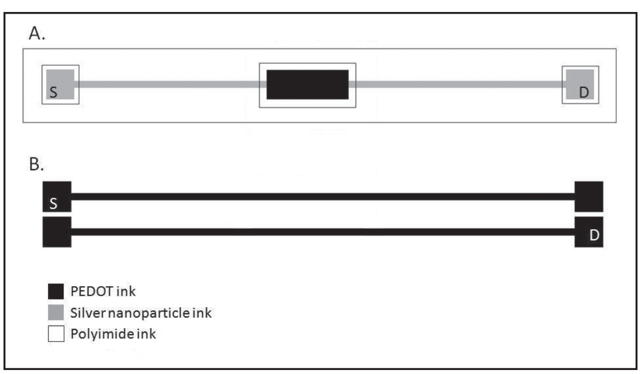

Figure 1: A. Pattern for multilayered OECTs using source (S) and drain (D) silver nanoparticle electrodes, polyimide passive layer, and a PEDOT active site. B. Pattern for all-PEDOT OECT.

PEDOT:PSS was the active material for both OECT designs. PEDOT:PSS is a degenerately doped *p*-type semiconductor [1]. The design for the OECTs, seen in Figure 1, utilized a source and drain electrode and a channel where the electrolyte being tested was placed. The gate voltage was applied through the electrolyte. When a positive gate voltage was applied, positive ions from the electrolyte entered the conducting polymer film and changed its hole concentration.

The decrease of holes in the PEDOT:PSS is called de-doping and, when it occurs, the source-drain current decreases. Then, as the gate voltage is increased, the source-drain current is decreased. If a small change in gate voltage causes a large change in source-drain current, then the device is a good ion-to-electron convertor and a suitable transducer for biosensors.

Experimental Procedure:

To identify the optimal printing parameters for each ink, a test pattern consisting of horizontal lines, vertical lines, and dots of various sizes was printed on Parylene-C glass slides with varying parameters. Patterns were printed with drop spacing between 12 to 35 μm, and substrate temperatures between 28°C and 40°C.

When the optimal printing parameters were identified, the OECTs were printed. The multilayered OECT was printed in three steps. First, two layers of silver nanoparticle ink were printed; the ink was annealed in an oven for 2.5 hours at 130°C. Second, three layers of polyimide ink were printed; the ink was dried on a hotplate for five minutes at 80°C and annealed at 150°C in an oven for an hour. Finally, several

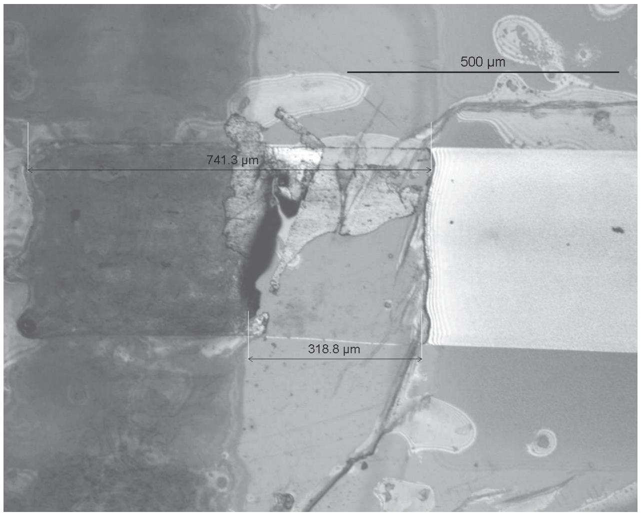

Figure 2: The silver nanoparticle electrode on the multilayered OECT after exposure to electrolyte and degrading. The silver nanoparticle ink has been removed between the PEDOT:PSS layer (left) and the polyimide layer (right).

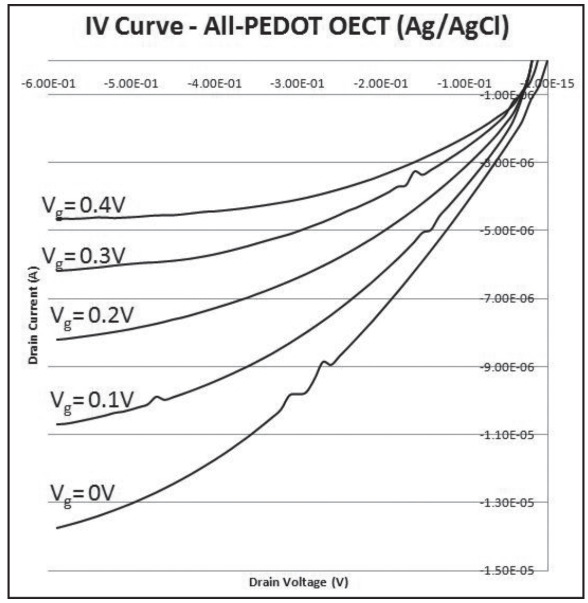

Figure 3: Current vs. voltage graph for all-PEDOT OECT using an Ag-AgCl gate electrode. The gate voltage (V_g) is applied between 0.0V and 0.4 V at 0.1V intervals.

layers of PEDOT:PSS ink were printed and annealed for five minutes on a hotplate at 120°C.

The planar all-PEDOT:PSS OECT was printed in one step with four layers. The PEDOT:PSS was then annealed using a hot plate at 150°C for two hours.

Electrical testing was performed on each device using probe station and phosphate buffered saline (PBS) as the electrolyte.

Results and Conclusions:

It was found that the PEDOT:PSS ink would not spread adequately on the Parylene-C surface to print a successful pattern; the Parylene-C was too hydrophobic to allow for the ink to spread. To make the Parylene-C more hydrophilic, each slide was treated with a 30 second O_2 plasma treatment. With this, the surface energy of the Parylene-C was adequately changed to allow for printing of PEDOT:PSS.

The optimized parameters for polyimide and silver ink could be varied significantly and still print successfully; however, a drop spacing of 23 μm and a substrate temperature of 35°C gave the most accurate printed pattern for both inks. PEDOT:PSS, when printed on plasma treated Parylene-C, was most effectively printed at a drop spacing of 23 μm and a substrate temperature of 28°C.

Both OECT designs were successful transistors. However, due to inadequate annealing of the silver nanoparticle ink in the multilayered device, the OECT failed in electrolyte and detailed electrical characterization could not be performed. The picture in Figure 2 shows the degradation of the silver nanoparticle electrode after exposure to electrolyte. Nevertheless, the all-PEDOT:PSS OECT was successfully tested using PBS electrolyte and a probe station with a Ag/AgCl gate electrode. According to the data in Figure 3, as the gate voltage was increased, the drain current was decreased.

In conclusion, all-PEDOT:PSS OECT were fabricated using inkjet printing techniques on a biocompatible substrate (Parylene-C). It showed regular ion-to-electron converter behavior and is suitable for biosensing applications.

Acknowledgements:

NSF, National Nanotechnology Infrastructure Network International Research Experience for Undergraduates (NNIN iREU) Program, EMSE, Professor George Malliaras, Associate Professor Sébastien Sanaur, my research partner Jaqueline Mandelli, my travel partner Fiona O'Connell, and all of the lab members of the fantastic BEL in Gardanne.

References:

[1] Daniel A. Bernards and George Malliaras. "Steady State and Transient Behavior of Organic Electrochemical Transistors." Advanced Functional Materials. 2007.