Fabrication of Microchemical Field-Effect Transistor

Ming-Lun Wu
Biomedical Engineering, University of Florida

NNIN REU Site: Minnesota Nano Center, University of Minnesota-Twin Cities, Minneapolis, MN
NNIN REU Principal Investigator: Dr. Stephen Campbell, Department of Electrical and Computer Engineering, University of Minnesota
NNIN REU Mentor: Jun Young Lim, Department of Electrical and Computer Engineering, University of Minnesota
Contact: minglwu427@gmail.com, campb001@umn.edu, limxx218@umn.edu

Abstract:
The commonly manufactured metal-oxide field-effect transistor (MOSFET) amplifies electrical signals applied to the gate electrode. If one replaces the metal gate of a MOSFET with a selectively permeable membrane, it enables transistors to amplify electrical signals based on the ion concentration of a solution. Such devices are known as chemical field-effect transistors (ChemFETs). A research group at Minnesota envisions these micro-scale ChemFETs could analyze sweat droplets as small as one millimeter in diameter. This will allow noninvasive tests to detect diseases such as cystic fibrosis, osteoporosis, diabetes, and other conditions, as part of a larger program to use the mapping of sweat production to detect loss of neural function due to diabetes, chemotherapy, industrial or defense-related exposure to toxins, alcoholism, HIV, and other conditions. Casting of poly(2-hydroxyethyl methacrylate) and including ionophores, valinocycin and ETH 2120 in the membrane enhances the selectivity and responses of ChemFETs.

Introduction:
The ultimate goal of this project is to find a way to quantify sweat gland function to detect peripheral neuropathy. Peripheral neuropathy is damage of the peripheral nervous system; its symptoms include decrease of sensory sensitivity, random pain, and itching in the damaged region. Although these symptoms are definitive, the severity can be different based on the other parameters like ages and pain tolerance. In order to prevent peripheral neuropathy, precise monitoring of nervous function is required. The Minnesota group is developing a way to electrically measure sweat production. This determines sudomotor neural function, a good replacement for the function of the central nervous system. However, if sweat were to be measured, it would be useful to measure the content of sweat. It is possible to detect many conditions through a simple noninvasive test.

A transistor amplifies electric signals according to the voltage applied to the device. For most transistors, they contain three major regions: the source, the drain, and the gate. Source and drain are where the electric current is being amplified, while the gate is where the external voltage is provided. For a chemical field-effect transistor (ChemFET), a selective membrane replaces the gate oxide. The membrane, with positive charge ionospheres, would work similarly to an external voltage and amplifies the electrical signal according to positive ion concentration in a solution.

Experimental Procedure:
Prior to the fabrication process, a design of wafer map was completed with L-Edit programs. Every wafer included twelve chips, shown in Figure 1. Each chip included 120 ChemFETS,
120 n-type metal oxide semiconductors (nMOS), and four actives regions. The ChemFET and nMOS channel lengths varied from 5 to 10 µm. One 100 µm capacitor was used as well.

Thermal oxidation of silicon wafers was performed with steam at 1000°C for 100 minutes. Active regions were opened with the first lithography step and followed by wet etching. Etch completion was determined by the hydrophobic nature of Si compared to SiO₂. Impurities were induced by diffusion; a phosphorous-containing liquid was cast onto the wafer followed by heating at 1000°C for 10 minutes. The presence of the impurity was confirmed using four-point probe. The middle oxide was removed with the second mask. Growth of the gate oxide was achieved by dry thermal oxidation for 15 minutes. The contact region was opened with the third mask. Aluminum was deposited by thermal evaporation or sputtering and patterned with the fourth mask. Finally, annealing was performed at 450°C for five minutes.

An nMOS functionality was used to verify the fabrication procedures. Each transistor was tested by sweeping the drain voltage while keeping the gate at a constant voltage between zero and eight volts (Figure 3). Once fabrication validity was confirmed, silyation was carried out by submerging the wafer in a mixture of 2.5 ml of 3-(trimethoxysilyl) propyl methacrylate and 22.5 ml of toluene at 90°C for four hours. The 40 mg of polyHEMA crystal was dissolved within 2 ml of reagent alcohol overnight. Finally, 71.2 mg 2,2 dimethoxyphenylacetophenone photoinitiator was added to the polyHEMA mixture and cast onto the wafer, followed by UV light exposure for two minutes.

**Results and Conclusions:**

The validity of fabrication techniques was confirmed. The first successful fabricated chip has 44% of functioning devices, while the latest chip has 100% yields. The increased in yield is believed to be due to changing the dopant diffusion cycle from 950°C for 15 minutes, to 1000°C for 10 minutes. Based on the preliminary result, the higher diffusion temperature increased the doping concentration. The anneal process proven to be essential to the functionality of the device. Without annealing, the yield of successful devices in a chip was zero.

The final dimension of the device is roughly 450 µm in width and 800 µm in length. This is important considering the smallest test droplet produced from a syringe is 1000 µm in diameter. Although the hydrogel was visible under microscope, it is unclear whether the bonding between the gate oxide and hydrogel is covalent or mechanical (Figure 4). More tests are required.

**Future Work:**

Investigating the bonding mechanism of the hydrogel is essential to the functionality of our device. Hence, testing the mechanism by ethanol washing should be performed. The selective membrane casting should be the following step of fabrication. Once the membrane is attached characterization of ChemFETs can begin.

**Acknowledgements:**

The author would like to thank National Science Foundation and National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program for making this project possible. Also, special thanks to the University of Minnesota, Nanofabrication Center, Dr. Stephen Campbell, and Mr. Jun-Young Lim, a graduate student in Professor Campbell’s research group.