

Biomedical Lance Ion Sensitive System

Charles D. Sturdevant, RIT Microelectronic Engineering

Abstract— The fabrication of a pH sensor which can be used in practical applications in biological and medical fields was designed and manufactured using a new lance style ion sensitive field effect transistor. The lance can be used to measure pH levels in micro biological cultures without disruption of the culture and can be a powerful tool in real time Invitro medical diagnostics tool.

The reference electrode can be placed onto the chip by depositing a noble metal contact in the field region. This is referred to as a Pseudo Reference Electrode, PRE. By bringing the PRE design closer to the membrane, the active test area for the ISFET will then be contained to the small perimeter of the gate. Also, with the PRE being very close to the gate membrane, a larger percentage of charged ions will interact with the membrane which can allow for a smaller gate membrane and still have strong sensitivity. The combination of these two benefits can create a very compact Perimeters PRE ISFET design.

With this compact design, it can be implemented on a MEMS cantilever for new testing methods in the medical and biological fields. By combining the ISFET device at the tip of a cantilever, the device can be put into use to test with minimum impact.

Deep silicon etching was attempted using a protective front side coat and a hot KOH bath to etch a patterned backside. Complications in preserving sensitive ISFET components need to be resolved before completion of freestanding cantilever lance MEMS probe with ISFET sensor.

I. INTRODUCTION

Ion sensitive field effect transistors, ISFET, are traditionally too large and impractical for bio probe applications. An ISFET device has 5 main components. Figure 1 shows a basic ISFET design. 'A' is a reference electrode that is suspended in the solution. The reference electrode is traditionally off chip. The charge increase ion activity, increasing the sensitivity to the solution pH. 'B' is the ion sensitive gate. The gate traditionally is very large, so as to be exposed to as many ions in the solution as possible. It is usually comprised of a dielectric and a sensitive membrane. The membrane is an important aspect that shows different sensitivity characteristics. 'C' is an ion filled solution that has to large enough to cover both the reference electrode and the gate membrane. 'D' is a thick protective oxide needed to protect the source and drain from the ion solution and reduce ion contamination. 'E' is the source and drain components of the ISFET and are the means of sensing the V_t adjust cause during the ion interaction with the gate membrane.

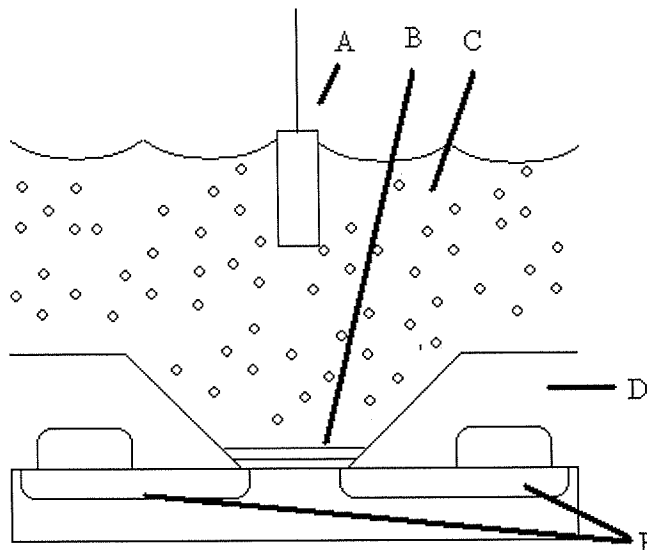


Fig 1: Basic ISFET design component diagram

The ISFET is a relatively large device. The reference electrode can be placed onto the chip by depositing a noble metal contact in the field region. This is referred to as a Pseudo reference electrode, PRE. Figure 2 shows a type of PRE design.

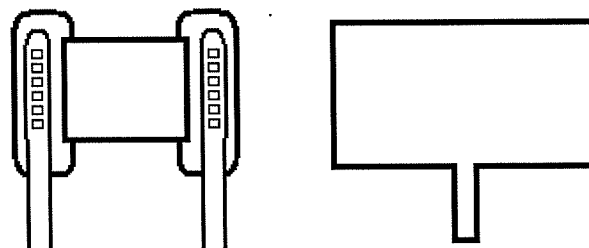


Fig 2: PRE design

The problem with this type of PRE design, a very broad testing area is needed and the sample solution must carry the charged electrons laterally instead of near the gate membrane. By bringing the PRE design closer and membrane, the active test area for the ISFET will then be contained to the width of the gate. Also, with the PRE being very close to the gate membrane, a larger percent of charged ions will interact with the membrane which can allow for a small membrane. The combination of these two benefits can create a very compact ISFET. Figure 3 shows a Perimeters PRE ISFET design.

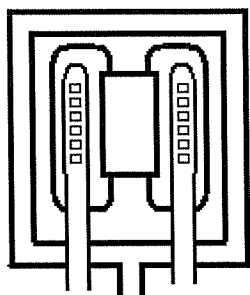


Fig 3: Perimeter PRE ISFET design

With this compact design, new applications can open for the sensor. Previously, with the need for an exterior electrode, the solution needed to be fairly large. With the PRE, the solution needed to be placed onto a chip. With the new smaller design, the ISFET can be more flexible in its applications. One application that was not viable with the previous designs is the opportunity to be manufactured at the end of a MEMS probe lance. With a very fine probe, Medical testing and biological applications expand greatly. The ability to test acidic level in burn wounds, damaged tissue, and the ability to detect body chemistry changes instantly during surgery can be crucial information for medical professionals. This can be done using a compact ISFET design that can be manufactured on the end of a MEMS lance.

II. PROCEDURE

Four inch n type wafers are used to create the PMOS ISFET device. The wafers are thinned using a wafer grinder on the backside of the wafer and a CMP tool to reduce the thickness to approximately 330 μ m. The wafers are cleaned in a RCA clean cycle. Oxide is grown in a wet furnace to create a mask for the active regions device. The oxide is patterned using a contact aligner and is etched in the active areas. A p-type spin on glass is used to dope the PMOS source and drain. The oxide is removed. A pad oxide is grown for a nitride backside pattern. The nitride is removed from the front of the wafer using a SF₆ plasma and the pad ox is removed in a BOE 10:1 bath. The backside is patterned using the front side active mask to align in the contact aligner. The patterned nitride is etched using a SF₆ plasma and the oxide pad is removed in a BOE 10:1 bath.

A 140nm wet oxide is grown in a furnace. Contact cuts to the active area are patterned using a 5x g-line stepper and etched in a BOE 10:1 bath. A 600nm LPCVD Poly silicon layer is grown over the oxide and is doped with a p-type spin on glass. The poly silicon is patterned using a 5x g-line stepper and etched in SF₆ plasma. A thick 1 μ m oxide is deposited using a TEOS deposition tool to protect the source, drain, and poly silicon from the electrolyte solution.

The gate is patterned using the 5x g-line stepper and is etched using a BOE 10:1 bath. The photo resist is removed before a dry 25nm gate oxide is grown. A lift off process is used to deposit the Al₂O₃ so to limit acid contamination to the gate membrane. The 5x g-line stepper patterns the Al₂O₃ membrane before deposition. An electron beam evaporation tool is used to deposit 40nm of Al₂O₃ onto the wafer. The

photo resist is removed in an ultrasonic acetone bath.

Poly silicon to pad contacts are patterned using the 5x g-line stepper and etched in a BOE 10:1 bath. The gold perimeter PRE pattern is also a lift off process. The PRE is patterned using the 5x g-line stepper before metal deposition. An electron beam evaporation tool is used to deposit a 50nm chrome layer followed by a 150nm gold metal contact. The photo resist is removed in an ultrasonic acetone bath.

The front side of the wafer is etched to define the thickness and edges of the lances. The front side etch is patterned on a 5x g-line stepper and is etched using an SF₆ plasma. The etch recess is approximately 30 μ m. The wafer is then etched from the backside with the nitride pattern. The front side of the wafer is protected with a Brewer Science *Protek B3* product. A *Protek* primer is spun and baked on the front and edges of the wafer, followed by the *Protek B3*. The wafer is etched in a 75°C KOH bath for 3 hours. The wafers are cleaned in a KOH decontamination bath. The *Protek* is removed using a solvent strip and the front side is cleaned using an acetone ultra sonic bath to remove residue.

III. RESULTS

The first wafer was observed after the KOH three hour etch. The front side of the wafer showed signs of partially etched regions. The *Protek* product is optimized to adhere to a SiO₂ surface. The top etched region was largely bare silicon. The *Protek* did not properly adhere to the bulk silicon or the Al₂O₃ gate. Only the thick oxide and gold coated regions were protected with the *Protek*. The front side etched silicon increased from 30 μ m to 90 μ m, suggesting that the KOH only etched for approximately one hour on the front side. Figure 4 shows a SEM image of the front side of the devices.

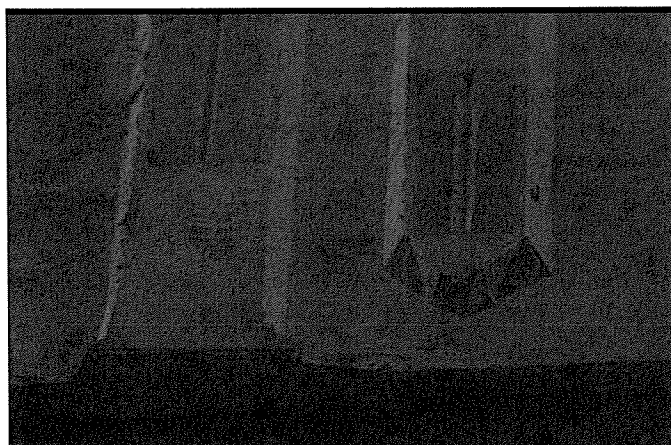


Fig 4: SEM of lance topside cut

In the gate region, the KOH created a self terminating etch. This makes it unclear if the *Protek* failed to adhere to the Al₂O₃ or the side walls of the 1 μ m gate. It is also unclear when the failure happened in the KOH etch. Figure 5 shows a SEM image of the gate region.



Fig 5: SEM of etched gate region

The *Protek* is a stackable film that can be layered. The bulk of the device was properly protected. Using the *Protek* to adhere to itself in multiple layers can be used to bridge the gate and protect the membrane during the etch.

If the *Protek* cannot protect the gate membrane due to adhesion, a deep silicon etch can be used to release the lances. Using a thick photo resist such as SU-8, a long SF₆ plasma etch can be used to remove the bulk of silicon under the lance using the backside lithography step at the end of the process.

IV. CONCLUSION

The perimeter PRE ISFET design was successfully designed and manufactured. The integration of the design onto a lance cantilever MEMS was unsuccessful due to complications in deep silicon etching processes. Further work can produce a freestanding lance with an ion sensitive field effect probe.

ACKNOWLEDGMENT

Dr. Lynn Fuller, Ivan Puchades, Sean O'Brien, Victor Prajapati,

REFERENCES

- [1] Hon-Sum Wong, Marvin H. White, "A Self-Contained CMOS Integrated pH Sensor," *Electron Devices Meeting, 1988. IEDM '88. Technical Digest., International*, pp. 658-661, (1988).
- [2] Rozina Abdul Rani, Othman Sidek, "ISFET pH Sensor Characterization: towards Biosensor Microchip Application," *TENCON 2004. 2004 IEEE Region 10 Conference*, Vol. 5, pp. 660- 663, (2004).
- [3] P.A. Hammond, D.R.S. Cumming, D. Ali, "A Single-Chip pH Sensor Fabricated by a Conventional CMOS Process", *Sensors, 2002. Proceedings of IEEE*, Vol 1, pp. 350- 355, (2002).
- [4] Haingang Yang, Hongguang Sun, Jinghong Han, Jinbao Wei, Zengjin Lin, Shan hong Xia, Hua Zhong, "A pH-ISFET based micro sensor system on chip using standard CMOS technology *System-on-Chip for Real-Time Applications*", 2005. *Proceedings. Fifth International Workshop on*, pp. 180- 183, (2005).
- [5] Shahriar Jamasb, Scott D. Collins, Rosemary L Smith, "A Physically-Based Model for Drift in Al₂O₃-gate pH ISFET's", *TRANSDUCERS '97, International Conference on Solid-state Sensors and Actuators*, pp. 1379-1382, (1997).