Utilizing Low-Cost Ion-Sensitive FET Sensors

Timothy Wentzien, Computer Engineering
John Rabolt Materials Science and Engineering; Richard Martin, Electrical and Computer Engineering; Wei-Jun Cai, School of Marine Science and Policy

Abstract

Monitoring water quality is important as it can provide valuable information about aquatic life, contamination, pollution, and much more. One important aspect to measure is the pH level. Ocean acidification is the gradual decrease in the average pH of ocean water, caused by absorbing an increasing amount of carbon dioxide from the air. This can affect the ability of aquatic life to build and maintain their shells, search for food, or find suitable habitats. We have been working on finding, testing, and implementing low-cost ion-sensitive field-effect transistors (ISFETs) that can be used in applications to measure or monitor the pH level of water.

Introduction and Background

The pH of water can tell you a lot about the quality of water. It determines the amount and availability of various nutrients and metals present in water which can affect drinking water and sea life. A high pH can damage water pipes and appliances by forming solid deposits of calcium carbonate and requires additional chlorine to disinfect the water. Low pH can also cause damage by corroding metals[1].

According to the National Oceanic and Atmospheric Administration (NOAA), the pH level of the ocean has been becoming more acidic (decreasing). They state this is caused by the ocean absorbing the increasing amount of carbon dioxide (CO_2) in the atmosphere from pollution. Many ocean species are already being affected by this trend, known as ocean acidification. Organisms that use carbonate ions to build shells and skeletons are at risk since ocean acidification decreases the amount of available carbonate ions in the water. These calcium carbonate structures will dissolve over time if the pH level of the water is too low. Decreased pH levels also affect the ability for certain fish to detect predators and find a suitable habitat[2].

Given the importance of pH, it is a commonly monitored property of water. Many sensors used to monitor the pH level are bundled with other water sensors and electronics into one product that can record and save the sensor readings. This proves useful as it makes monitoring water quality simpler, but it leaves little room for customizability and comes with a large price point. The alternative is to buy the sensors alone and create your own method or device to read from the sensors.

One important distinction that comes up with sensors is the difference between an analog and digital signal. Most sensors are a part of a circuit that is has an electrical output: voltage, current, or resistance. This output is usually an analog, or continuous, value. If it goes through an analog to digital converter (ADC), it is translated into digital data, ultimately in a binary format, that can be read by a computer or microcontroller. The precision of this conversion is dependent upon the number of bits (a 1 or 0) used in the binary representation of the output value. Although a sensor may be stated as an analog sensor, in the end it will be converted to a digital signal when it is read by a microcontroller, computer, or processor of some kind.

Methods and Experimental Design

The focus of this research was on a specific type of pH sensor known as an ion-sensitive field-effect transistors (ISFET). An ISFET operates act like a transistor, an electrical component with 3 terminals: source, drain, and gate. A voltage applied to the gate terminal will control if current flows through the source to the drain. In the case of an ISFET, a reference electrode is used as the gate terminal and the ion concentration of the solution will affect the current through the transistor[3]. A measuring circuit like the one shown in figure 1 can then be used to get an output signal, V_s in this case which will linearly change depending on the pH of the solution.

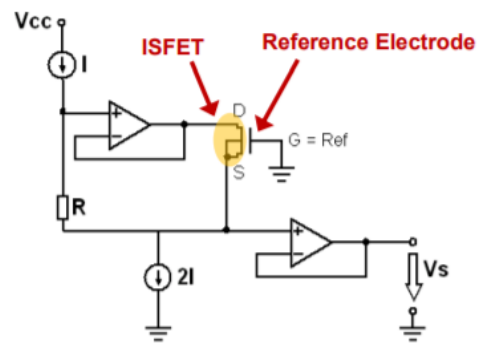

Figure 1: The recommended measuring circuit for MICROSENS SA ISFETs[4]

To find ISFETs to use in this research, we looked for the following properties:

- low cost
- low overhead
- easy to integrate

A low price point would make it viable to use the ISFETs we purchased in a field or lab setting and in other projects. By keeping the amount of additional electronics needed for the ISFETs to a minimum, we would be able to customize the measuring procedure and variables ourselves. We selected two manufacturers to purchase sensors from: MICROSENS SA and Sentron.

The MICROSENS ISFET, shown in figure 2, is connected to a waterproof circuit that includes the reference electrode. This circuit is then connected to a digital interface board that implements a measuring circuit, converts the output voltage to a digital value using an ADC, uses calibration data to calculate a pH, and outputs a digital signal that contains the pH value. Our microcontroller can then read this digital signal and print the message being sent. This method makes it easier for us to get the pH value directly but gives us little control over the actual measuring itself.

Figure 3 shows the Sentron ISFET. The ISFET is placed on a probe that is connected to an analog front-end board along with the reference electrode probe. This board contains the measuring circuit and outputs the analog voltage to one of the 6 pins on the end. The rest of the pins are used for power and an integrated temperature sensor (not used). Our microcontroller can read directly from the output pin using an integrated ADC, or we could feed it to an external ADC and then have our microcontroller connect to this ADC.

Figure 2: The MICROSENS SA ISFETs

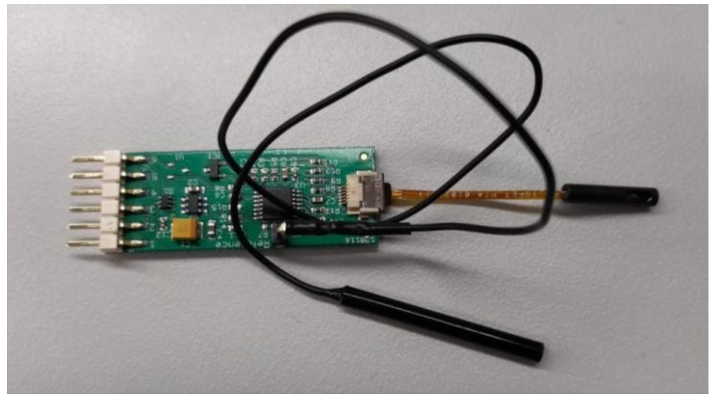

Figure 3: The Sentron ISFET, reference electrode, and analog front-end board

To create the calibration data needed for both sensors, we used pH buffers at 10.0, 7.0, and 4.0 and measuring the output voltage at these levels. For the MICROSENS ISFET, we can send these numbers to the digital interface board and it will calculate the pH for us. Since the Sentron analog front end only gives us the analog value, we implemented this data into the code on our microcontroller and then calculated the pH value ourselves. A plot of our MICROSENS ISFET calibration data vs the values given by MICROSENS is shown in figure 4.

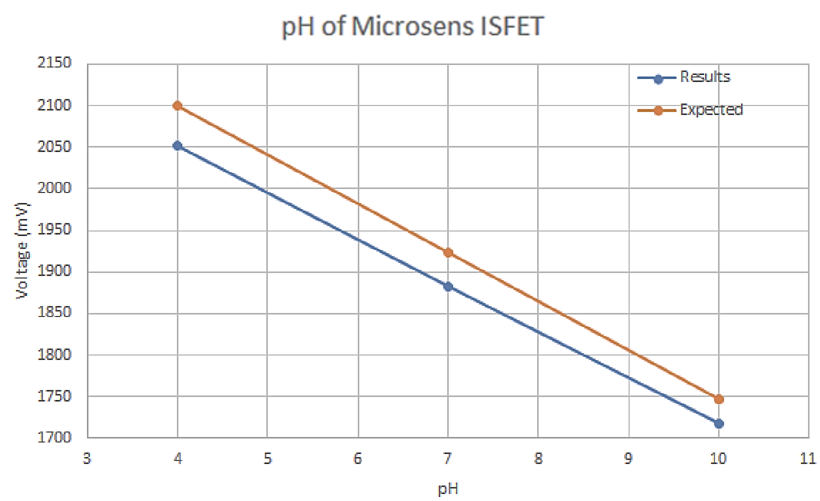

Figure 4: MICROSENS ISFET calibration data

Results and Discussion

While both the MICROSENS and Sentron ISFETs gave similar pH level readings, the Sentron ISFET seems much better for our desired usage. We ran into many problems with reading from the MICROSENS digital interface board including missing parts of a message, garbled data, and the rest of our program running incorrectly. The Sentron ISFET and analog front-end allows us much more freedom in adjusting the frequency and precision of the readings, while being easier to use.

By buying the sensors alone, it makes it possible to create a system to monitor water quality without the expensive cost of many sensors that are actively used in the field. Currently, I am implementing the Sentron ISFET into a wireless, solar-powered sensor package for my senior design project. Figure 5 shows the enclosure I created to keep the ISFET and reference electrode in the water while keeping the electronics safe from water damage.

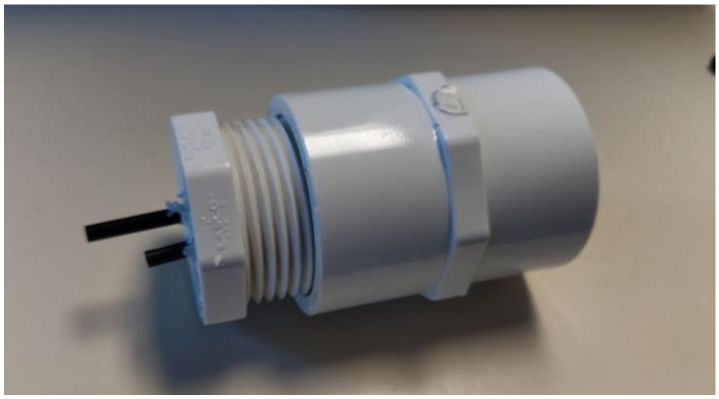

Figure 5: Waterproof enclosure for the Sentron ISFET

Moving forward, more data needs to be gathered about sensor lifetime and long-term drift (the slow change of voltage readings for the same pH level over a long period of time) to prove the feasibility of using these sensors in the field. Our ISFETs would also have to be compared against pH sensors currently used to measure or monitor pH levels. With adequate results from these tests, using the ISFETs over expensive sensor packages could prove beneficial in applications to monitor ocean acidification and look for unusual or dangerous pH levels in bodies of water.

References

1. United States Geological Survey. pH and Water. (n.d.). Retrieved from https://www.usgs.gov/special-topic/water-science-school/science/ph-and-water?qt-science_center_objects=0#qt-science_center_objects

2. National Oceanic and Atmospheric Administration. Ocean acidification. (n.d.). Retrieved from https://www.noaa.gov/education/resource-collections/ocean-coasts-education-resources/ocean-acidification

3. Duroux, P., Emde, C., Bauerfeind, P., Francis, C., Grisel, A., Thybaud, L., Arstrong, D., Depeursinge, C., & Blum, A. L. (1991). The ion sensitive field effect transistor (ISFET) pH electrode: a new sensor for long term ambulatory pH monitoring. Gut, 32(3), 240–245. https://doi.org/10.1136/gut.32.3.240

4. MICROSENS SA. (2017). MSFET-3330 pH sensor. Retrieved from http://microsens.ch/products/pdf/MSFET_3330_Datasheet.pdf