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Integrated Microsensors

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1. Introduction

There is growing interest in the design and implementation of sensor devices that can be closely integrated to conventional CMOS technologies. The topic has its grounding in the early 70's when devices such as the ion sensitive field effect transistor (ISFET) were being intensively researched, and VLSI was emerging as a core technology for electronics [1]. Recently the field has blossomed with the development of single chip pH measuring instruments, as described here, for use in devices such as the laboratory-in-a-pill [2], and sophisticated microelectrode arrays [3, 4].

2. The CMOS ion sensor

One of our objectives has been to minimise the extent to which a foundry CMOS process must be modified in order to integrate a useful ISFET. Fortunately many processes use a silicon nitride passivation layer, a material that is well known as a pH sensing membrane. As a consequence, a floating gate ISFET can be implemented with a metal via stack so that the gate forms the lower electrode of a nitride membrane layer, and the top-side is in contact with the analyte. The structure is shown in cross-section in Fig. 1 for a 3-metal CMOS process.

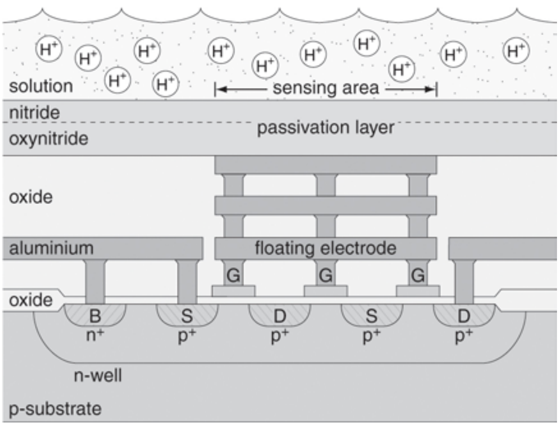

Figure 1. A cross-section through a p-type floating gate ISFET formed in a 3-metal, 0.6 μm process.

The source and drain regions of the CMOS ISFET are interleaved to form a compact device with a large width/length ratio.

The nitride membrane layer yields a linear shift in the transistor threshold voltage, V_T, over a wide pH range. In order to use this property effectively the ISFET requires a bias circuit that ensures a linear transfer of the change in V_T to an output signal, V_{OUT}. This is achieved using the circuit in Fig. 2 in which a closed-loop bias circuit maintains constant I_{DS} (100 μA) and V_{DS} (0.5 V) for the ISFET irrespective of V_T or the reference voltage, V_{RE}.

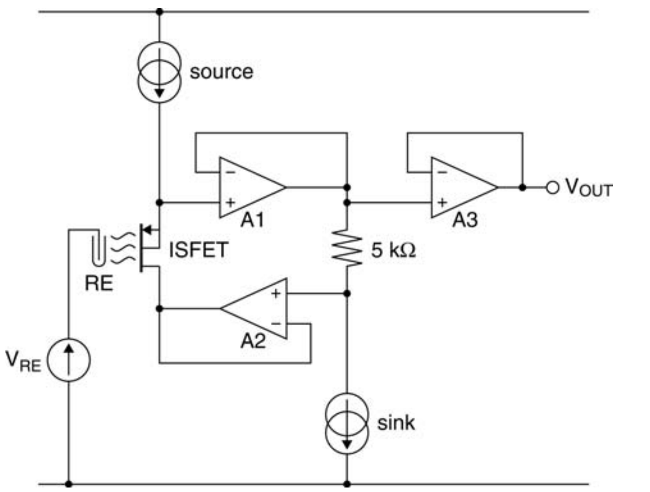

Figure 2. Circuit diagram of an ISFET bias circuit using a pair of unity-gain non-inverting op-amps.

As a consequence of the floating gate architecture the devices can experience fabrication induced anomalies due to the uncontrolled amount of charge left on the electrode. This problem can be solved during device packaging by a flood illumination of UV (λ = 365 nm) to enable excess charge on the gate to move into the substrate.

3. The integrated sensor system

In order to use the CMOS ISFET in a microsensor application (e.g. the laboratory-in-a-pill) we have integrated the device and associated bias circuitry as though it were a conventional design block into an integrated circuit as shown in Fig. 3. The chip consists of the sensor, DAC for bias control, ADC for data acquisition, a microcontroller to fully instrument all the device functions, an SRAM block for program memory and a data interface.

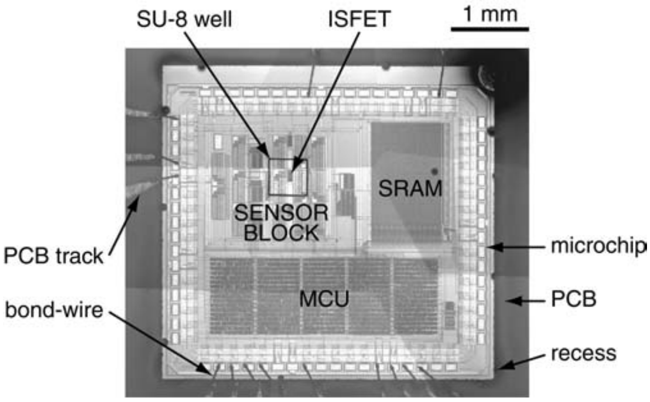

Figure 3. Photomicrograph showing some of the key elements of the system-on-chip pH meter that is encapsulated in a printed circuit board.

The chip is mounted in an accurately-milled recess in a PCB and bond-wire connections are made between the PCB tracks and chip bond-pads. The chip and PCB are spin-coated with a thick (150 µm) protective layer of SU-8 photoresist and a hole is lithographically defined above the ISFET.

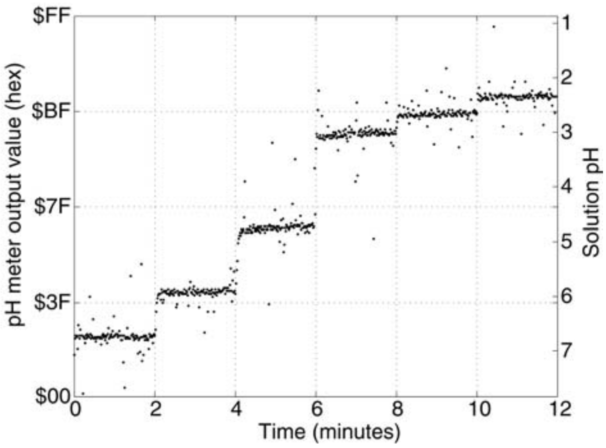

Figure 4. Graph showing the response of the system-on-chip pH meter to changes in solution pH.

As can be seen in Fig. 4 the device works as intended delivering an 8-bit digital value for the pH to the user.
To demonstrate the performance of the instrument metered quantities of 1 M HCl were added to the pH 7 buffer solution at 2-minute intervals causing a reduction in pH. The scatter in pH meter output values at each of the six steps is caused by interference from the magnetic stirrer that was used to ensure complete and rapid mixing of the solution. Even with the added noise from the stirrer the RMS sensitivity of the instrument is 0.2 pH points.

4. Sensor arrays

A growing application area for integrated CMOS technology is in micro-arrays for cell-based assay. In this embodiment the cells are the primary sensor and the integrated ISFETs act as a secondary sensor to deliver an electronic output. We have converted the technology for this purpose by introducing multiplexing transistors into the basic device so that *N*x*N* arrays of ion sensitive pixels can be constructed. Such arrays can be used to obtain temporal and spatial information. As for the first chip the device is packaged in a protective epoxy to ensure fluid access is only to the sensor area. Figure 5 shows one such array that we have designed with a culture of BHK21 C13 cells growing over the surface.

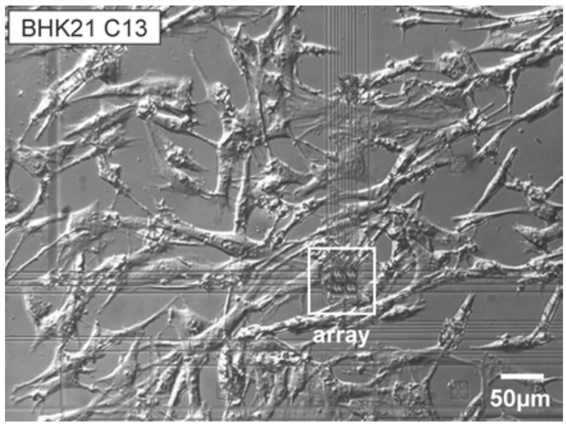

Figure 5. A multiplexed CMOS ISFET array with BHK21 C13 cells growing over the surface.

5. Conclusion

In summary we have presented a method for achieving electronic and bioelectronic system integration on to a single chip. The technology requires minimal modification to conventional device handling and packaging, providing a low cost route to making sophisticated bioanalytical devices.

References

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