Fabrication and Design of EGFET Devices for Biosensing

Abigail Magee

Biomedical Engineering, University of Central Oklahoma

NNIN REU Site: ASU NanoFab, CSSER Facility, Arizona State University, Tempe, AZ

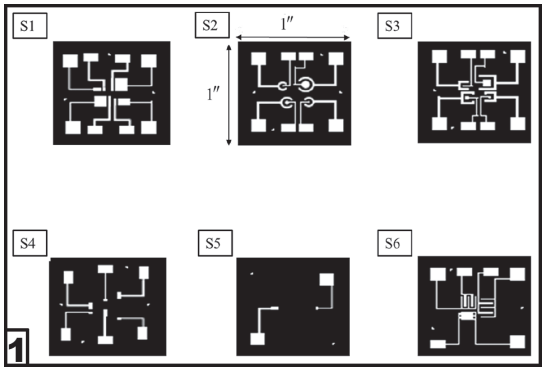
NNIN REU Principal Investigator: Jennifer Blain Christen, Electrical Engineering, Arizona State University, Tempe, AZ

NNIN REU Mentor: Uwa Obahiagbon, Electrical Engineering, Arizona State University, Tempe, AZ

Contact: amagee@uco.edu, jennifer.blainchristen@asu.edu, uwa@asu.edu

Abstract:

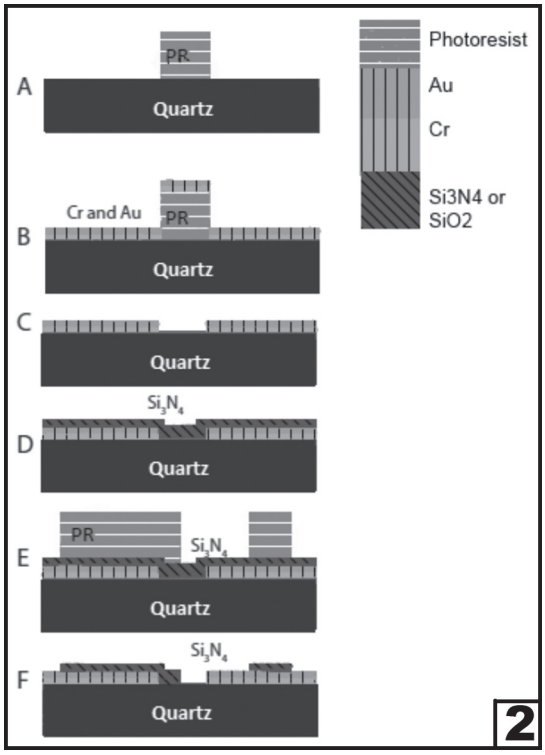
Ion-sensitive field effect transistors (ISFET) measure the presence of ions in a solution via their effect on current flow within the device. The ions induce charge in the device via capacitive coupling from the ion-sensitive membrane. The extended gate field effect transistor (EGFET) is a modified version of the ISFET that uses low cost FET transistors combined with a sensing membrane and reference electrode structure fabricated separately. This structure requires fewer fabrication steps and enables flexibility and adaptability in application. The EGFET is more suitable for continuous monitoring in harsh environments, since the sensing area is external to the transistor. While the EGFET's sensing area is physically remote, the principles of operation remain the same. This project focused on design and fabrication of EGFETs with different sensing membranes and geometries. The systematic investigation of the device parameters enables informed designs for increased sensitivity to pH. The devices were fabricated with chrome/gold reference electrodes and either a silicon nitride or silicon dioxide sensing membrane. The devices were tested with pH buffer solutions to provide consistent pH samples. Initial testing determined the silicon nitride layer had poor quality, with pinholes and cracks evident when surface features were analyzed with an optical profilometer, resulting in poor characterization and etching of the electrode.



Introduction:

Many sensors rely on pH in order to detect a change in a system and adjust pH or trigger another response. As an environmental sensor, EGFETs could be used to track pH changes in water to determine if there is contamination. In biological or biomolecule applications, EGFETs can be used to detect pathogens, antibodies, or proteins; they can also track pH levels for cultured cells.

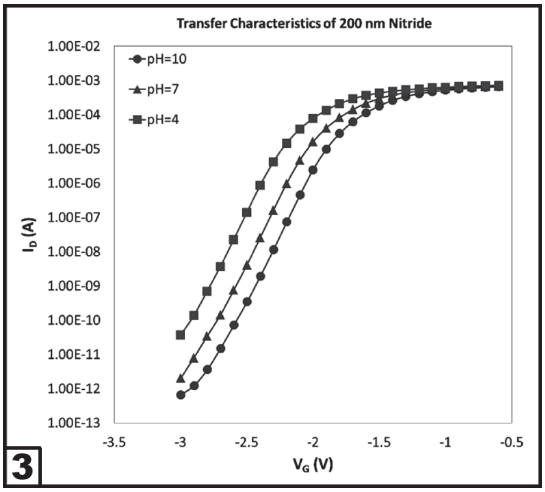
Increasing sensitivity of the device would increase the ability of the device to distinguish between minute pH changes in an electrolyte or pH changes due to biomolecules bound to its surface. This research project investigates several geometric and spacing variations to optimize for pH sensitivity.



Experimental Procedure:

Fabrication of the Biosensor. The masks for the fabrication steps were designed using L-Edit, as shown in Figure 1. The designs were printed on a Mylar film using a 25,400 dpi printer, attached to a soda-lime glass substrate, and used in the photolithography steps. Positive photoresist was used for photolithography.

The fabrication of the devices followed the process shown in Figure 2. An adhesion layer of 10 nm chromium was deposited



Sensor	Area/Spacing	pH Sensitivity
	12mm^2	49.97 mV/pH
	3.14mm^2	50.39 mV/pH
	4mm^2	49.98 mV/pH
	1mm	49.98 mV/pH
	11mm	49.99 mV/pH
	1mm	49.98 mV/pH

4

followed by 170 nm of gold; both were deposited using evaporation. The thickness of nitride or oxide deposition was intentionally varied between the sets. Sets 2, 3, and 4 had 200 nm of silicon nitride, 400 nm of silicon nitride, and 200 nm of silicon dioxide, respectively. For the set that contained oxide rather than nitride, the process followed the same format as in the previous sets; the nitride was simply replaced with silicon dioxide.

Setup for Experimentation. Wires were attached to the contact pads of the sensors using a silver-based conductive epoxy. A centrifuge tube, with a section cut off from the tip, was used in packaging the device by creating a confinement for the electrolyte. The centrifuge tube was bonded to the quartz substrate using a marine-grade epoxy, exposing the sensing areas so that the solutions used would be in contact with the correct locations on the device. The devices were exposed to an electrolyte for 24 hours without taking any measurements, allowing the interfaces and surfaces to reach a steady state.

Data Acquisition. In order to measure the pH values versus the voltage, we used a program in MATLAB in order to automate the measurements to determine this relationship. A Keithley source meter was also used for data acquisition purposes with TSP Express.

The devices were measured using buffer and titrated solutions. Once the solution was added to the device, we waited five minutes to start the program. A computer program was run for five sweeps and the device was reset within the first sweep. The sweeps were set up with a V_{GS} of -3.5V to -0.5V, a V_D of 0.2V and 0.5V, and a step size of 0.05V. Transfer and output characteristics were plotted in Excel and analyzed once data acquisition was complete.

Results:

During initial testing, it was observed that the nitride and the gold electrodes were being etched due to poor quality of the nitride layer. This affected the characterization, because the transistor and program picked up the etching mechanism rather than just the pH reaction.

The devices with the improved sensing membranes had no visible etching with the new buffer solutions. Transfer characteristics of these corrected devices had the expected pH sensitivities, as in Figure 3. Details concerning the pH sensitivity of the devices are shown in Figure 4.

Conclusions:

The results from testing in Figure 4 indicate the devices have the sensitivities expected. These results are not final, as more testing is needed to confirm these results. However, the current results demonstrate the devices are working as expected and could be used in further testing to determine a difference in pH sensitivity in relation to geometry, spacing, and surface area.

In the future, a better PECVD process will need to be used so the sensing membrane is deposited more evenly and with fewer defects. This would improve the characterization of the devices due to the elimination of etching processes. It would also prove beneficial to fabricate devices with different geometric structures, but with the same area, in order to compare the effect of geometry and spacing on pH sensitivity more effectively and with fewer compounding factors.

Acknowledgements:

Many thanks to Dr. Jennifer Blain Christen and my mentor, Uwa Obahiagbon for helping me with this research and giving me the opportunity to work in their lab. Thanks to the CSSER staff at Arizona State University for being available to help with the fabrication process and to my fellow interns. Thanks to the NNIN REU Program and to the National Science Foundation, Grant No. ECCS-0335765, for giving me this opportunity.