A Membrane-gate FET Sensor Platform using Monolithic 3-D Integration for Internet of Things (IoT)

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Motivation

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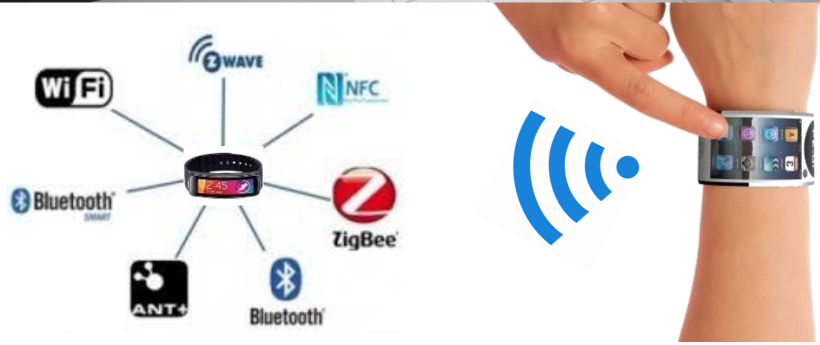
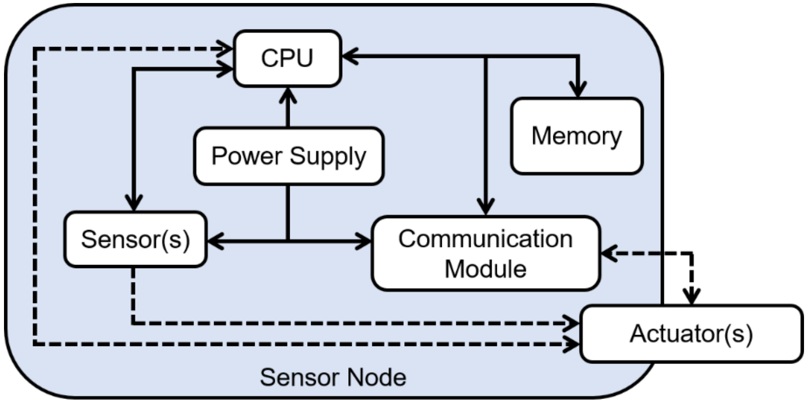
IoT Sensor Network

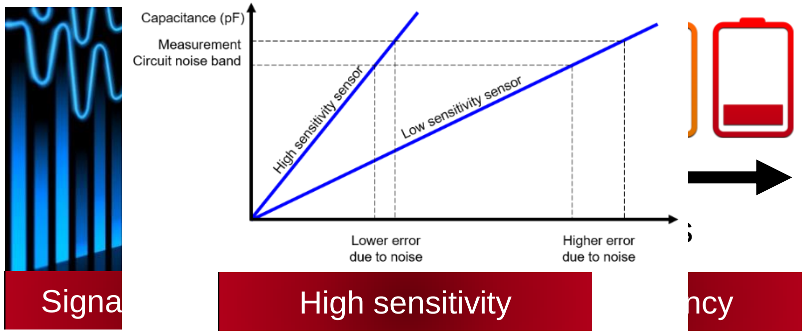


Sensor Node Reference Architecture



Standard Architecture ISO/IEC 29182-3

Must have …



Previous Works

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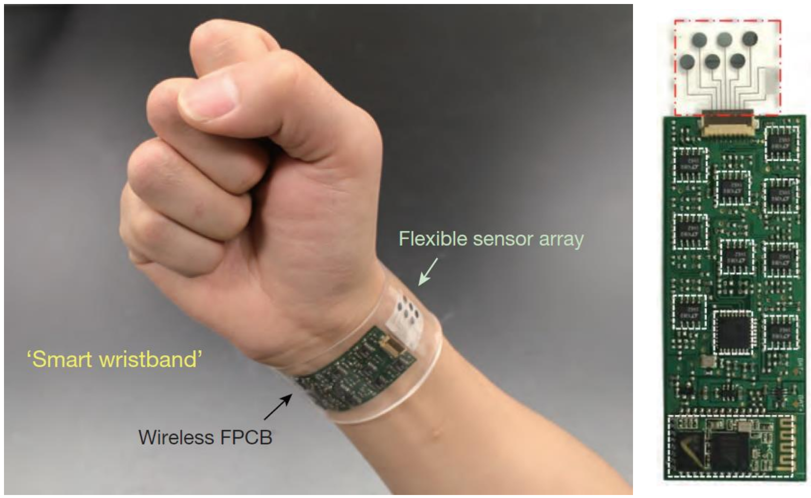
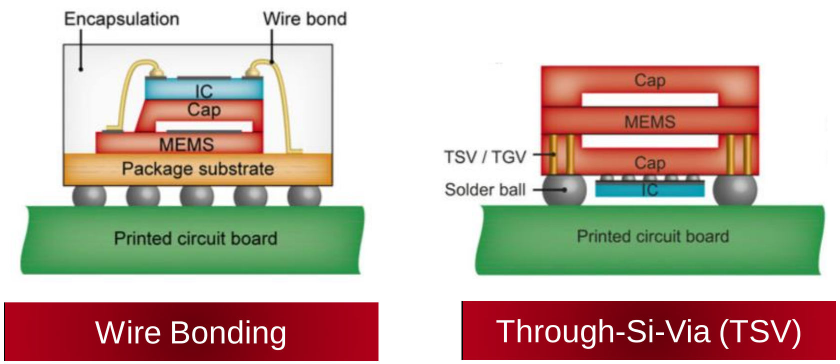
2D Integration in chip scale packaging



Ref : W. Gao, *et. al.* ***Nature*** **529**, pp. 509, 2016

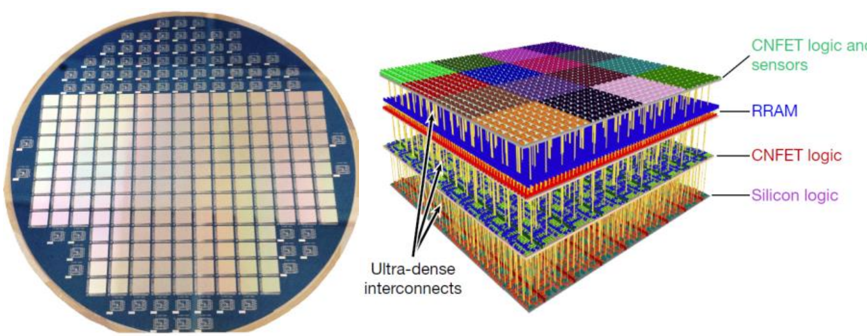
- Large area for integration
- Long range chip-to-chip interconnect
  - ✓ Cable loss (Heat dissipation)
  - ✓ Large parasitic capacitance (Cross-talk)

3D Integration in chip scale packaging



Ref : A.C. Fischer, *et. al.* ***Microsys. & Nanoeng.*** **1**, pp. 15005, 2015

3D Integration in wafer-level packaging



Ref : M.M. Shulaker, *et. al.* ***Nature*** **547**, pp. 74, 2017

Our Work

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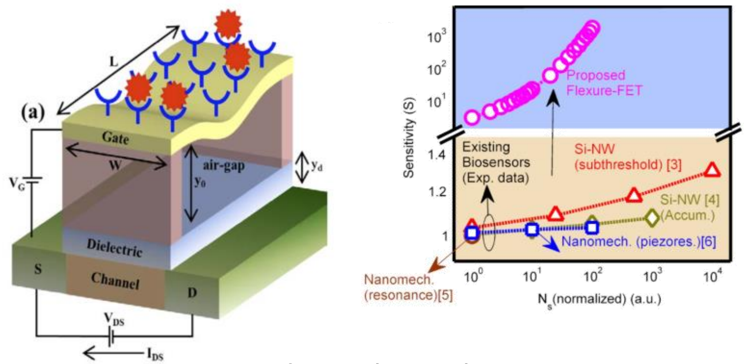
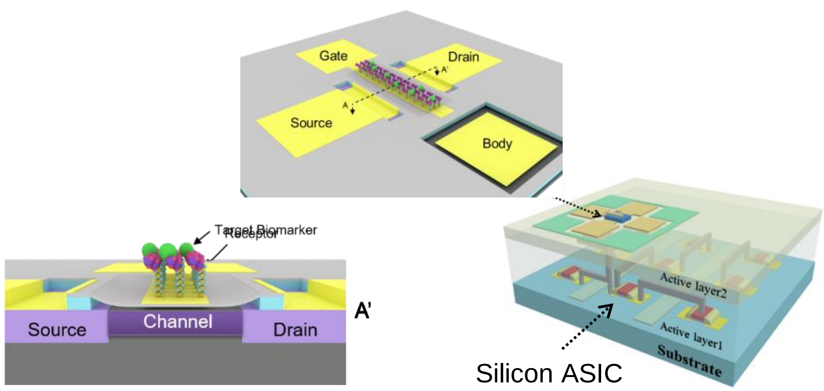
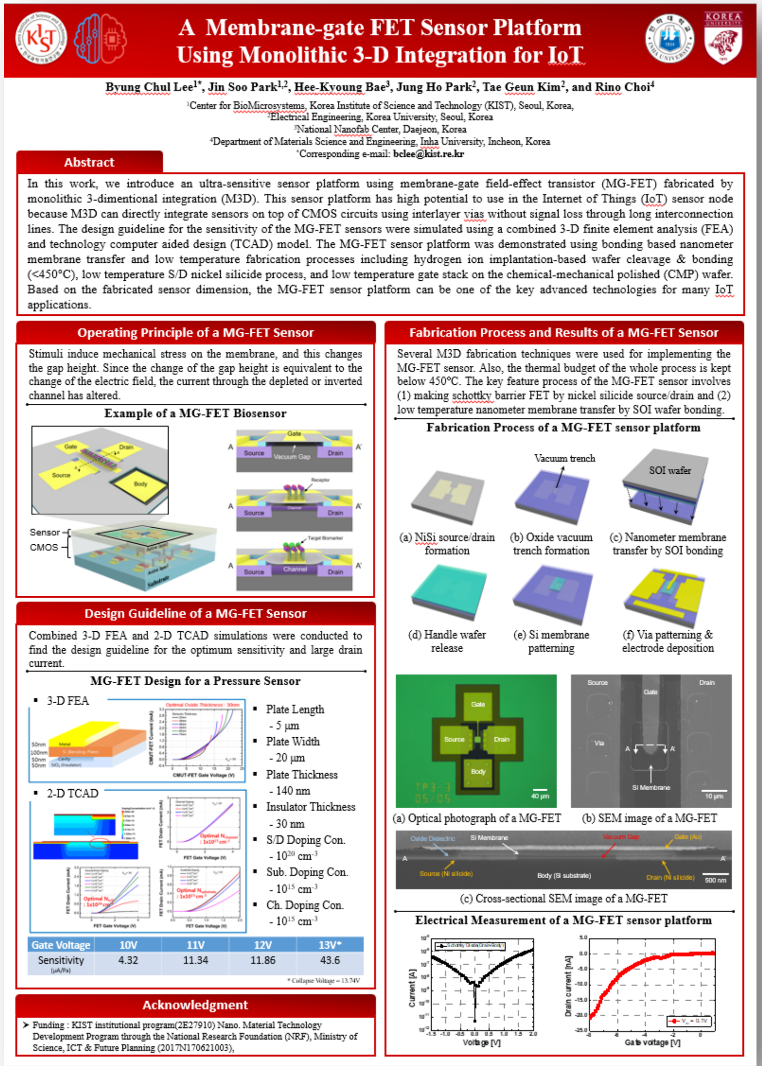
Mechanically moving gate FET



Ref : A. Jain, *et. al.* ***PNAS* 109**, pp. 9304, 2012

Membrane-gate FET (MG-FET)





A Membrane-gate FET Sensor Platform Using Monolithic 3-D Integration for IoT

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Abstract

In this work, we introduce an ultra-sensitive sensor platform using membrane-gate field-effect transistor (MG-FET) fabricated by monolithic 3-dimentional integration (M3D). This sensor platform has high potential to use in the Internet of Things (IoT) sensor node because M3D can directly integrate sensors on top of CMOS circuits using interlayer vias without signal loss through long interconnection lines. The design guideline for the sensitivity of the MG-FET sensors were simulated using a combined 3-D finite element analysis (FEA) and technology computer aided design (TCAD) model. The MG-FET sensor platform was demonstrated using bonding based nanometer membrane transfer and low temperature fabrication processes including hydrogen ion implantation-based wafer cleavage & bonding (<450°C), low temperature S/D nickel silicide process, and low temperature gate stack on the chemical-mechanical polished (CMP) wafer. Based on the fabricated sensor dimension, the MG-FET sensor platform can be one of the key advanced technologies for many IoT applications.

Operating Principle of a MG-FET Sensor

Stimuli induce mechanical stress on the membrane, and this changes the gap height. Since the change of the gap height is equivalent to the change of the electric field, the current through the depleted or inverted channel has altered.

Example of a MG-FET Biosensor

Design Guideline of a MG-FET Sensor

Combined 3-D FEA and 2-D TCAD simulations were conducted to find the design guideline for the optimum sensitivity and large drain current.

MG-FET Design for a Pressure Sensor

- 3-D FEA
- 2-D TCAD

- Plate Length
  - 5 µm
- Plate Width
  - 20 µm
- Plate Thickness
  - 140 nm
- Insulator Thickness
  - 30 nm
- S/D Doping Con.
  - 10^{20} cm^{-3}
- Sub. Doping Con.
  - 10^{15} cm^{-3}
- Ch. Doping Con.
  - 10^{15} cm^{-3}

Gate Voltage	10V	11V	12V	13V*
Sensitivity (µA/Pa)	4.32	11.34	11.86	43.6

* Collapse Voltage = 13.74V

Fabrication Process and Results of a MG-FET Sensor

Several M3D fabrication techniques were used for implementing the MG-FET sensor. Also, the thermal budget of the whole process is kept below 450°C. The key feature process of the MG-FET sensor involves (1) making schottky barrier FET by nickel silicide source/drain and (2) low temperature nanometer membrane transfer by SOI wafer bonding.

Fabrication Process of a MG-FET sensor platform

(a) NiSi source/drain formation
(b) Oxide vacuum trench formation
(c) Nanometer membrane transfer by SOI bonding
(d) Handle wafer release
(e) Si membrane patterning
(f) Via patterning & electrode deposition

(a) Optical photograph of a MG-FET
(b) SEM image of a MG-FET
(c) Cross-sectional SEM image of a MG-FET

Electrical Measurement of a MG-FET sensor platform

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THANK YOU
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