TECHNION – ISRAEL INSTITUTE OF TECHNOLOGY   DEPARTMENT OF ELECTRICAL ENGINEERING

CMOS Disruptive Sensing Systems for Dual Applications

From leading edge research to working prototypes

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Why CMOS?

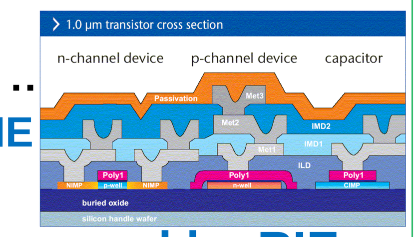
- Matured / Established Technology
  - Low Cost (wafer level, 8 inch)
  - Low Power
  - Low Weight
- Available: TowerJazz, STM, XFAB, TSMC, Global (former IBM) Foundries
- Enables smart sensors, integrating on a SoC
  - Drivers, Temperature compensation, Offset and noise reduction
  - Amplification, signal processing, wireless recharging/ transmission
  - Sensor fusion
- Ideal for mobile applications
  - Military
  - Commercial - IoT, Wearables

Why MEMS?

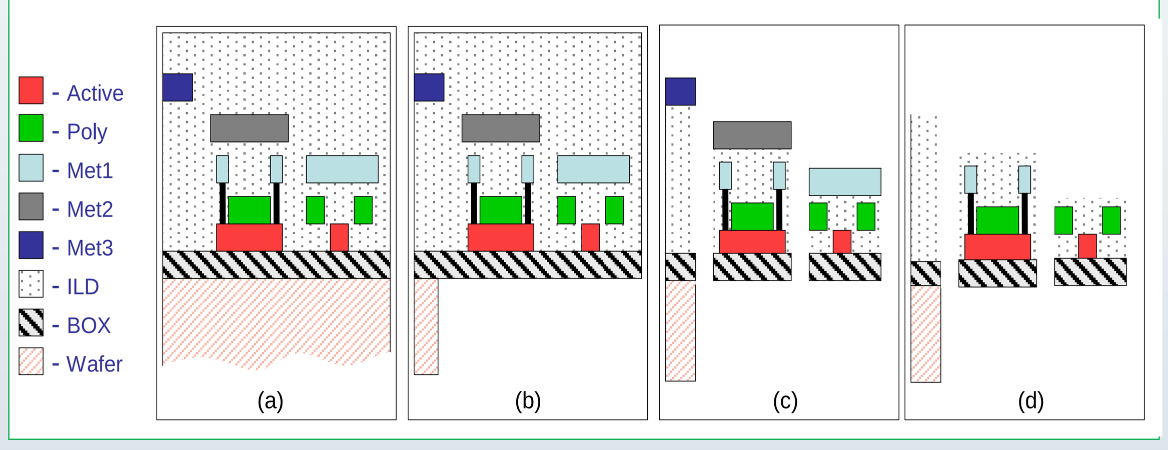
- MEMS/NEMS: the 21st Century Microelectronics Revolution
- MEMS Chips Interact with the outside world
  - VLSI/ULSI dies with > 100 mln transistors respond only to electrical signals
  - MEMS/NEMS: enabling technology to integrate sensors for different physical or chemical parameters and actuators on die, forming SoC-system on chip
- The benefits of scaling down
  - Weight reduction as (dimensions)^3
  - Strength reduction linear with dimension
- The benefits of batch production
  - Mass production
  - Low cost
  - Green industry
- Dual Use applications (military/consumers)

CMOS-SOI-MEMS/NEMS: CMOST"TM"

- CMOS-SOI Wafer Fabrication
  - Standard FAB:IBM, XFAB, STM ..

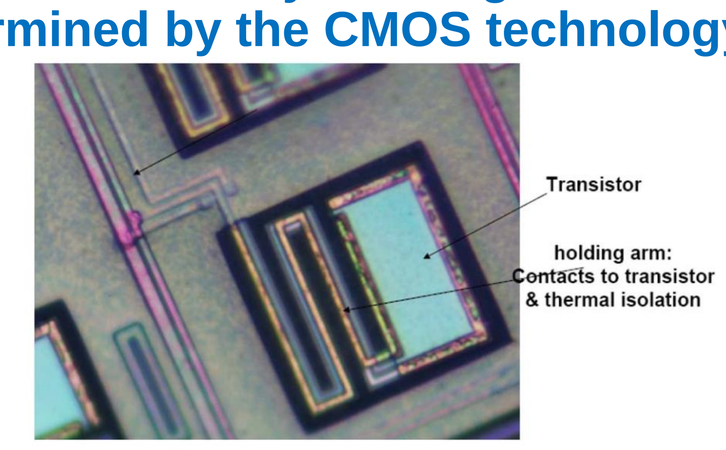


- Back Side handle removed by DRIE
  - BOX provides etch stop
- Front Side dielectric layers removed by RIE
  - CMOS–SOI metal layers (Al/Cu) provide *Built-in Masks for the MEMS* spared by Fluorine plasma
- Front Side Metal Masks are removed by etching



Our CMOST unique technology

- No need for expensive masks
- No need for 3D alignment
- Patterns accuracy and alignment are determined by the CMOS technology



The MEMS processing was performed at the Micro-Nano-Fabrication & Printing Unit (MNF&PU), Technion

Current Activities

With MEMS

- Thermal **TMOS** IR uncooled Sensors
- Thermal TeraMOS THz uncooled Sensors
- Thermal GMOS Gas Sensors

W/O MEMS

- CMOS SPAD camera for detection of gun flash
- CMOS SiPM Photomultiplier for LIDARs

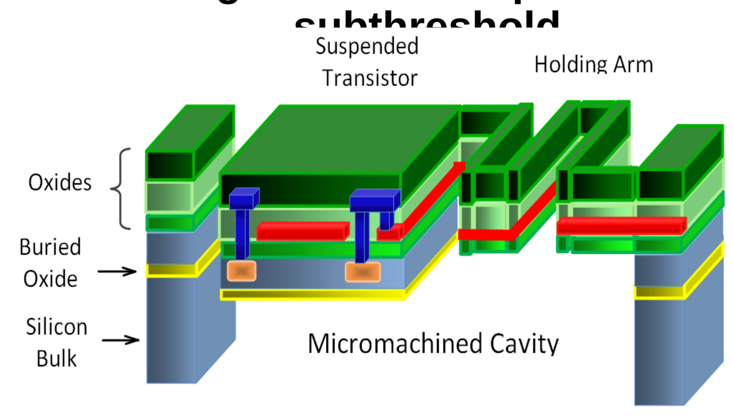
Thermal **TMOS** IR uncooled sensor

TMOS Operation Principle

The nano-machined thermally isolated transistor has very low thermal mass and very low thermal conductivity

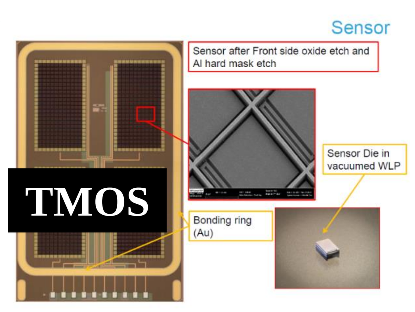
Absorbed radiation increases the TMOS temperature and modifies the current-voltage characteristics

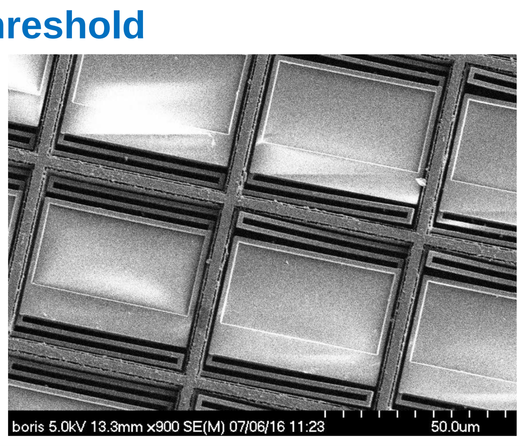
Transistor voltage detects temperature changes at subthreshold



TMOS Disruptive Advantages

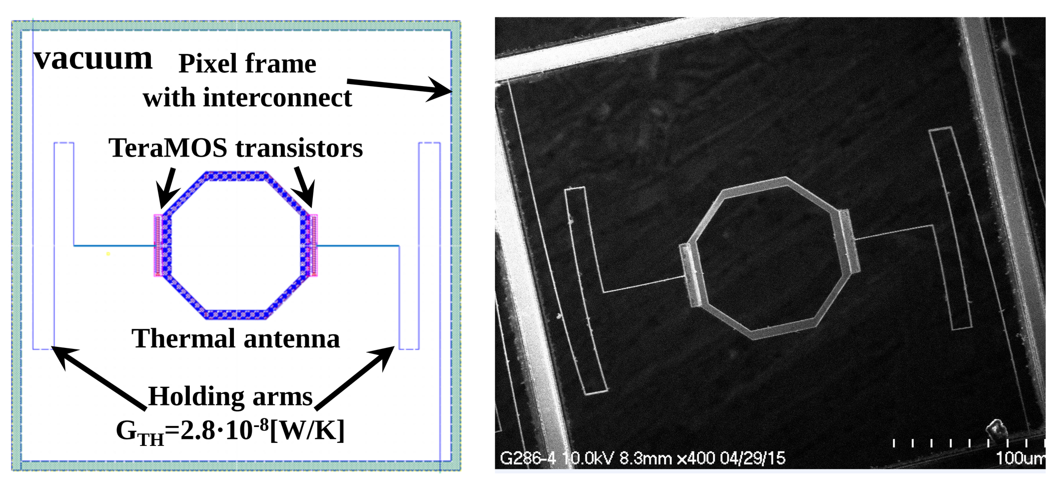
- CMOS-SOI Standard Technology
  - Matured/Low cost/Low power
- MEMS: Thermally Isolated by post-processing dry etching
  - High yield and uniformity
- TMOS transistor is an active sensor (amplifier) with internal gain
  - Highest responsivity: 10^7 V/W
  - All other thermal sensors are passive
- Low power operation at subthreshold
  - < 1 µWatt
- No "sun-burnt" effects as in bolometers
  - Sensors operate in the presence of sun
- Compatible to mobile, wearables, IoT battery operated applications





Thermal TeraMOS THz Uncooled Sensors

- TeraMOS: THz sensor that may enable monolithic uncooled passive THz imagers



- Current responsivity of ~2.6 A/W,
- NEP of the order of NEP/√Hz│1Hz=6.1pW/√Hz
- D* of 0.41·10^{10} cm√Hz/Watt

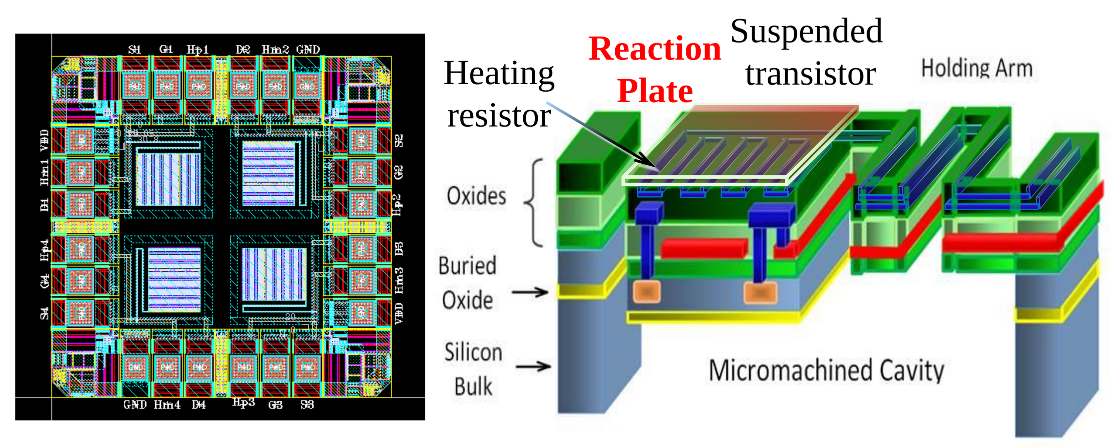
Thermal GMOS Gas Sensors

Operation Principle

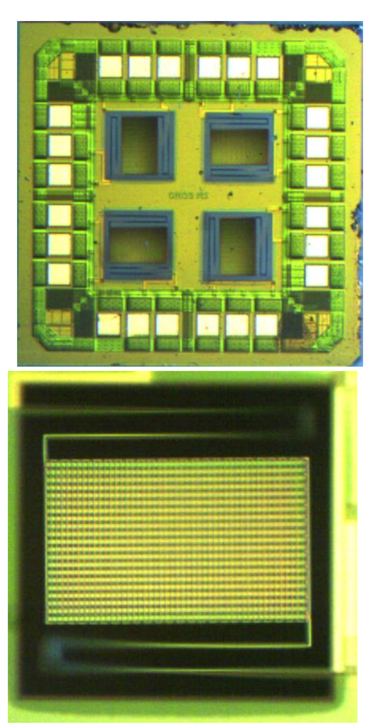
Heated catalytic reaction plate activates the reaction of gases with oxygen in the air. Reaction of Volatile Organic Components liberates heat which is detected by TMOS transistor whose voltage changes due to increased temperature

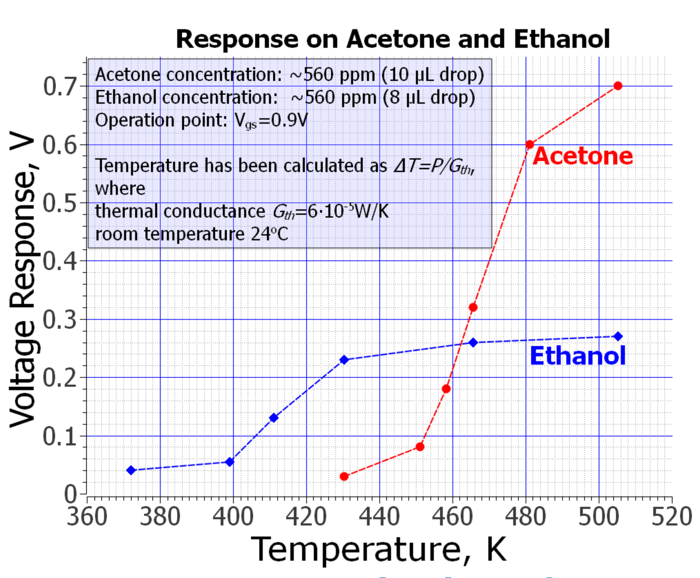
For Example:

$CO+O_2$ --> CO_2 + heat



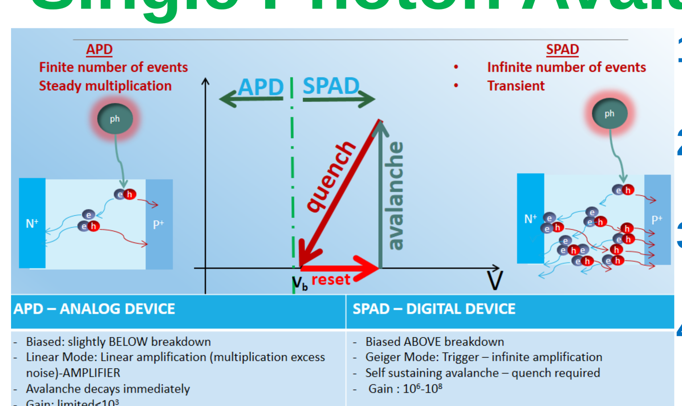
GMOS in the lab



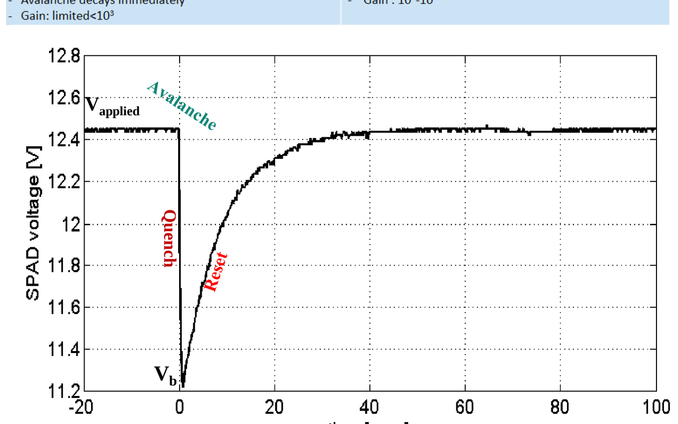


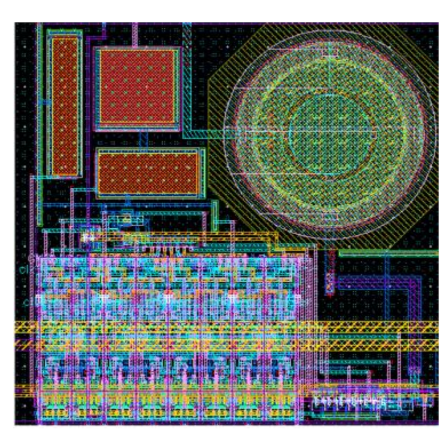
- GMOS sensor reponse to Acetone and Ethanol
- 1000A of Palladium sputtered on the reaction electrode
- Gas selectivity is achieved by heating the electrode to different temperatures

CMOS SPAD – Single Photon Avalanche Diode



1. Digital response to photon flux
2. Full immunity to read-out circuitry noise
3. Excellent sensitivity – single photon
4. Excellent timing – 10's psec





Journal Papers

[1] "CMOS-SOI-MEMS transistor for uncooled IR Imaging", IEEE Trans. Electron Devices, vol. 56, no. 9, pp. 1935-1942, Sep. 2009

[2] "Nanometric CMOS-SOI-NEMS transistor for uncooled THz sensing", *IEEE Transactions On Electron Devices*, vol 60(5), pp.1575-1583, 2013

[3] "CMOS-SOI-MEMS Thermal Antenna and Sensor for Uncooled THz Imaging", *IEEE Transactions on Electron Devices, vol. 63, no. 3, pp. 1260-1265, March 2016*

[4] "CMOS-SOI-MEMS Uncooled Infrared Security Sensor With Integrated Readout," *IEEE Journal of the Electron Devices Society*, vol. 4, no. 3, pp. 155-162, May 2016.

Patents

9 Technion-TODOS patents relevant to CMOS-SOI-MEMS

3 Technion patents relevant to CMOS SPAD and CMOS Silicon Photomultiplier