DC and RF reliability of Advanced CMOS technologies…

…and something else

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SBMicro
Sociedade
Brasileira de
Microeletrônica

EDS

Electron Devices Society

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IEEE
Advancing Technology for Humanity

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This is an eruptive talk that has to do with energy, reliability, monitoring, and prediction.

An example: self-driving cars(SDC)

- Sensors
- Communications
- Electronics
- Mechanics
- Software

Is the SDC reliable enough?

Which are the less reliable components?

The three-modules SDC

Computer system

1 Perception module	2 Prediction module	3 Response module
Cameras, radar, LIDAR	Forecasts the world	Address an action to the vehicle

Communication and transduction

Model of the world, and machine-learning systems that identify objects	Change of lane?, object crossing the road?, will or not a pedestrian will cross the road?	Slow down, speed up, total stop, detour, park, go ahead, turn off, etc

5G will do it!

5G technology

Lower end | 0.6 GHz | 3.1-3.55 GHz | 3.7-4.2 GHz

Higher end | 27.5-28.3 GHz | 37-40 GHz

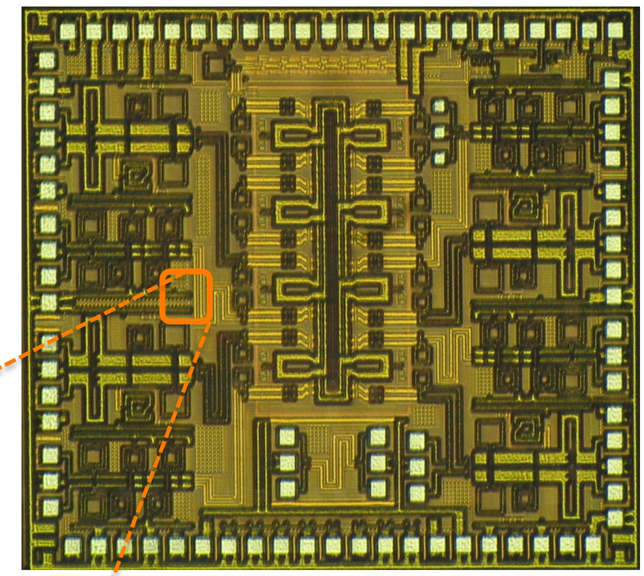
test | 64-71 GHz

Same as human-like reflexes velocity!

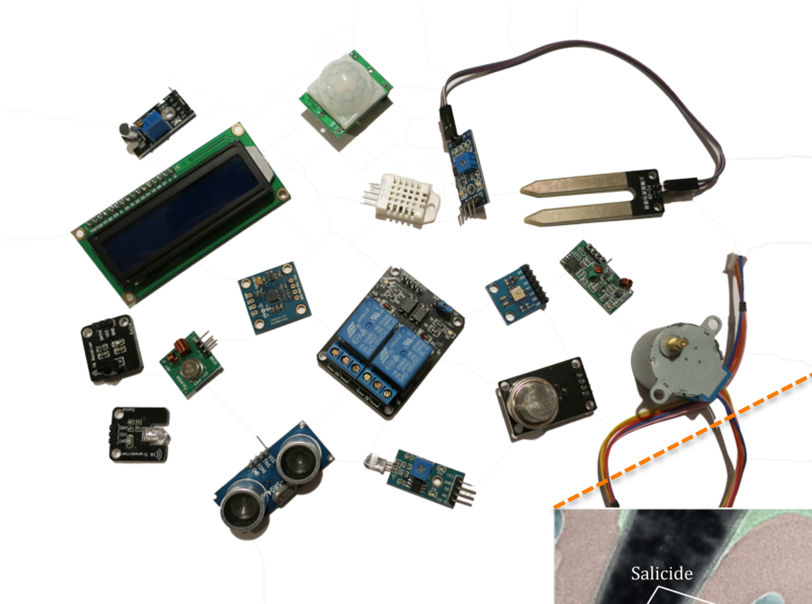
- IoT, virtual reality, artificial intelligence, a mobile phone connected to a SDC will get you the power of a supercomputer on the go!
- Speed and data processing will provide the SDC the timing of human reflexes with the equivalent of two-million gigabits!
- 5G electronics, data processing, and communications will become a SDC into a supercomputer on-wheels, and more…

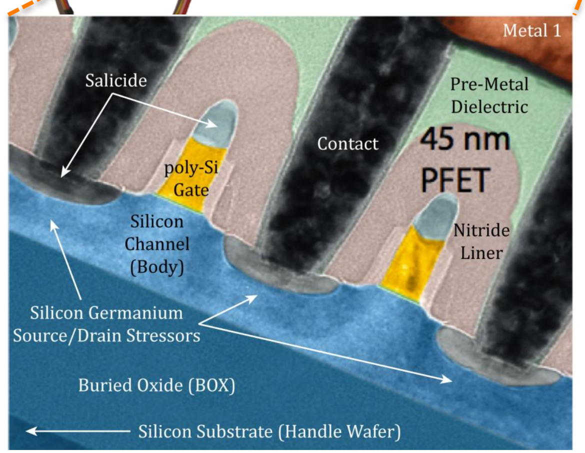
Lets focus on electron devices reliability

Solid-state electronic chip



Sensors of different kind





Software, communications?

Ethics!

[Lets open a technical breviary here]

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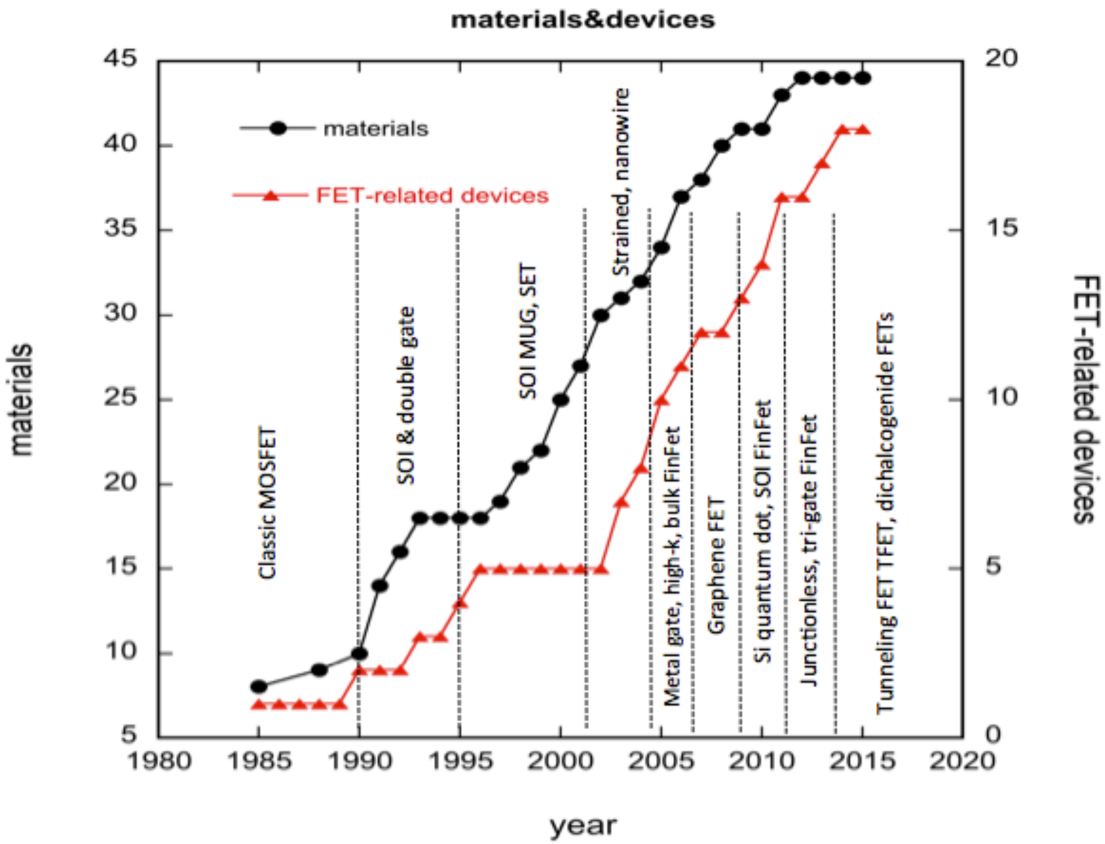
Today more the 50 different elements, of the periodic table, are used in the fabrication of FET devices.



Edmundo A. Gutiérrez-D.,
"Nano-Scaled Semiconductor Devices, Physics, Modelling, Characterisation, and Societal Impact", IET Press, 2016.

Why is this a relevant fact?

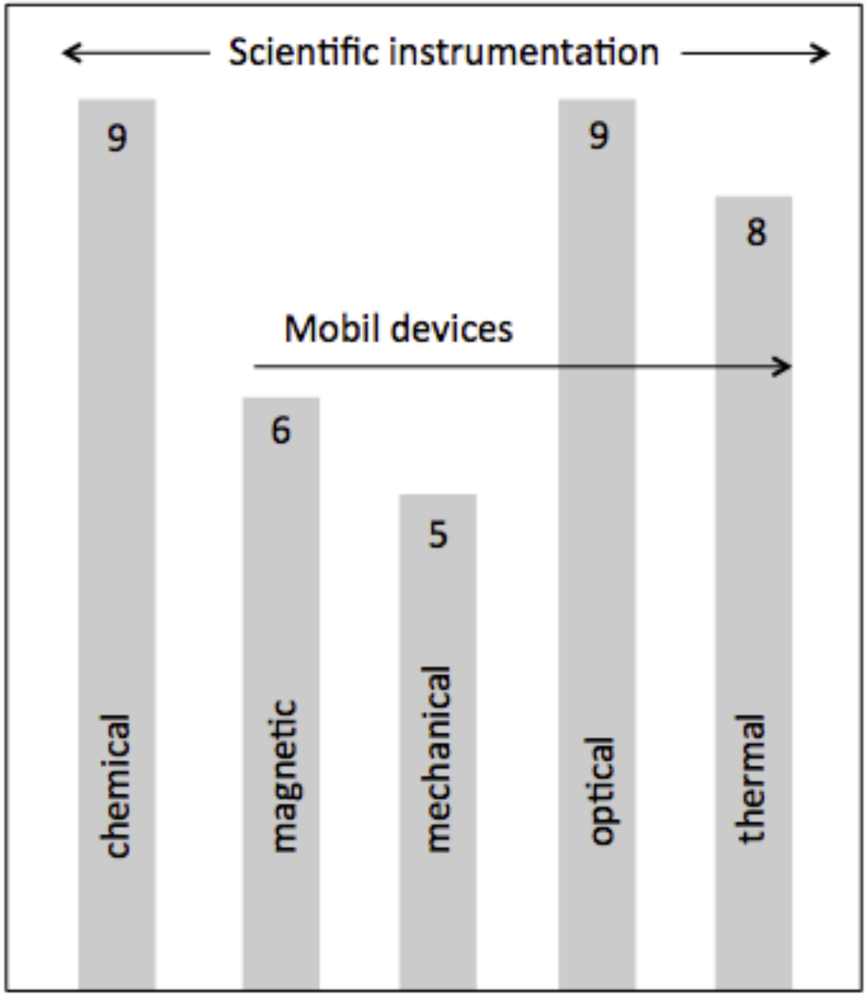
There are two ways to explore!

Bio-chemical, neurology, gas, e-nose, cancer detection, …

Pressure, fluids, Security, hearing-aid,…

Magnetic, DNA, NMR,…

Temperature, IR, imaging, medicine, flow,…



Edmundo A. Gutiérrez-D.,
"Nano-Scaled Semiconductor Devices, Physics, Modelling, Characterisation, and Societal Impact", IET Press, 2016.

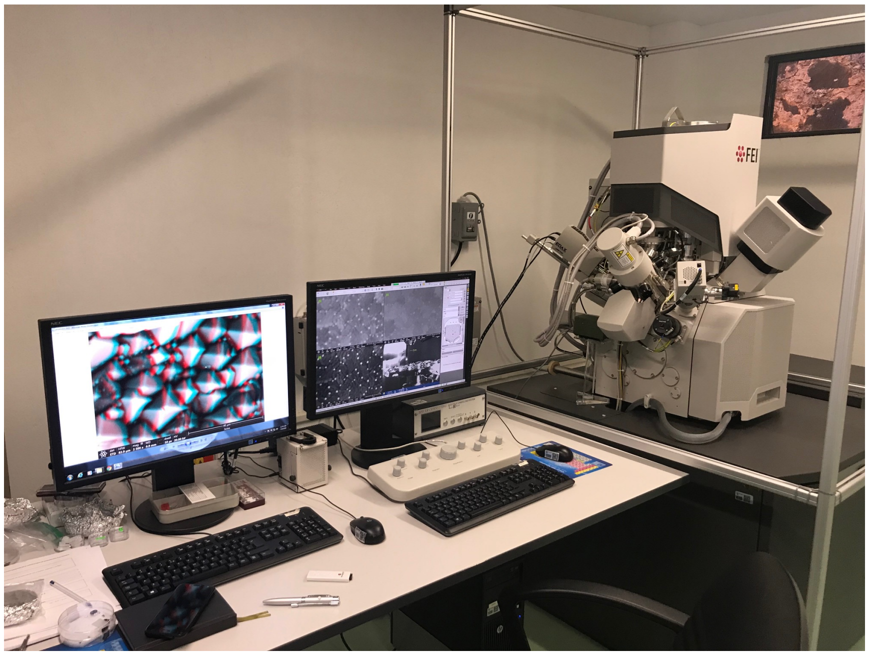
1.- Develop CMOS-compatible sensors, or

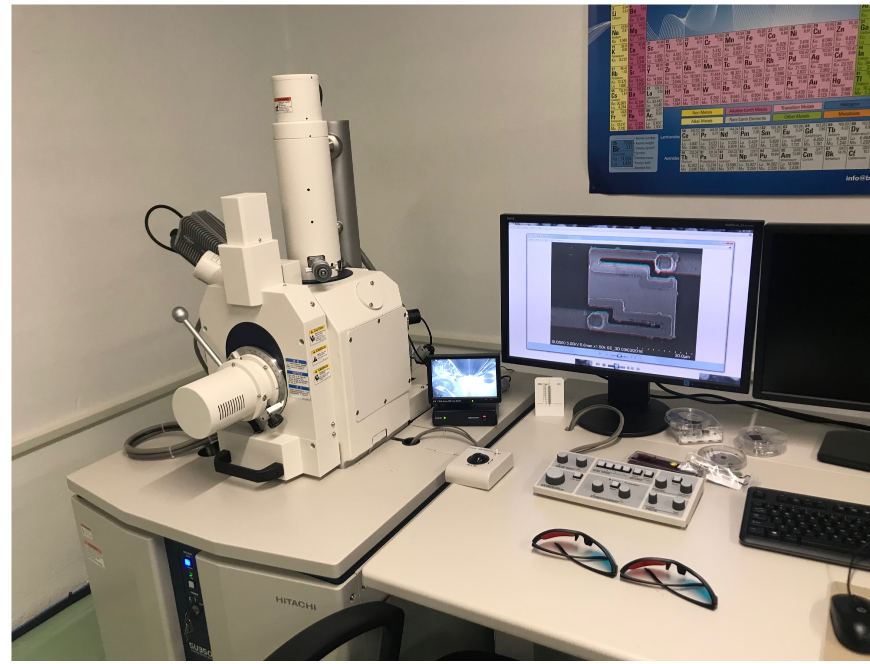
2.- Use built-in based sensors to monitor reliability, and study sensor reliability.

Devices & circuits

Lets go back, and go deeper into the nano-scale interfaces

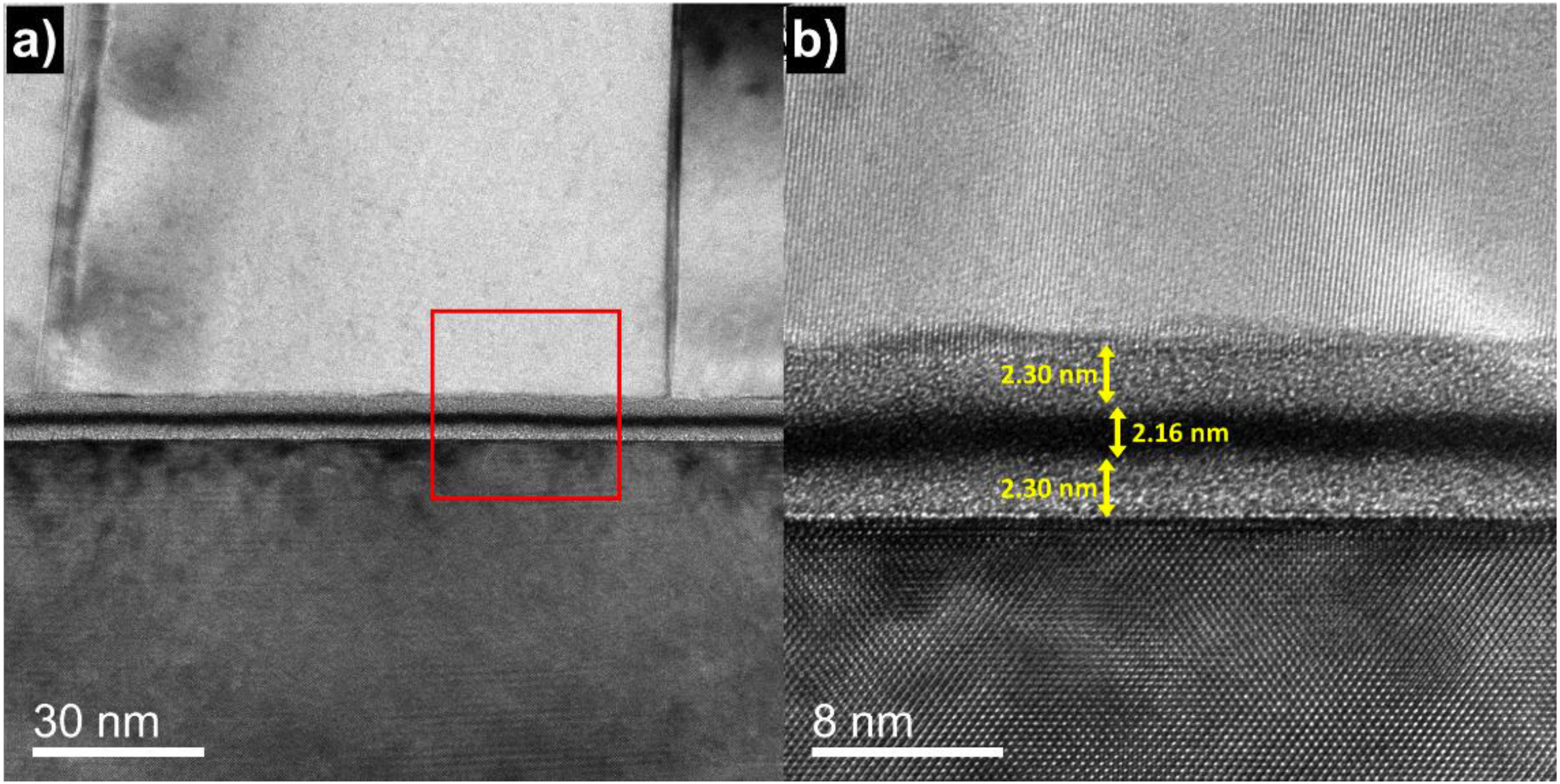
INAOE electron microscopy laboratory





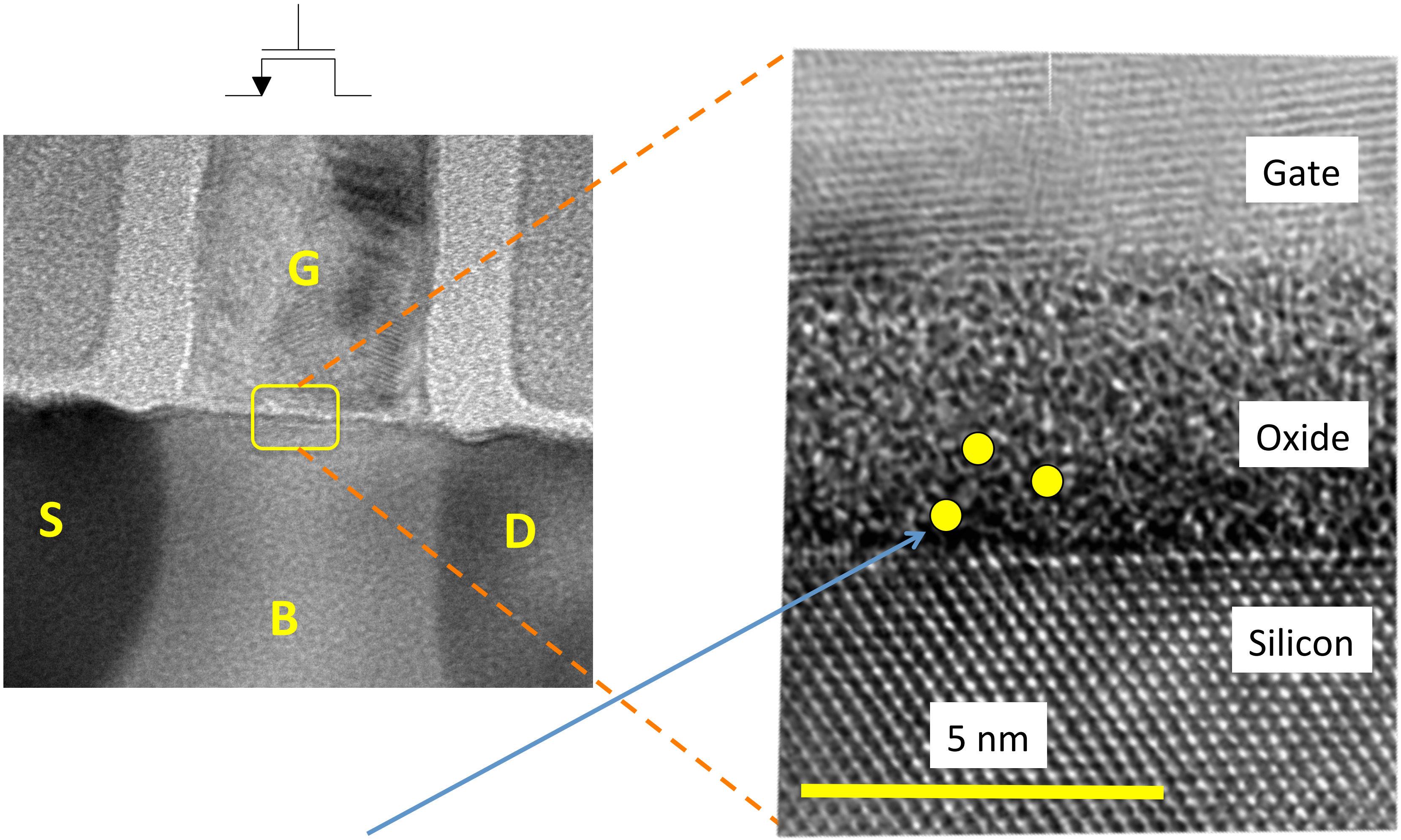
INAOE has the fabrication and characterization capability to study atomic-scale interfaces, and its interaction with external physical variables: light, temperature, magnetic field, etc.

…and see what is going on in the interfaces



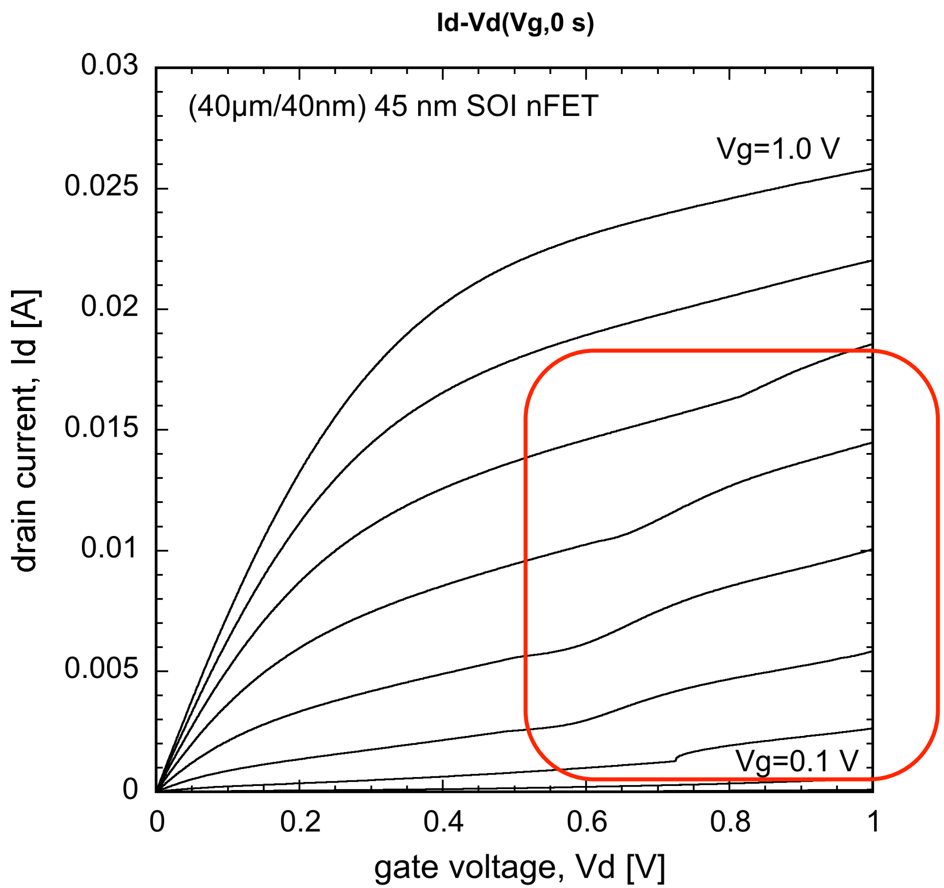
The FET semiconductor-oxide interface

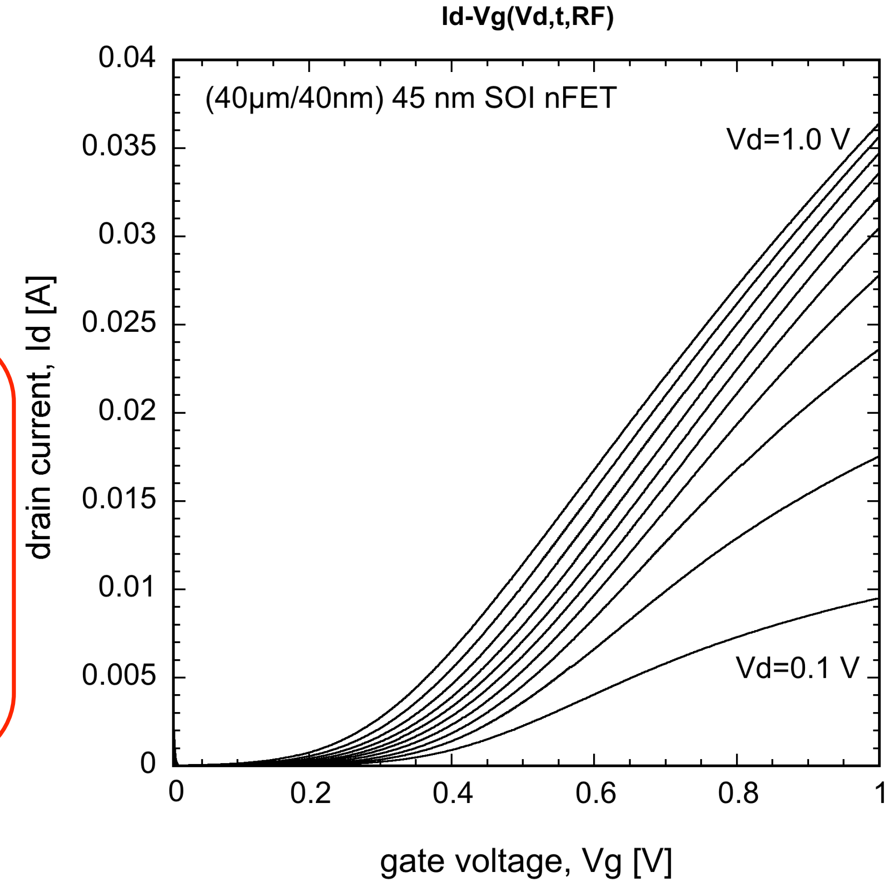
FET: Field Effect Transistor



Charge traps

The fresh I-V characteristics of a 45 nm SOI RF device

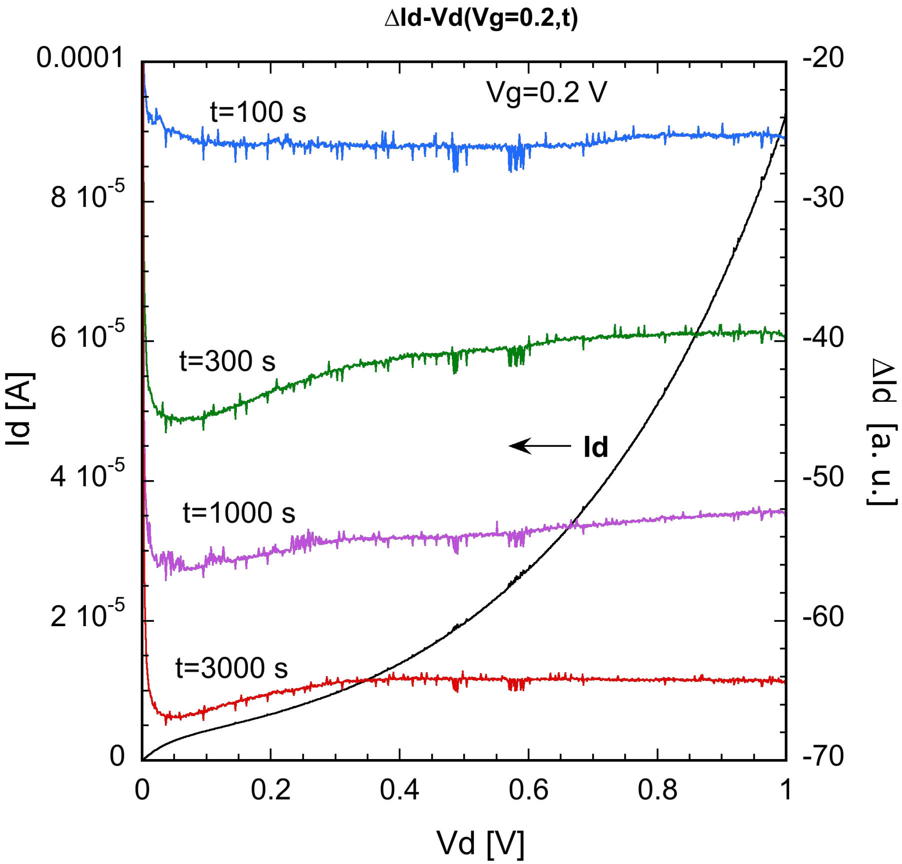


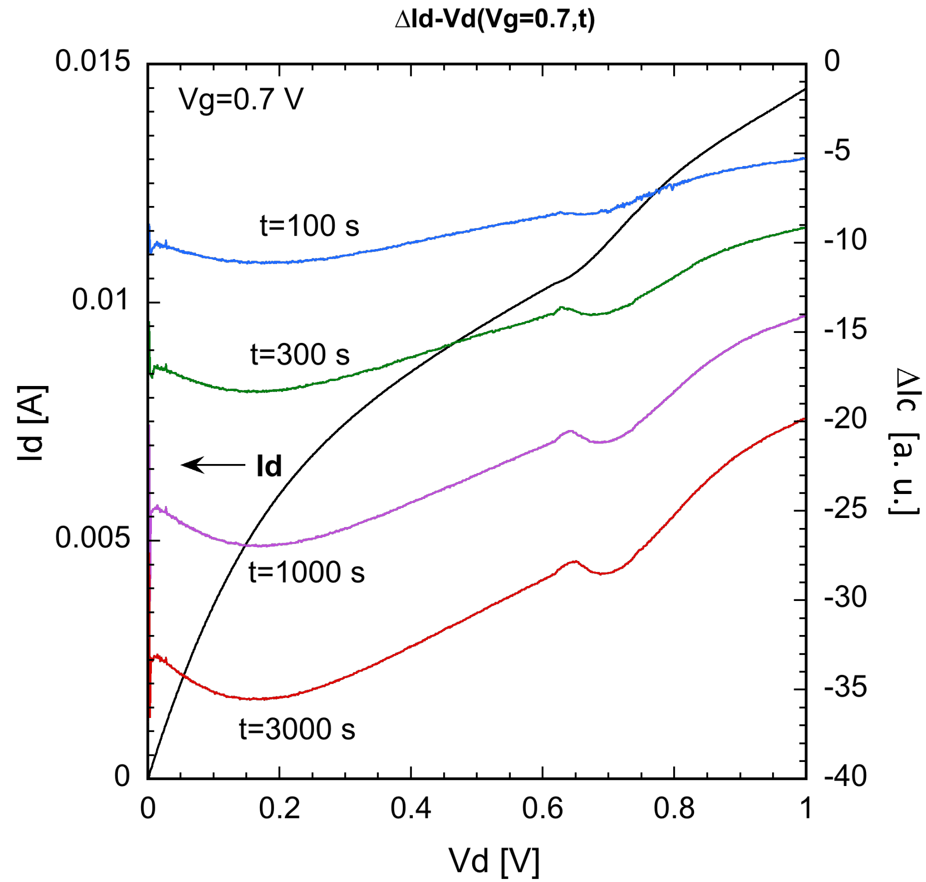


Hot-carriers (**HC**), Impact Ionization (**II**), and Self-heating (**SH**) ->degradation: reliability!

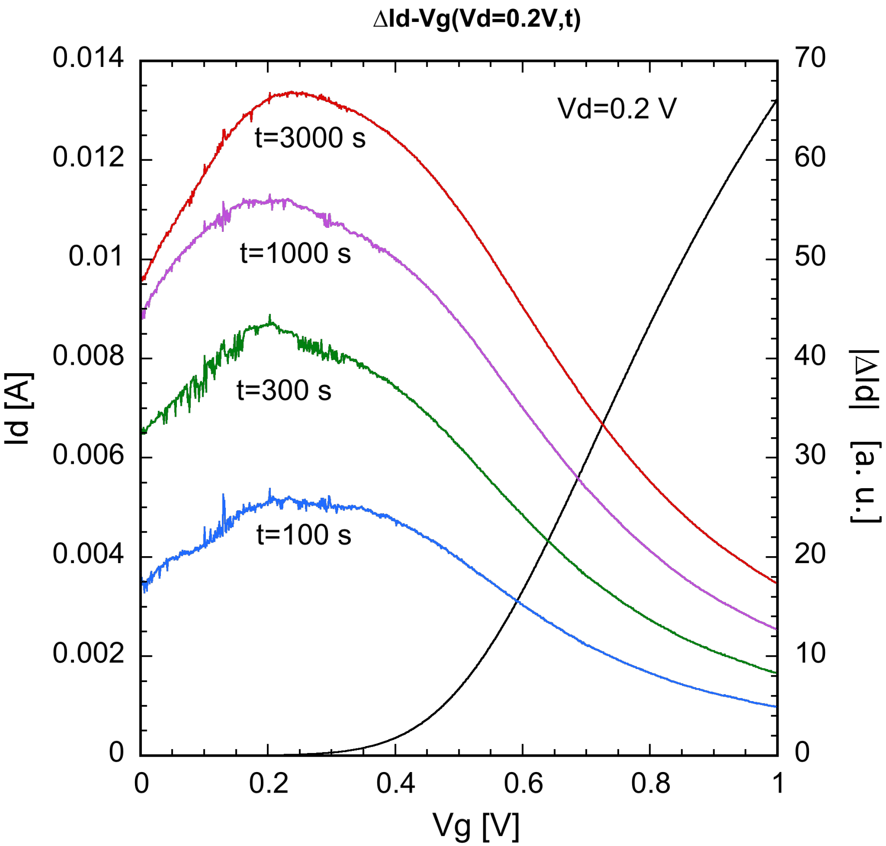
The Id-Vd degraded characteristics

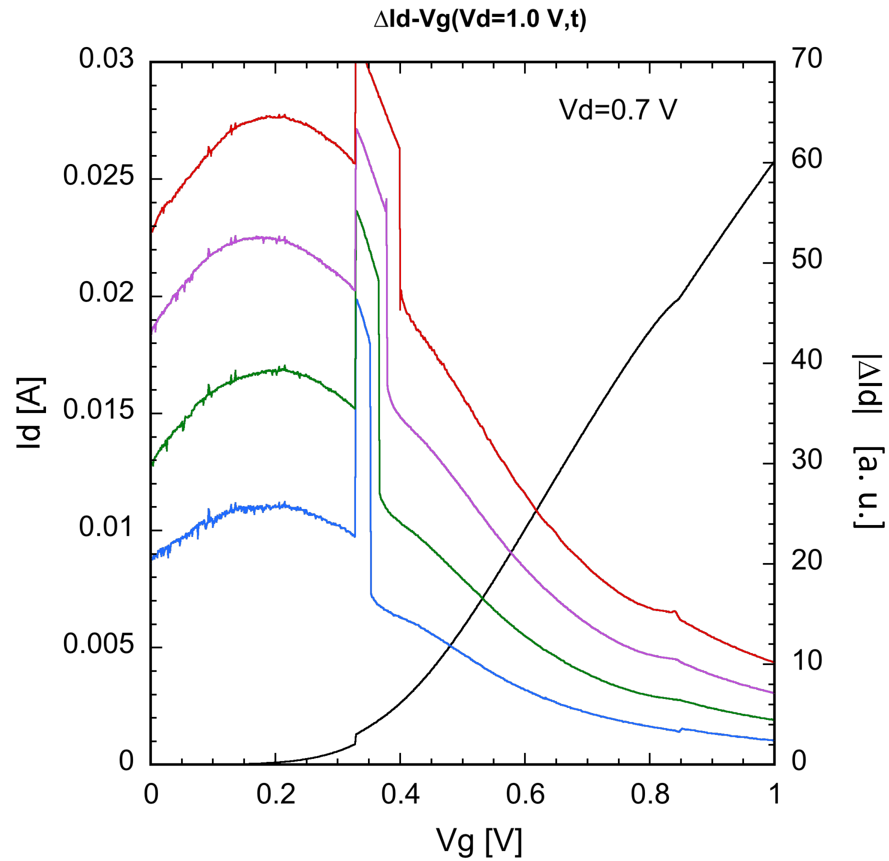
Stress over-bias conditions: Vd=1.6 V, Vg=0.8 V





The Id-Vg degraded characteristics

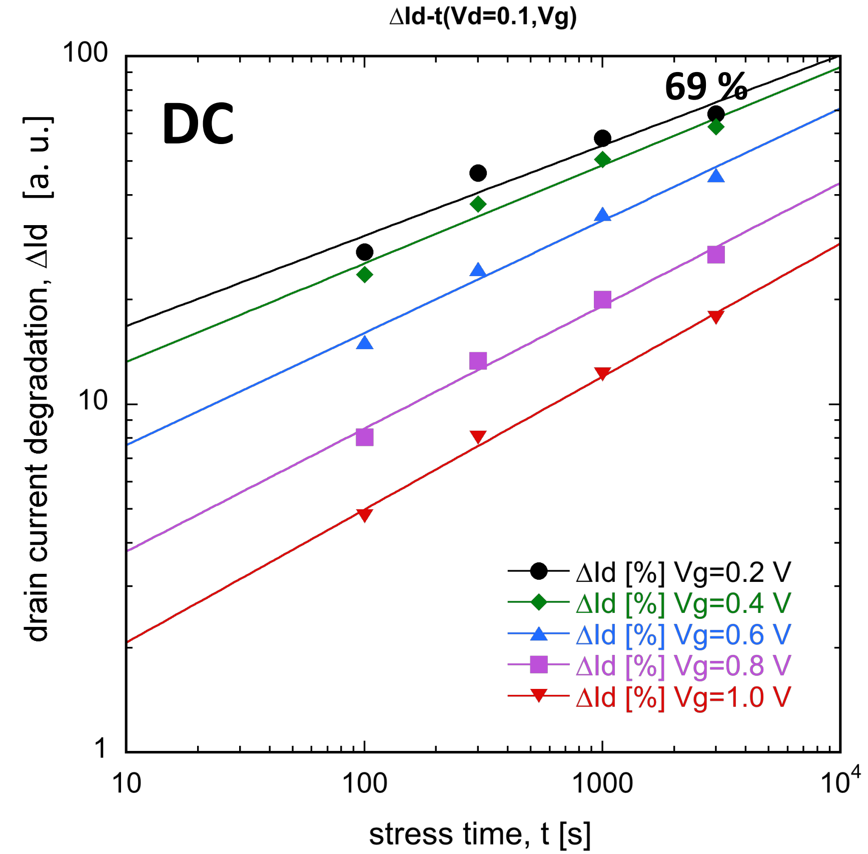


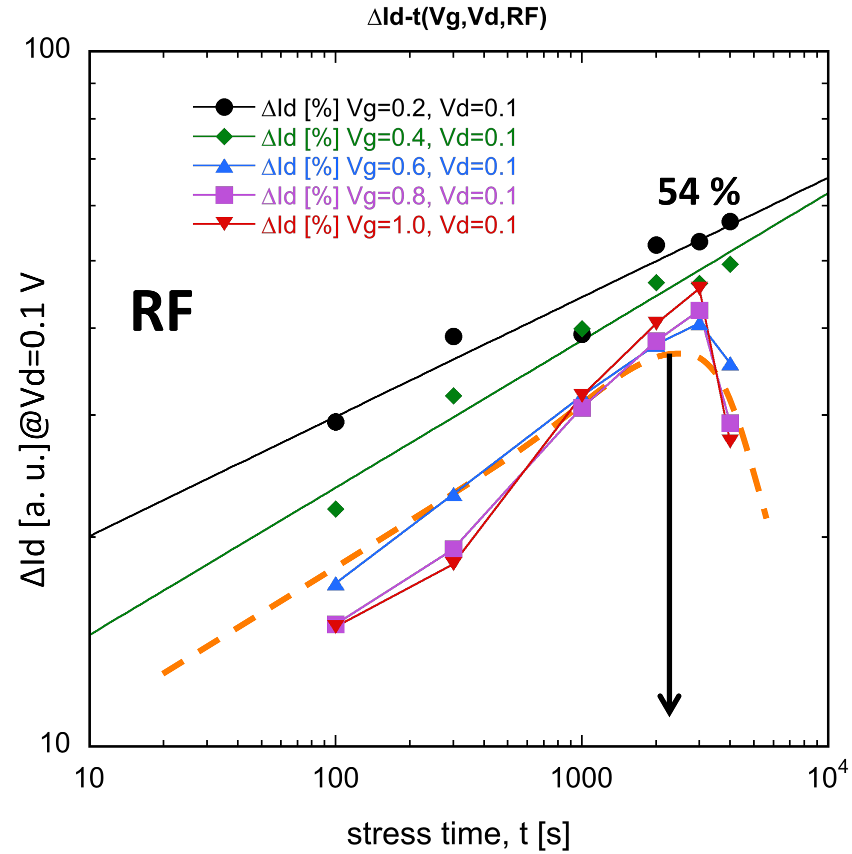


Id degradation: time evolution under DC and RF stress

$\Delta Id = A * t^n$

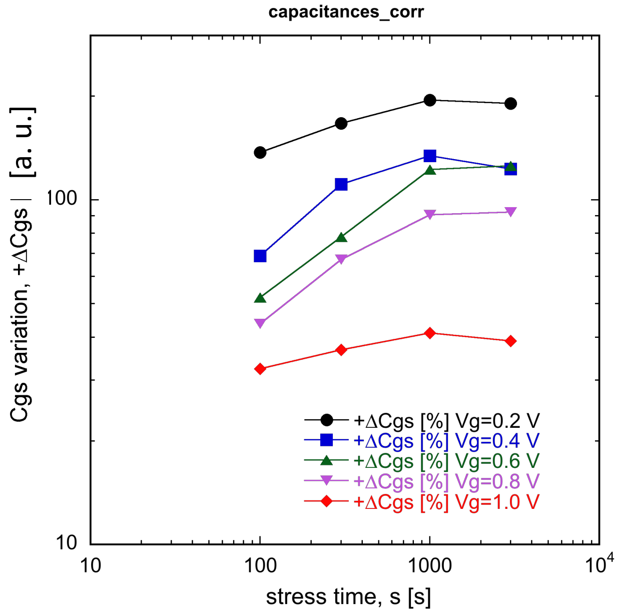
f=28 GHz, Pin=-20 dBm

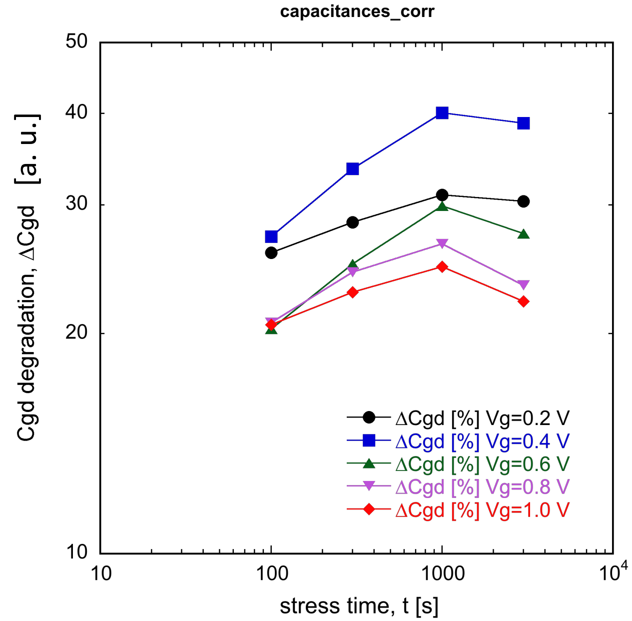


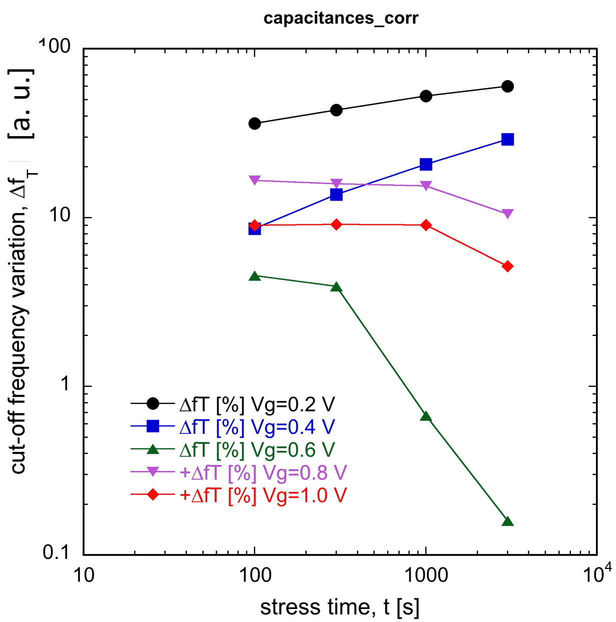


ΔId roll off at t>1000 s under RF stress

RF parameters reliability

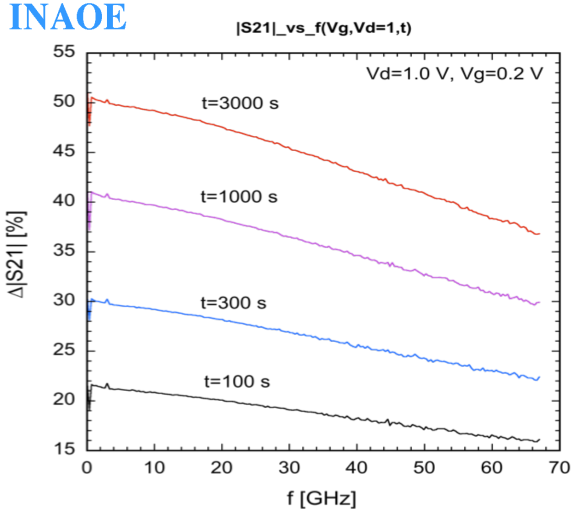


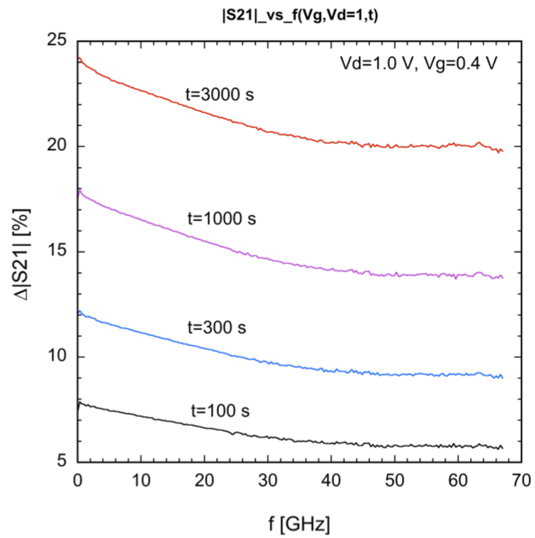


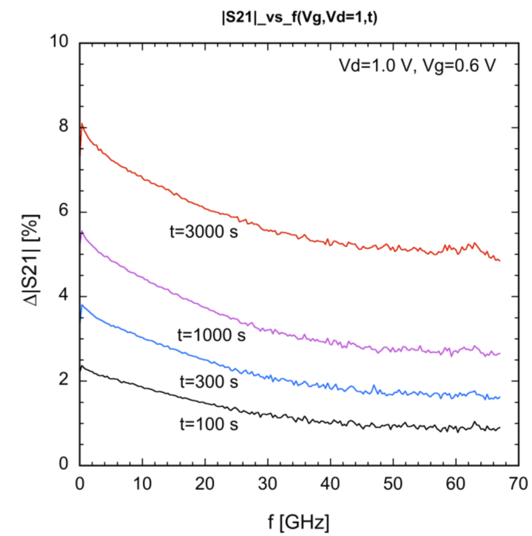


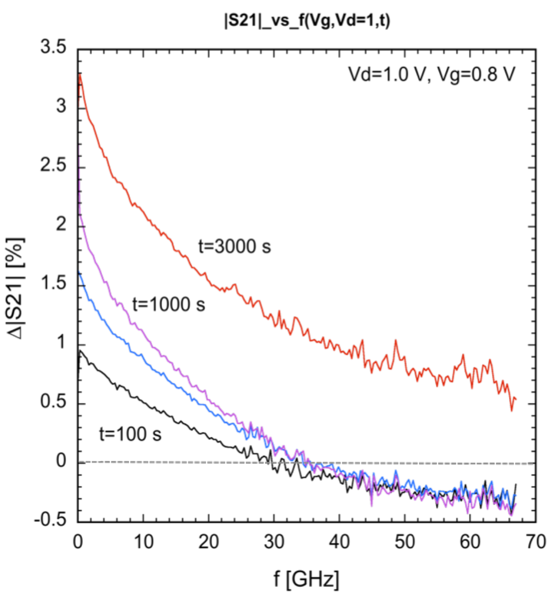
Opportunity:
Big open door for scientific research

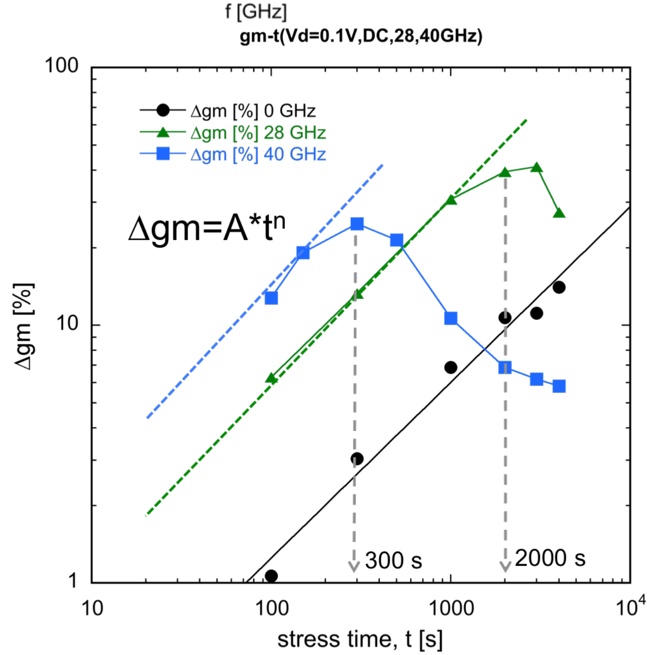
RF S-parameters degradation 10 MHz-67 GHz





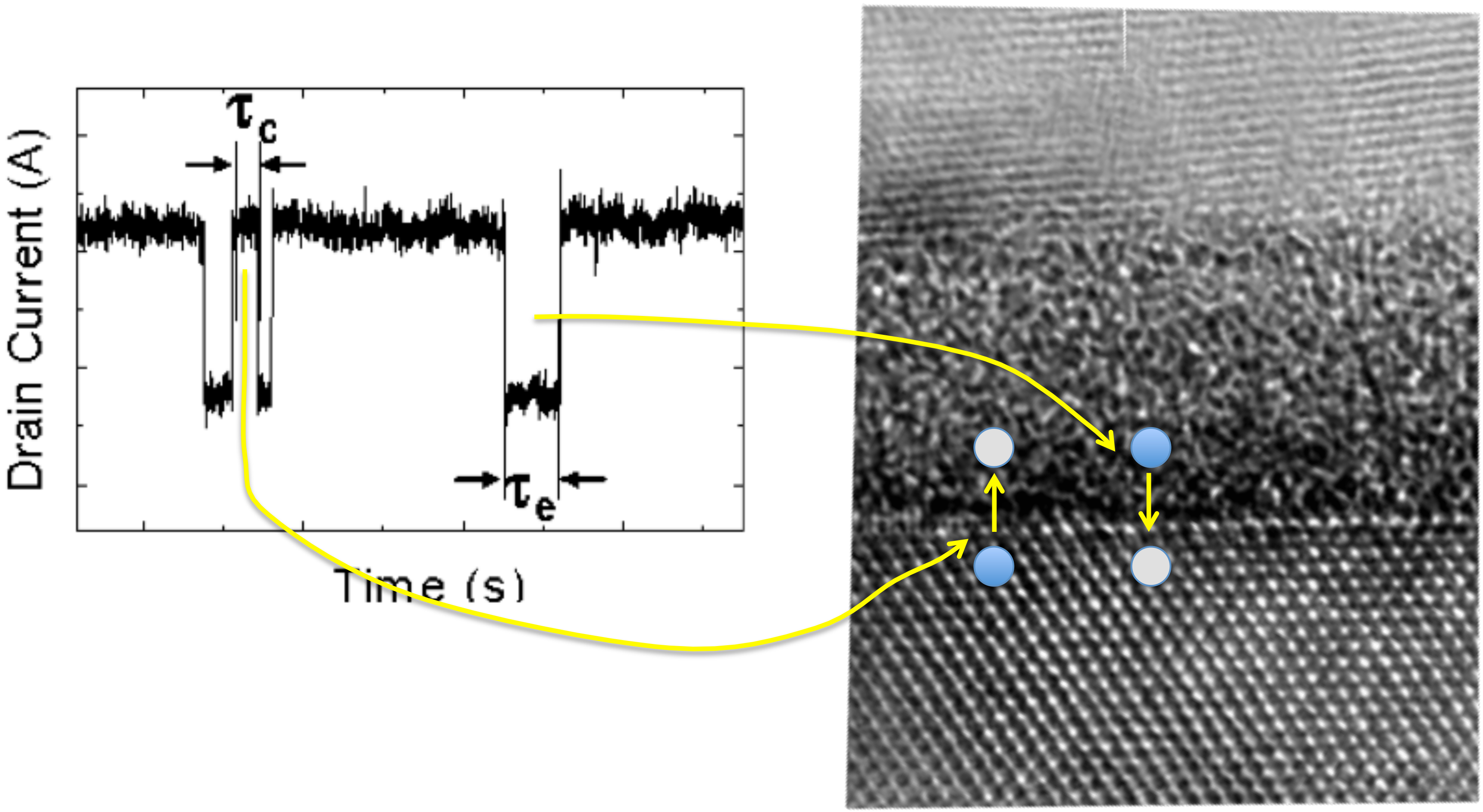




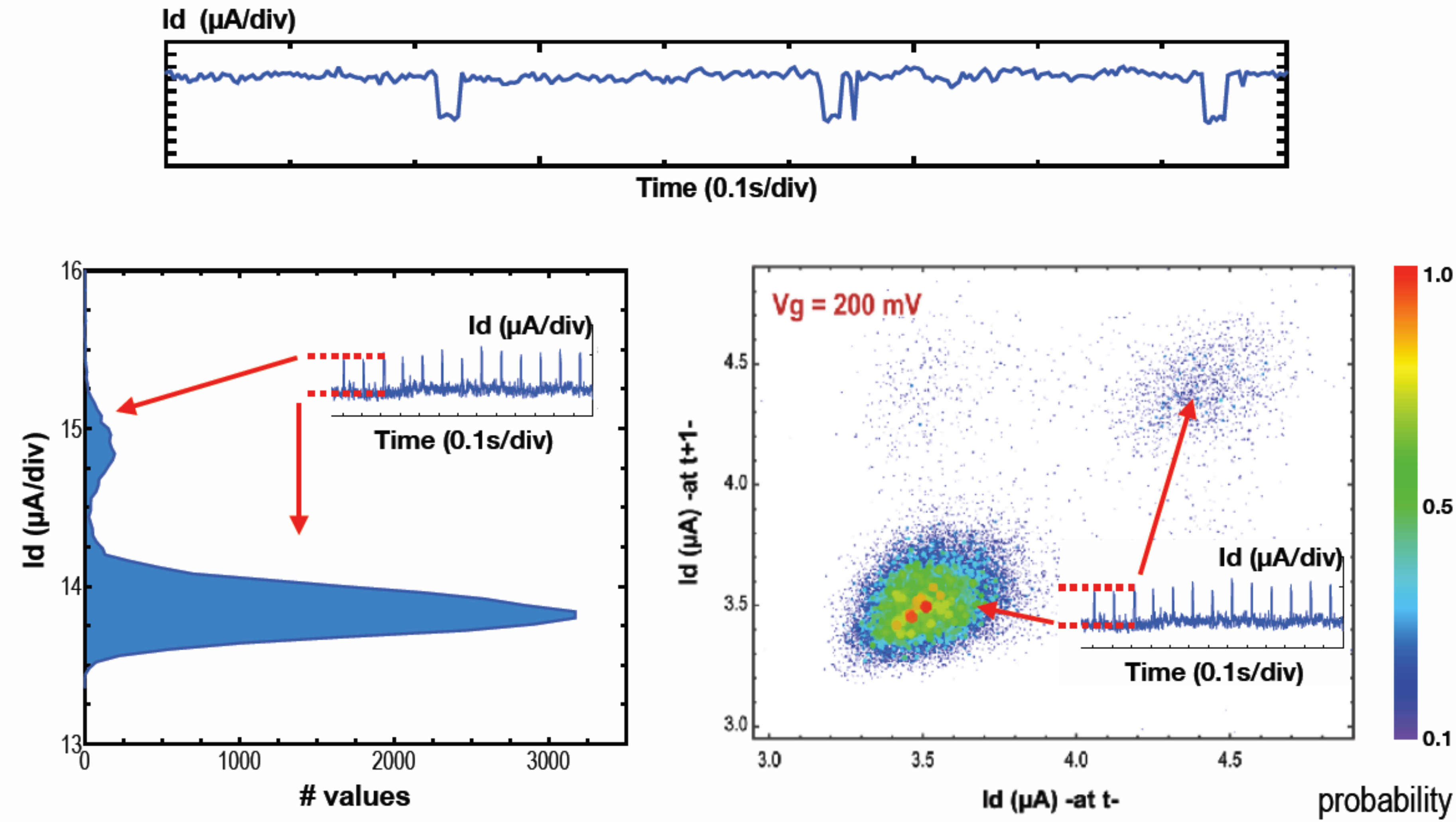


Trap quenching, annihilation, passivation,…?

Capture/emission at the semiconductor-oxide interface
RTN noise

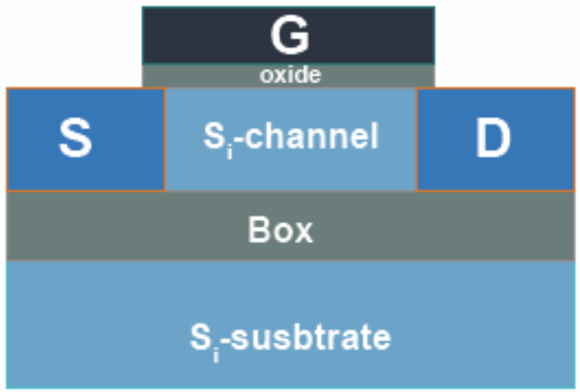


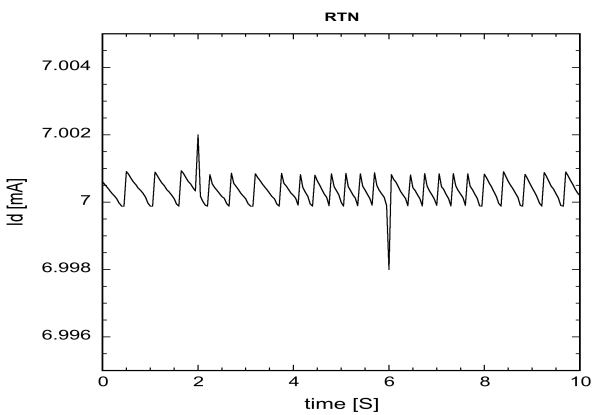
Random Telegraph Noise
RTN



Fresh 45 nm SOI RF device

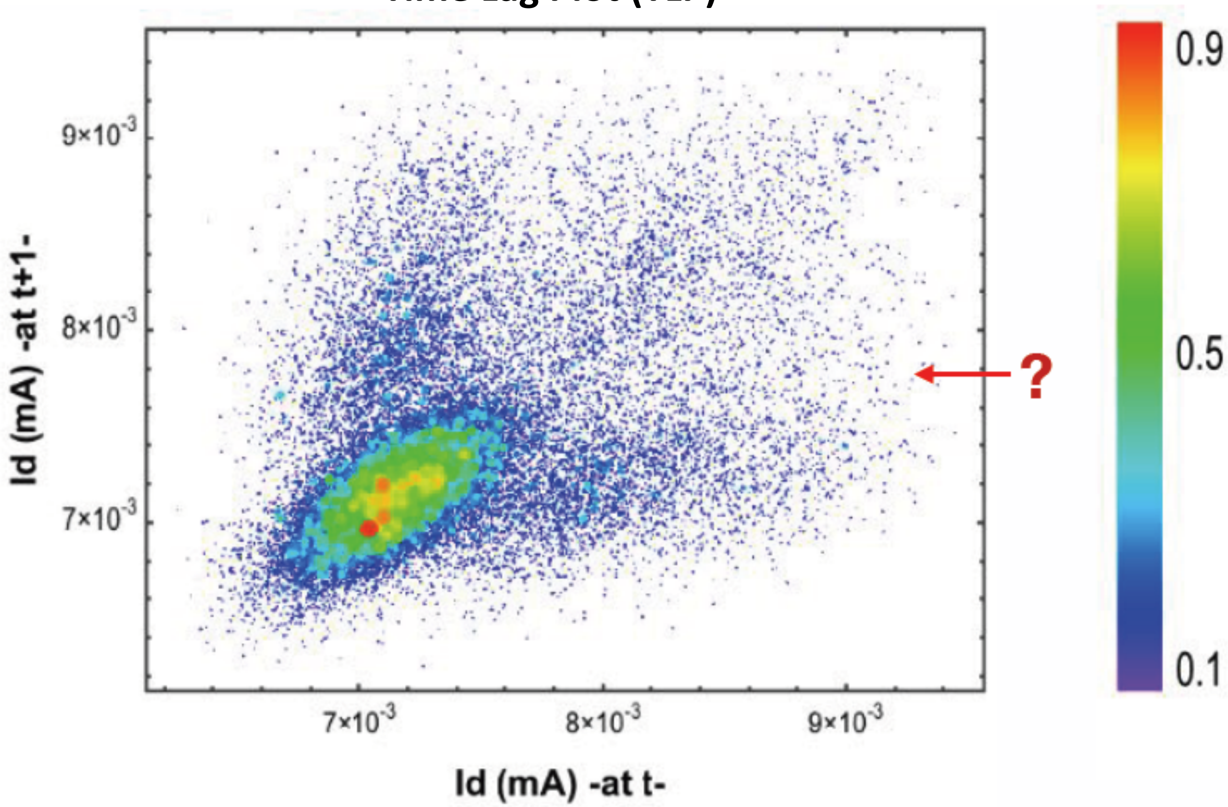
Vd=0.1, Vg=0.25 V, t= 0s



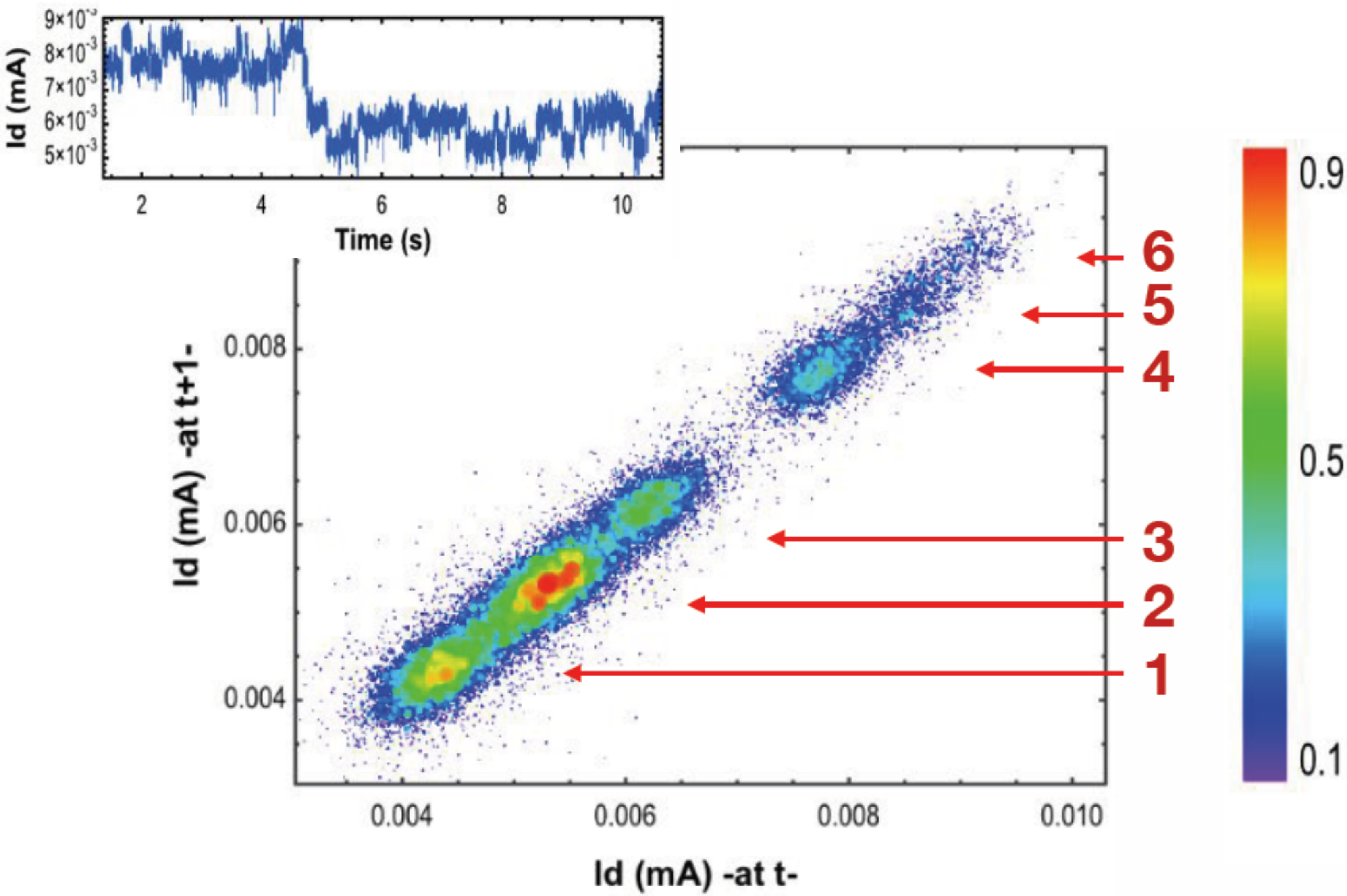


The color scale indicates the probability to find a current level in time.

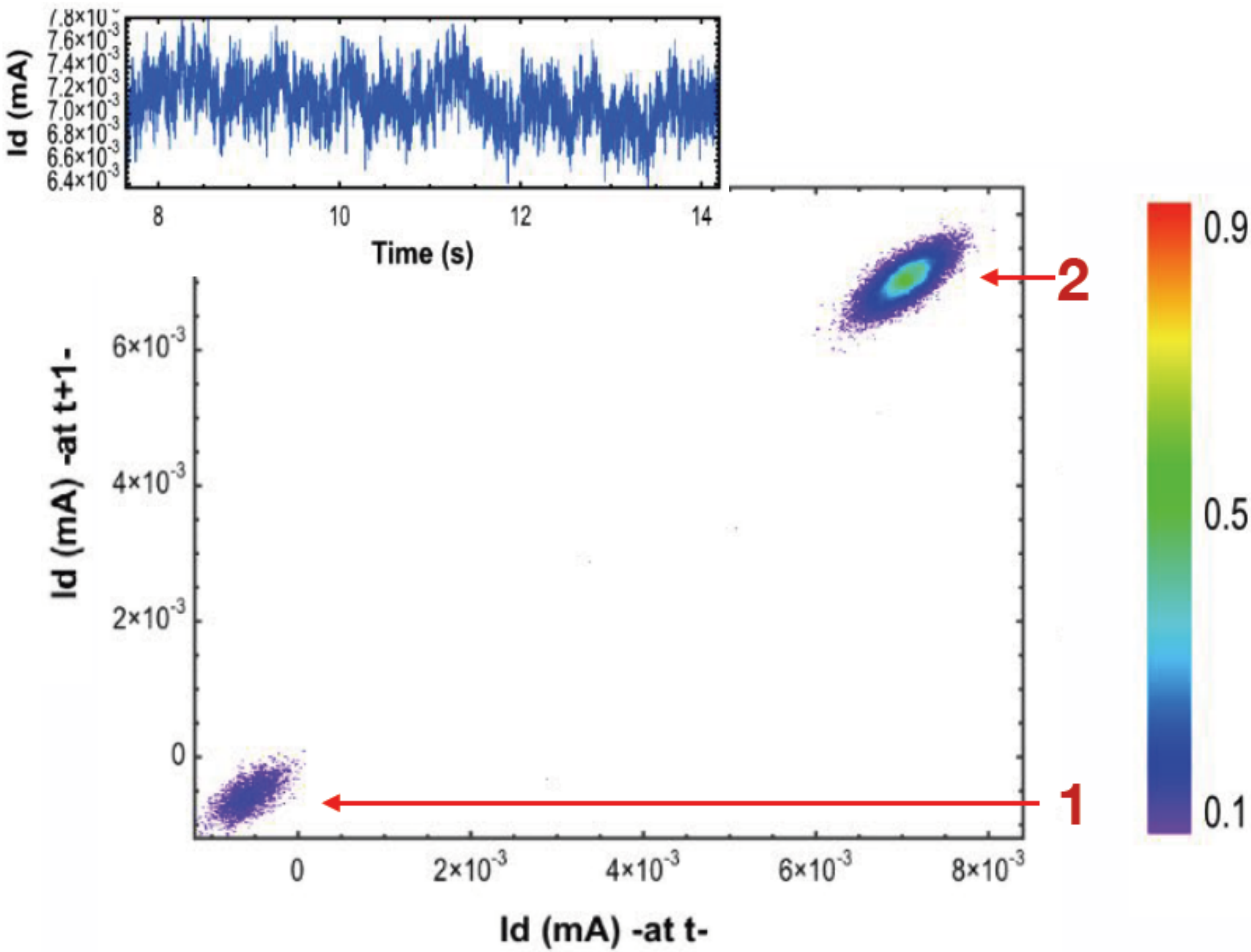
Time Lag Plot (TLP)



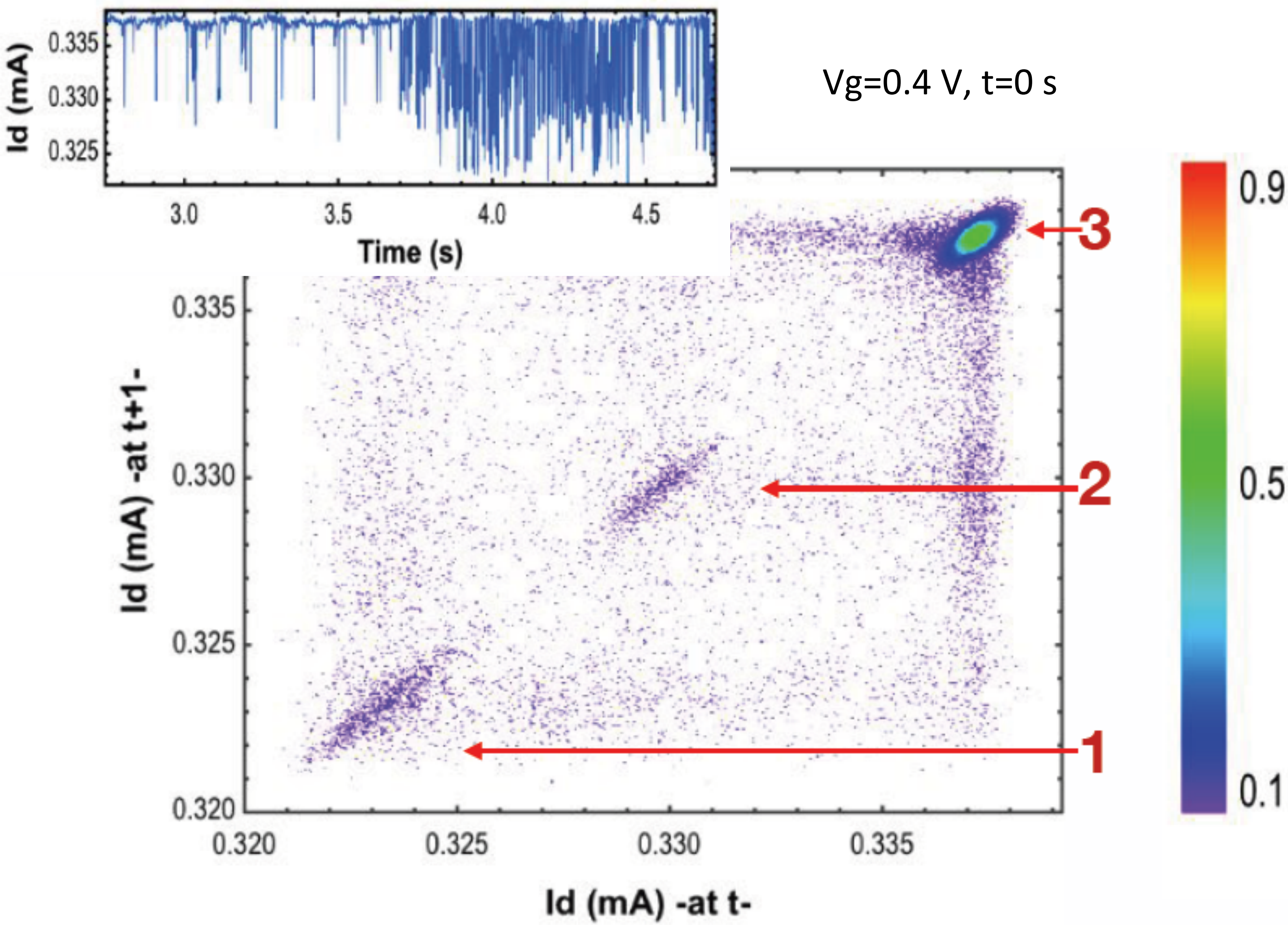
60 s stressed 45 nm SOI RF device



160 s stressed 45 nm SOI RF device



Fresh 45 nm SOI RF device



60 s stressed 45 nm SOI RF device

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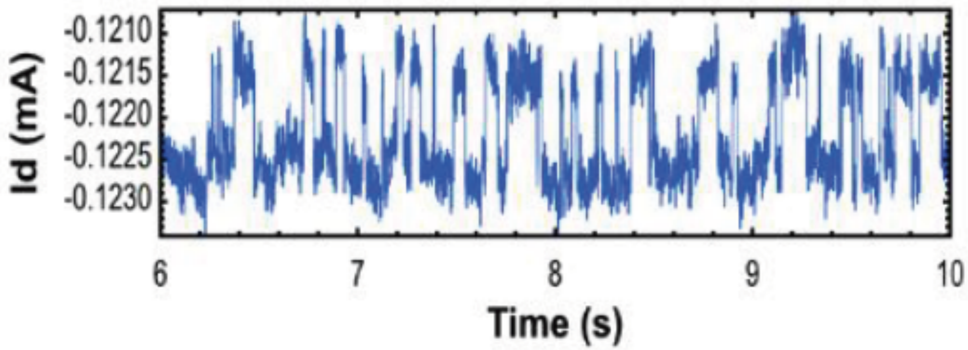
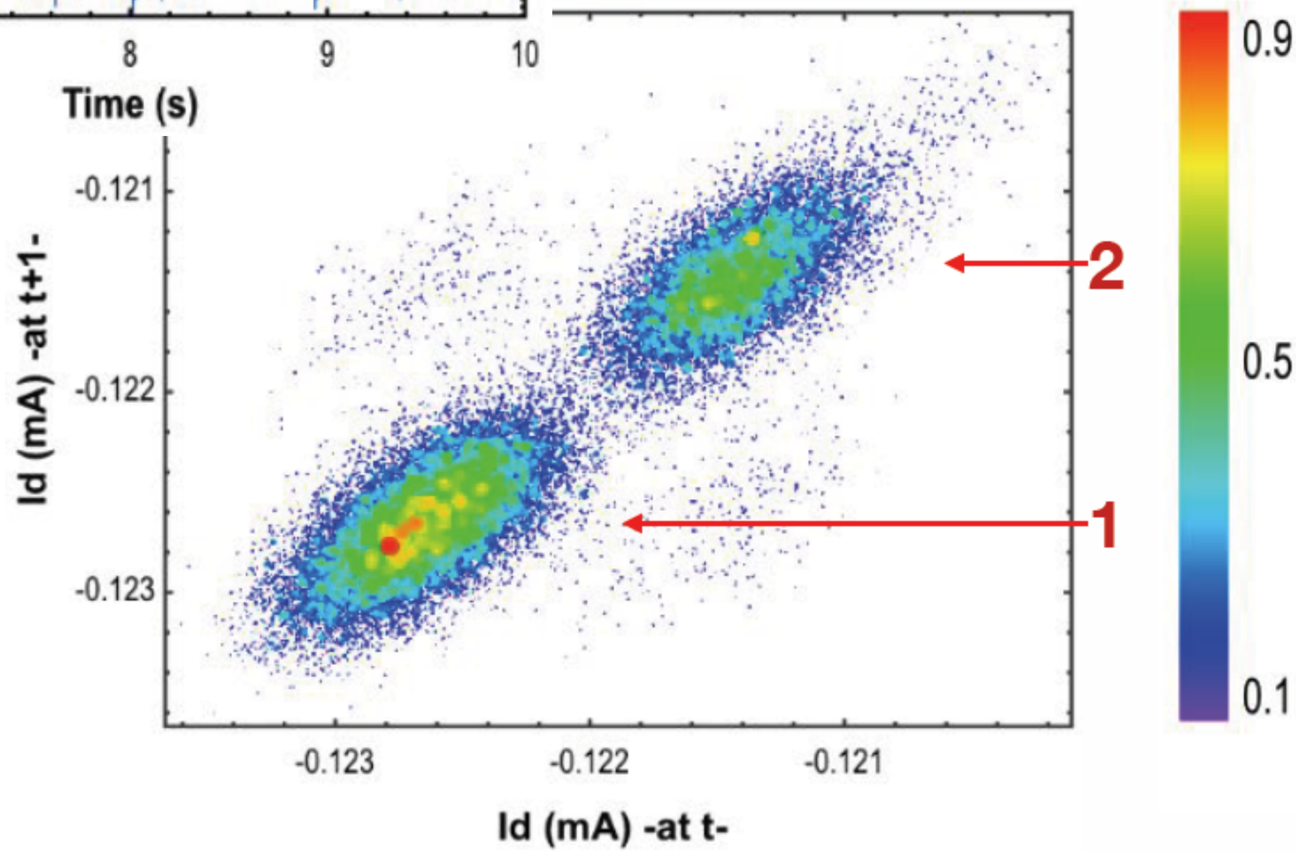
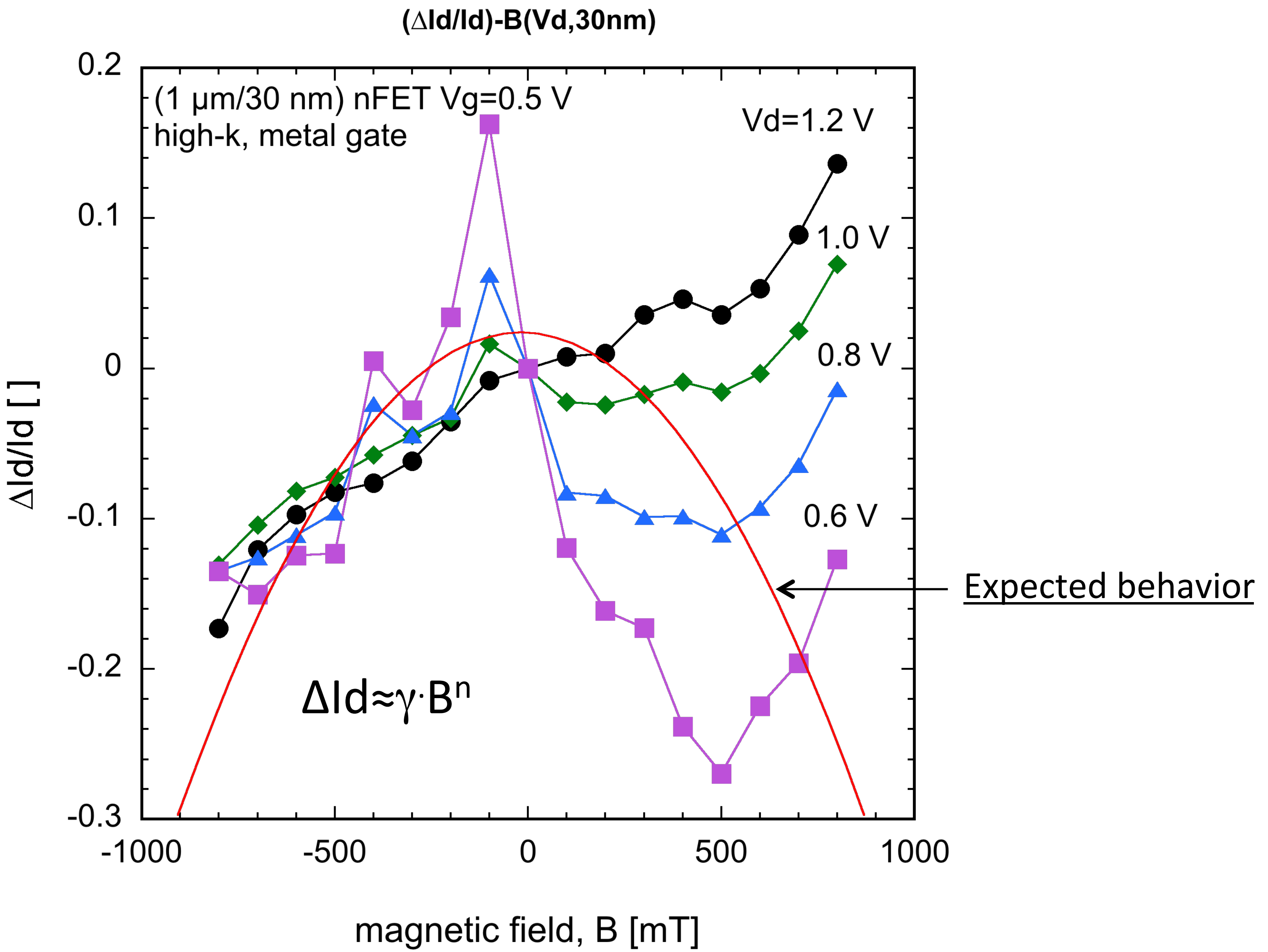
Vg=0.4 V

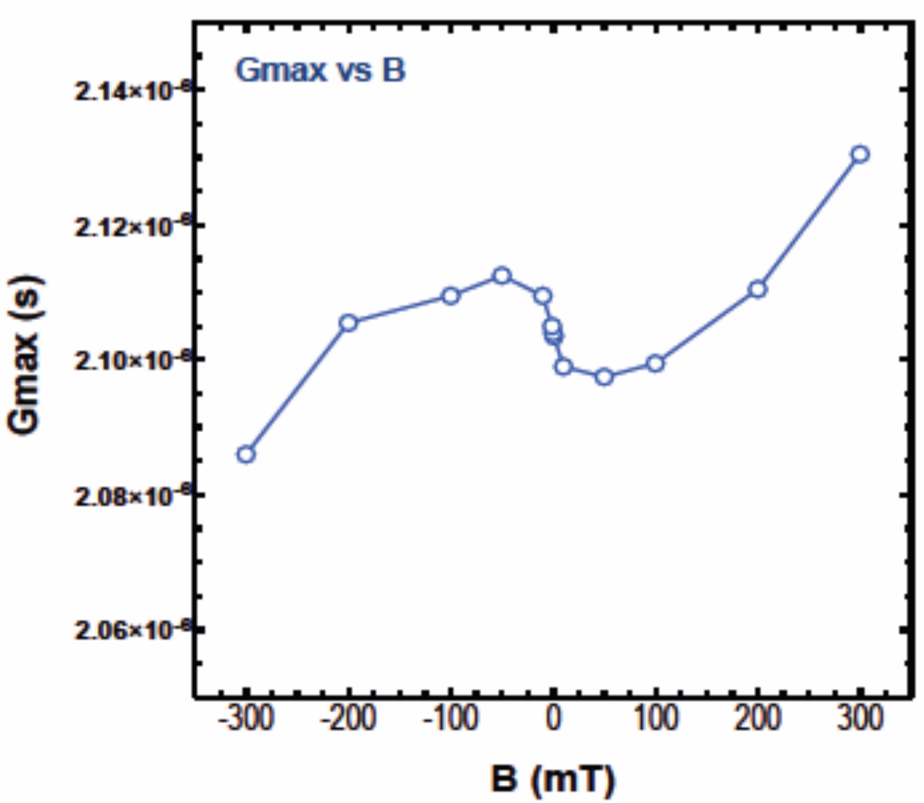


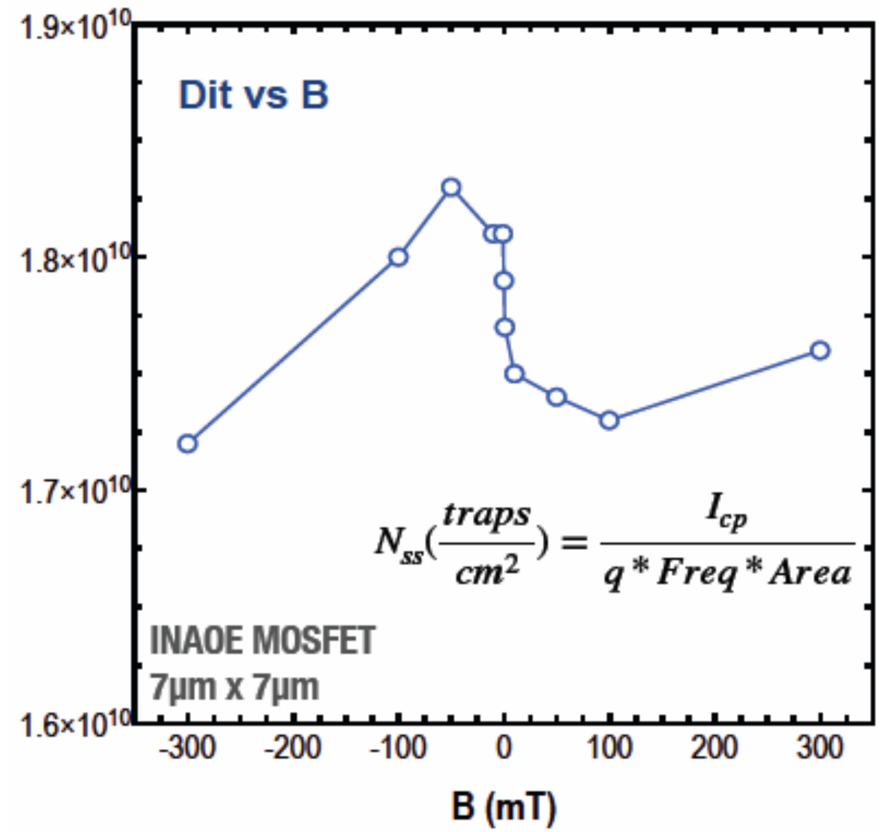


Sensing a magnetic field with a FET device at the Si-oxide interface



Asymmetric magneto-behavior of MOSFETs





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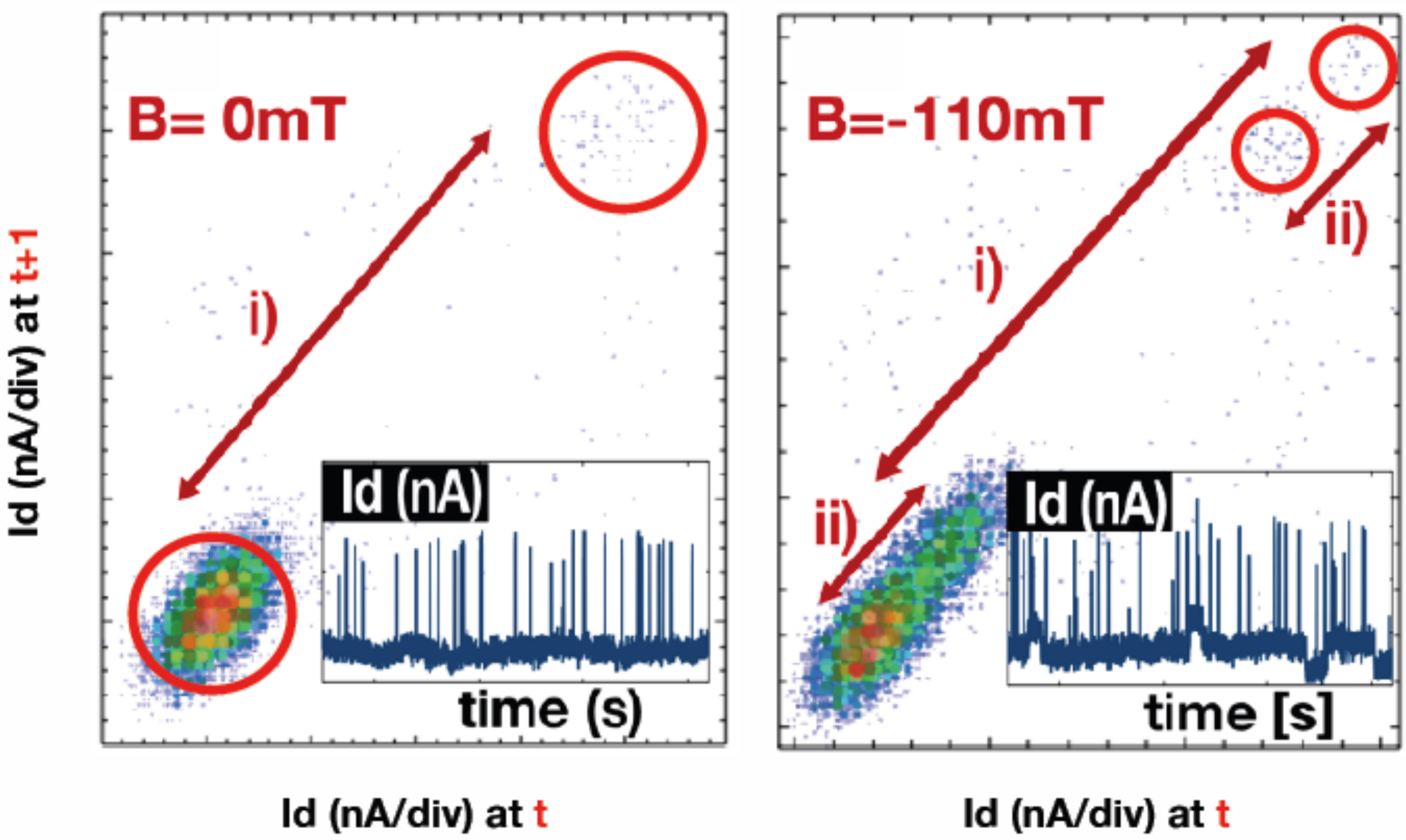
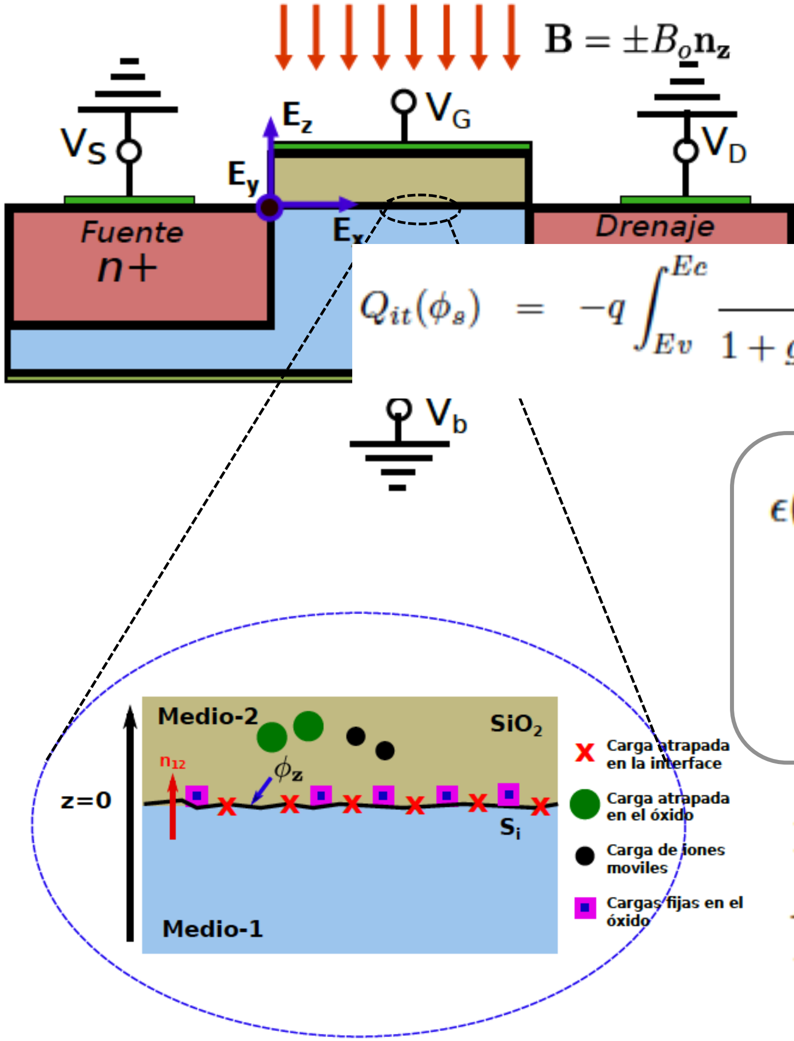
How the capture/emission is affected by a B field?



Other energy levels (ii) activates?

$$\frac{\tau_c}{\tau_e} \propto exp(\frac{E_T - E_F}{k_B T})$$

Fundamental research Schrödinger-Poisson with B field and energy traps included.



$$Q_{total} = Q_s(\phi_z) + Q_{it}(\phi_z) + Q_{ox}.$$

$$-\epsilon_{si}\epsilon_0 \frac{d\phi_{si}}{dz}|_{z=0^-} + \epsilon_{ox}\epsilon_0 \frac{d\phi_{ox}}{dz}|_{z=0^+} = Q_s + Q_{it} + Q_{ox},$$

$$Q_{it}(\phi_s) = -q\int_{Ev}^{Ec} \frac{D_{it}^a(E_a)dE_a}{1 + g_a \times \exp\left[\frac{E_a-(q\phi_s-E_F)}{kT}\right]} + q\int_{Ev}^{Ec} \frac{D_{it}^d(E_d)dE_d}{1 + g_d \times \exp\left[\frac{(q\phi_s-E_F)-E_d}{kT}\right]},$$

$$\epsilon(z)\frac{d^2\phi(z)}{dz^2} = q\left[N_D - n + p - N_A\right] - \frac{\epsilon(z)}{dz}\frac{d\phi(z)}{dz},$$

+

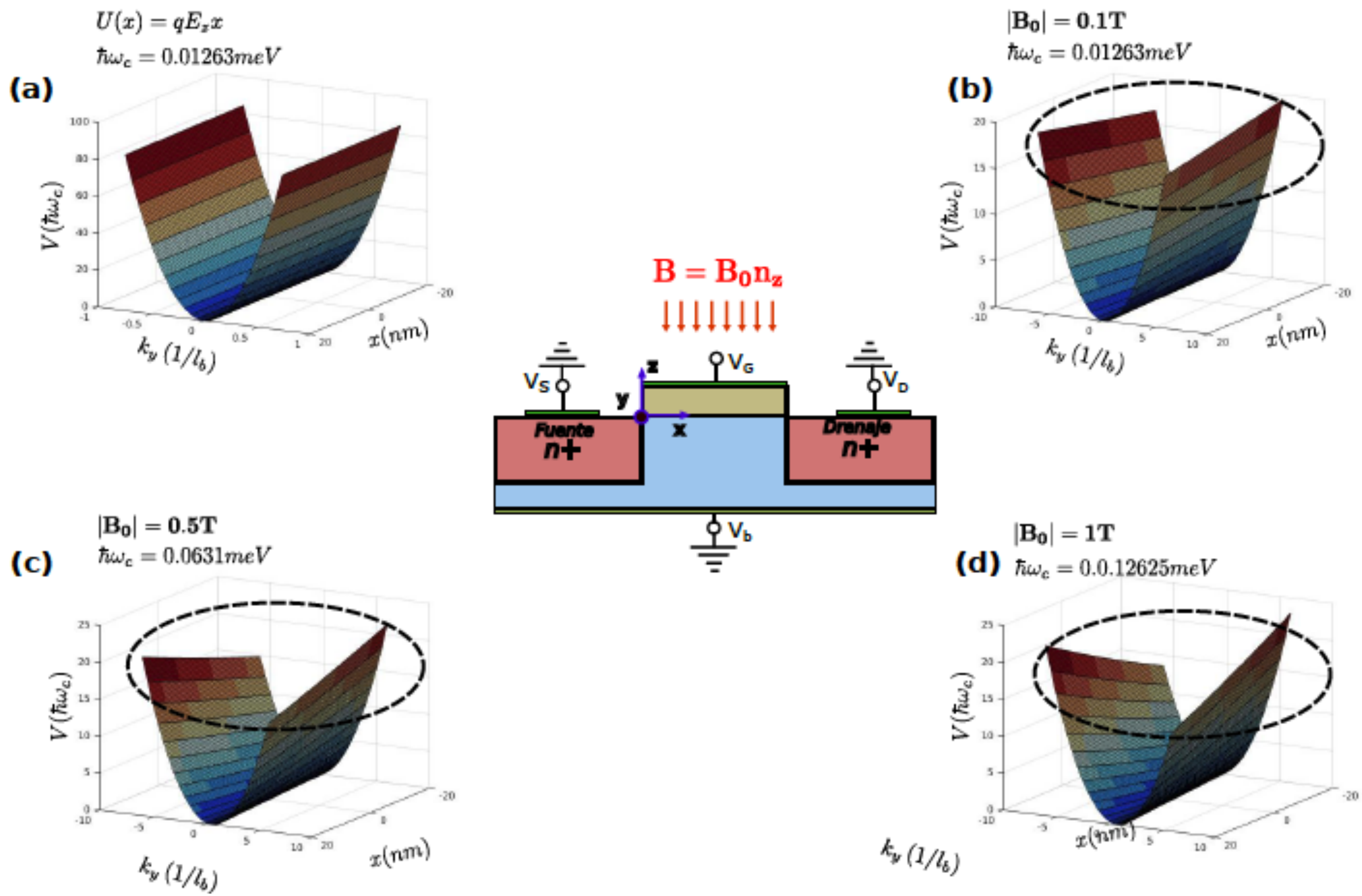
$$H^T = \frac{1}{2m}\left[\mathbf{p} - q\mathbf{A}(\mathbf{r})\right] + V(\mathbf{r}),$$

$\mathbf{p} = -i\hbar\nabla$:momentum operator

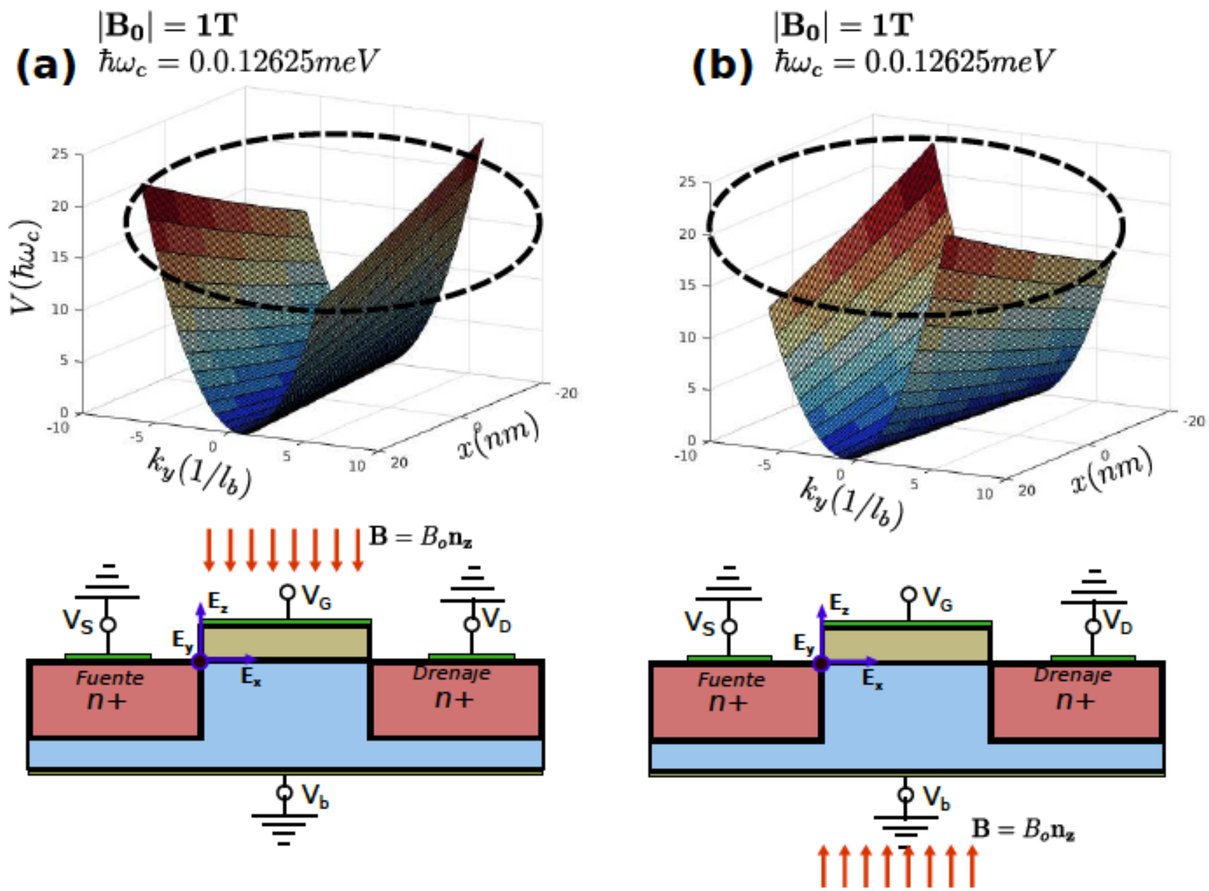
$\mathbf{A}(\mathbf{r})$: magnetic field potential vector; $\mathbf{B} = \nabla \times \mathbf{A}(\mathbf{r})$

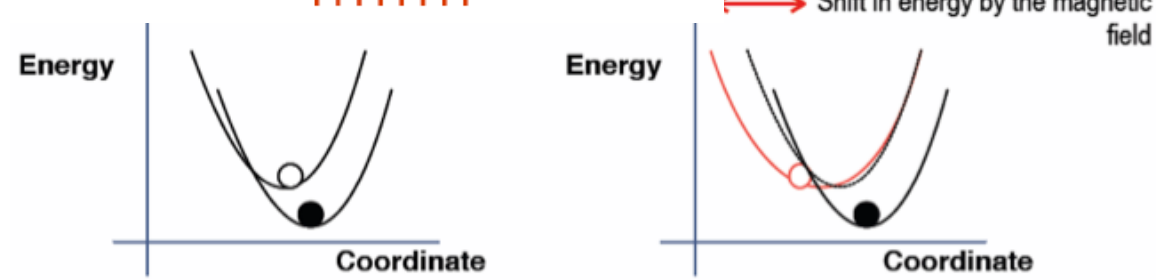
$V(\mathbf{r}) = -q\mathbf{E}\cdot\mathbf{r}$: potential energy experienced by the e⁻

Numerical calculations with B field included.

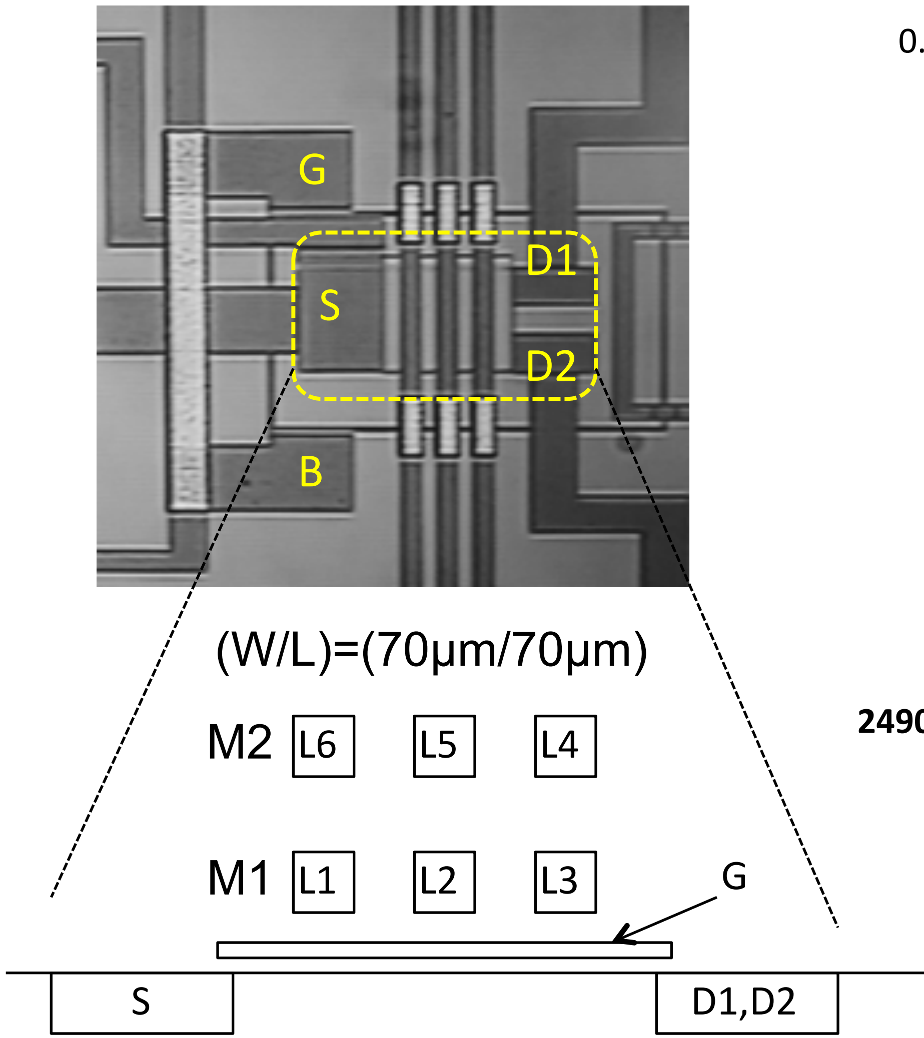


Fundamental research Schrödinger-Poisson with B field and energy traps included.

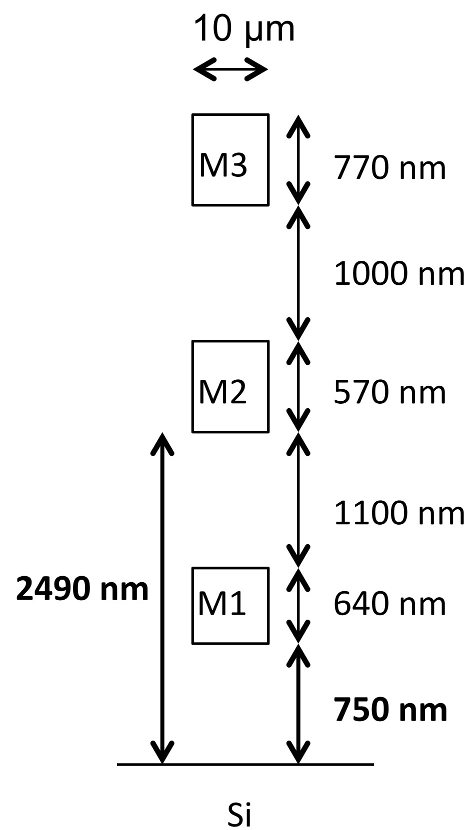




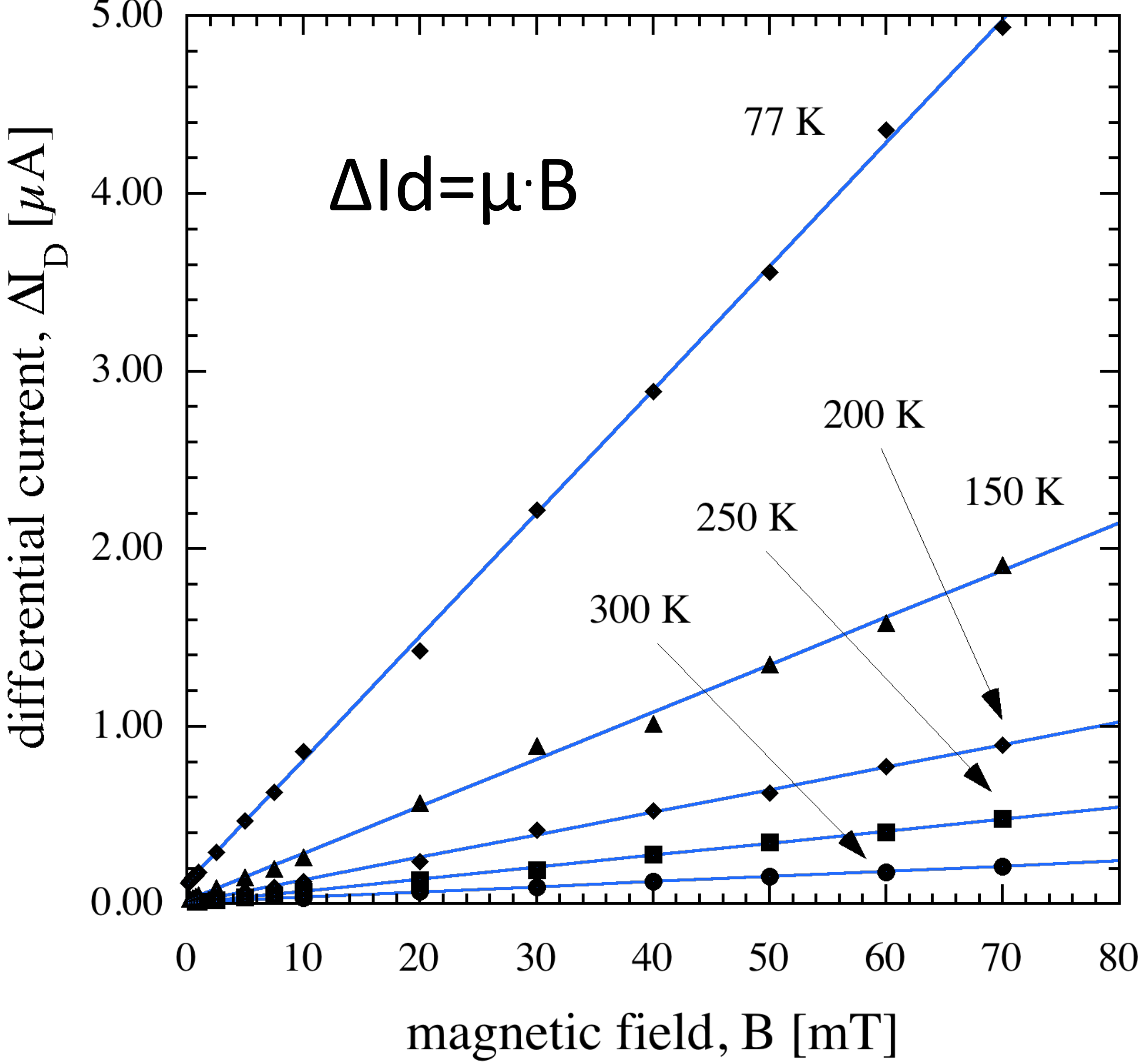
Integrated magnetic sensor MAGFET



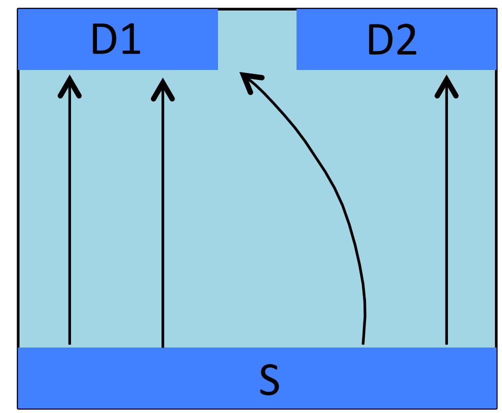
0.6 µm technology
3 metal layers



Magnetic sensor MAGFET behavior as a function of temperature



ΔId=|Id1=Id2|

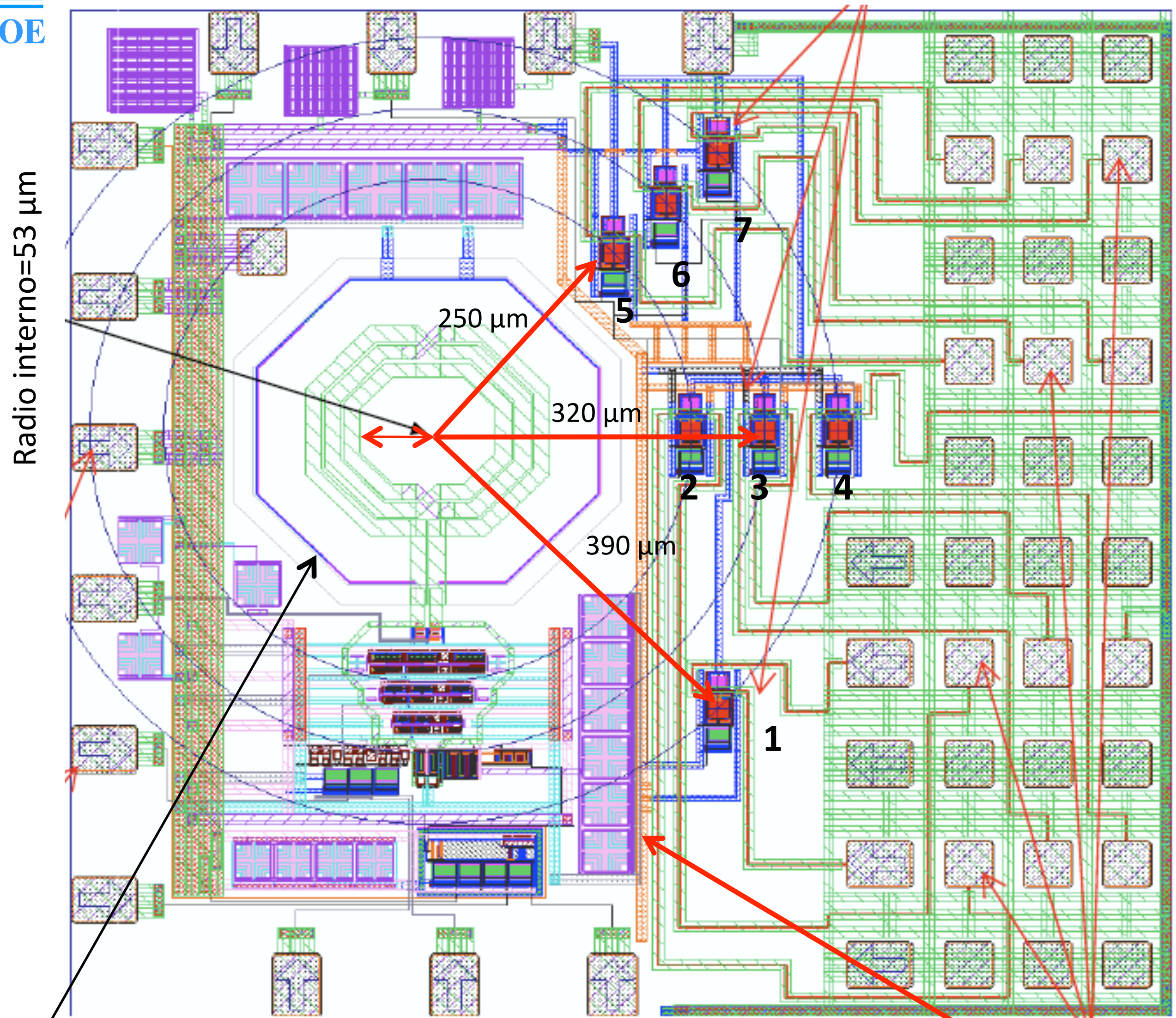


MAGFET on-chip for frequency monitoring

5.25 GHz VCO 90nm test chip

Autoinducción de la bobina = 2.0 nH, Q=22

Sensores magnéticos



3 vueltas con un ancho de línea de 15 µm en el nivel 9 con un radio interno de 53 µm, lo que da aproximadamente un radio externo de 98 µm.

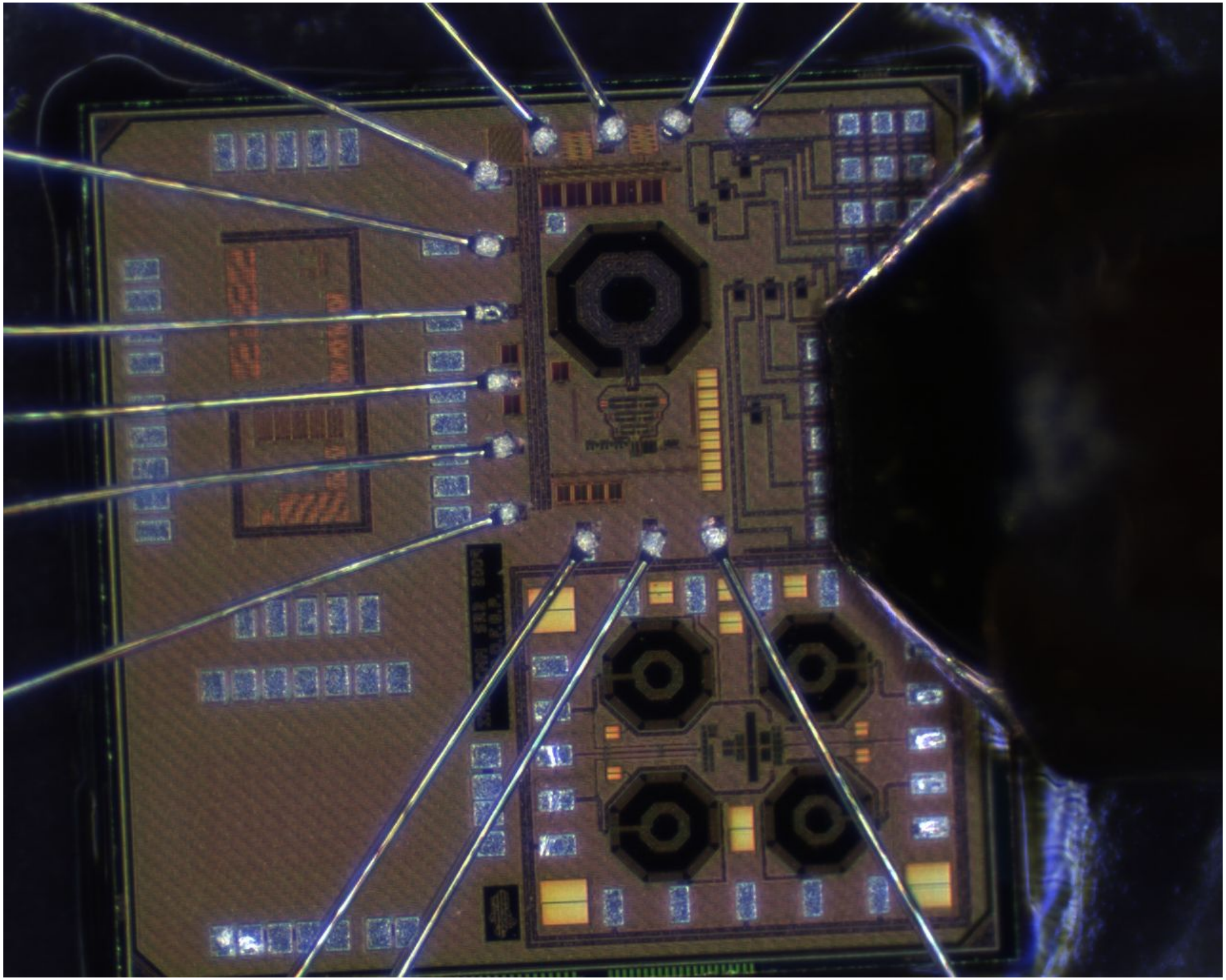
La corriente en la espira depende del estado de polarización del VCO, la nominal es una corriente aproximadamente sinusoidal de unos 12mA pico-pico de amplitud. Para el mínimo consumo del VCO es de unos 4mA pico-pico y para el máximo de unos 20mA pico-pico.

In collaboration with the University of Seville, Spain.

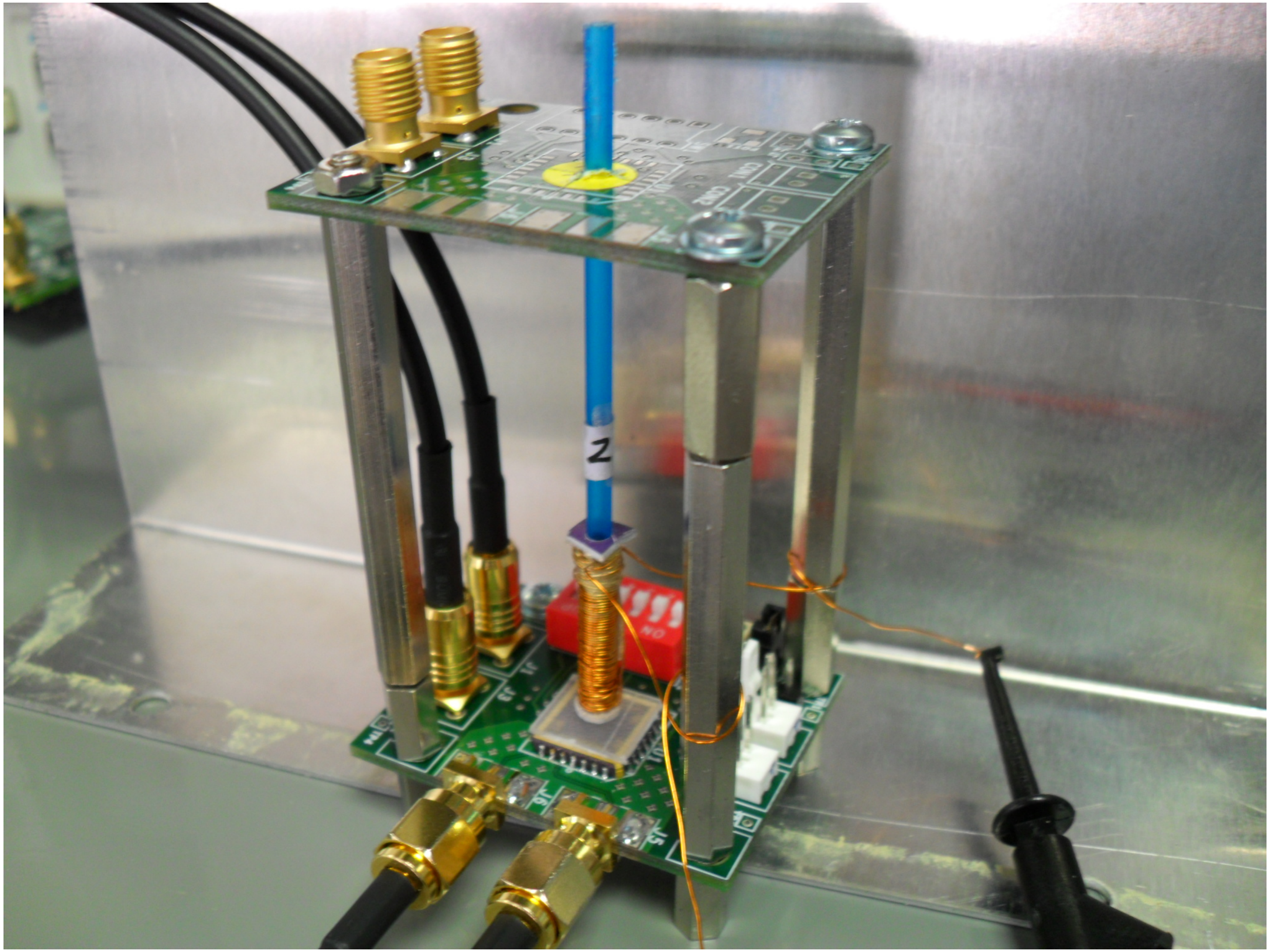
Paredes metálicas verticales desde el nivel 9 hasta el nivel 1 de metal

Barrera metálica en nivel 1

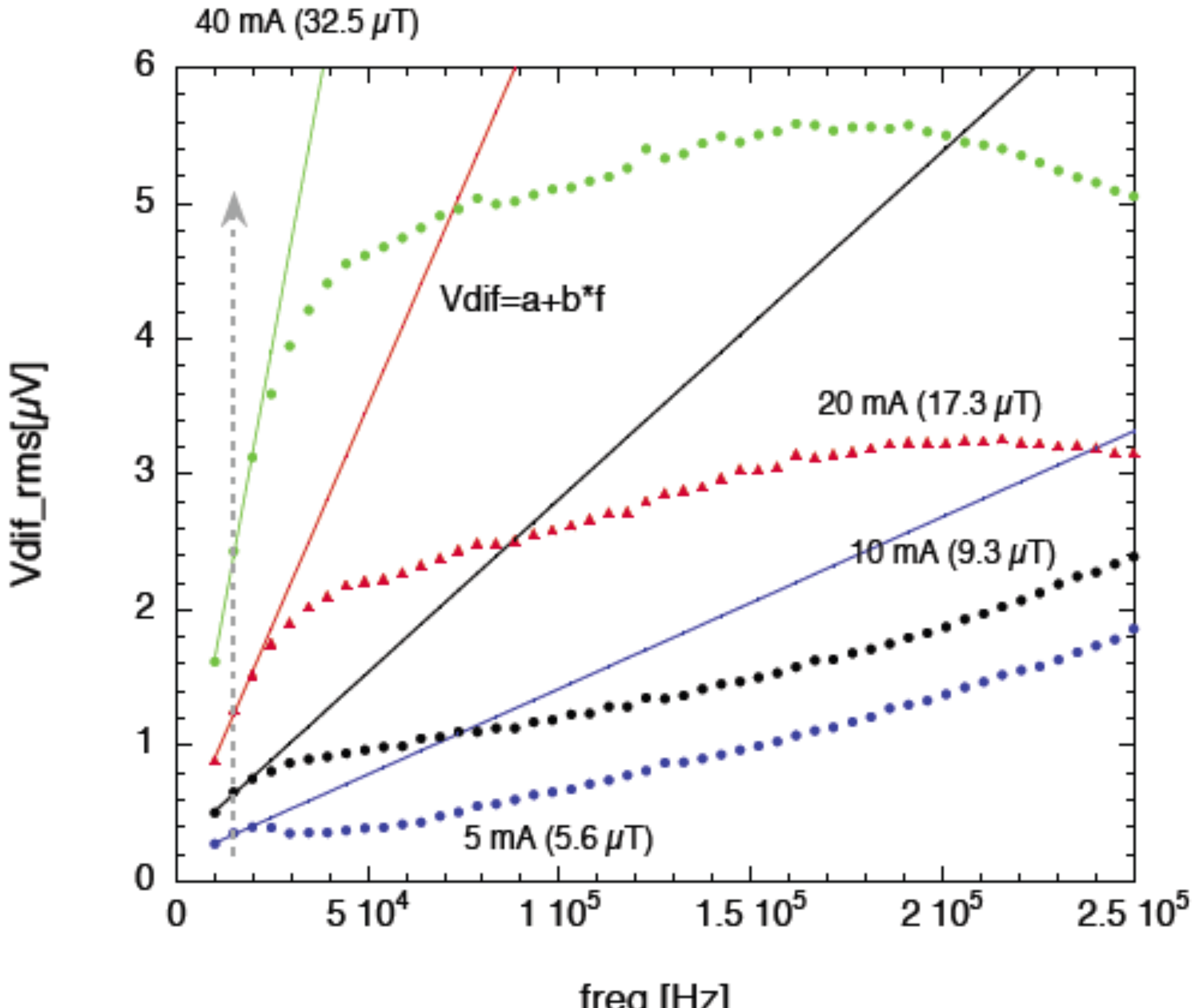
On-chip electro-magnetic testing at 5.25 GHz



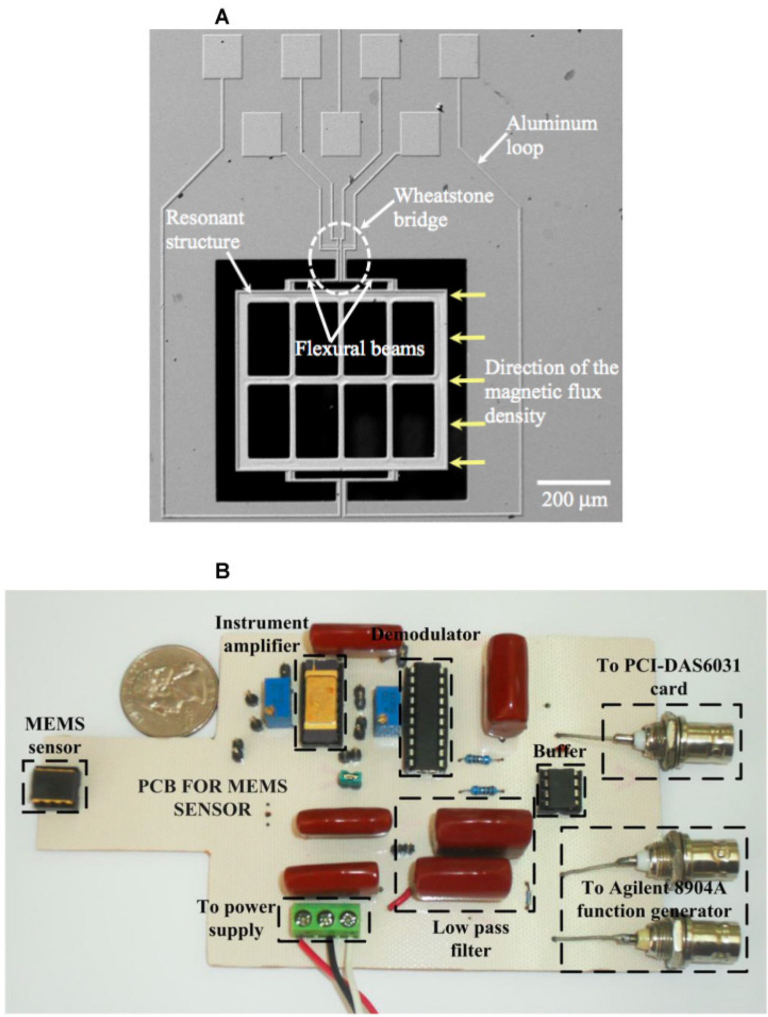
MAGFET calibration with an external coil

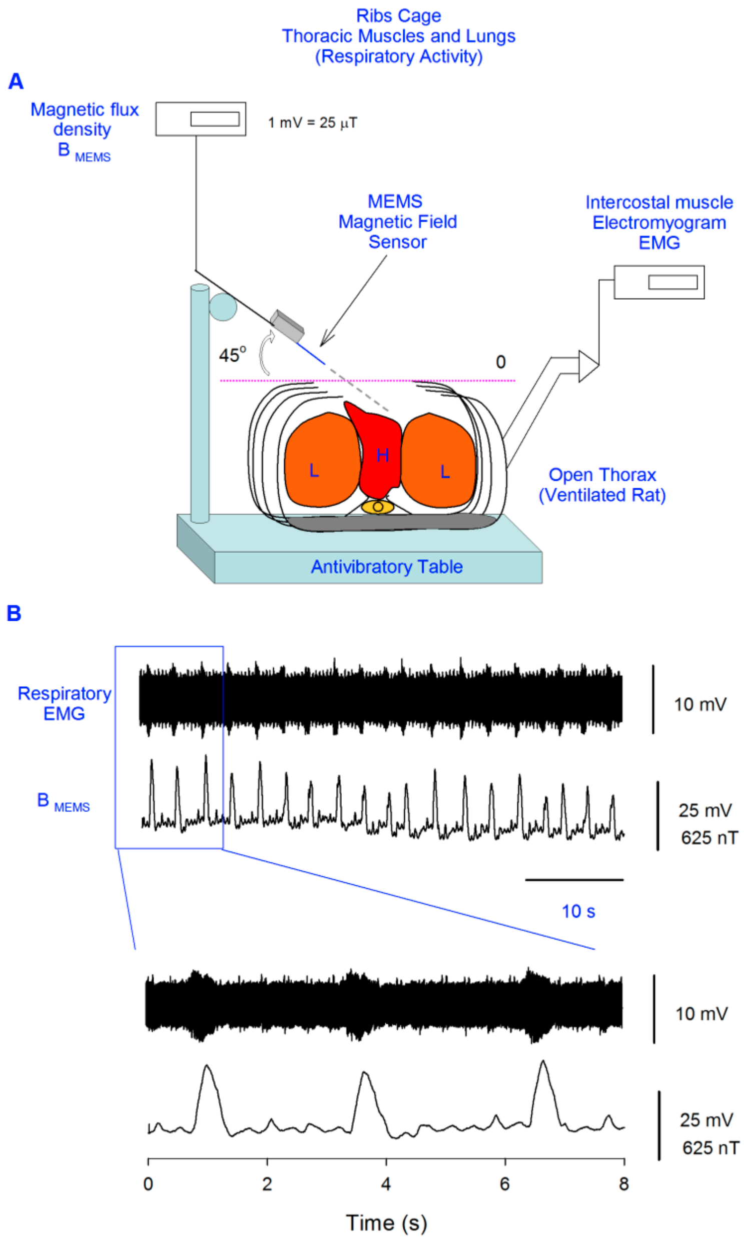


Experimental results of the on-chip B field sensing



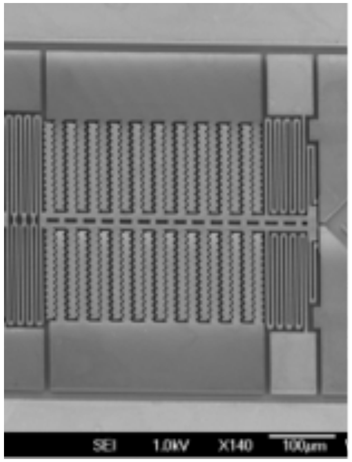
Cardiac and respiratory magnetograph

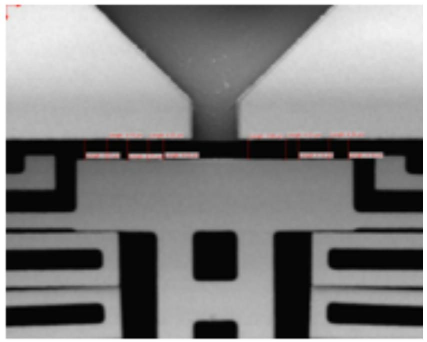


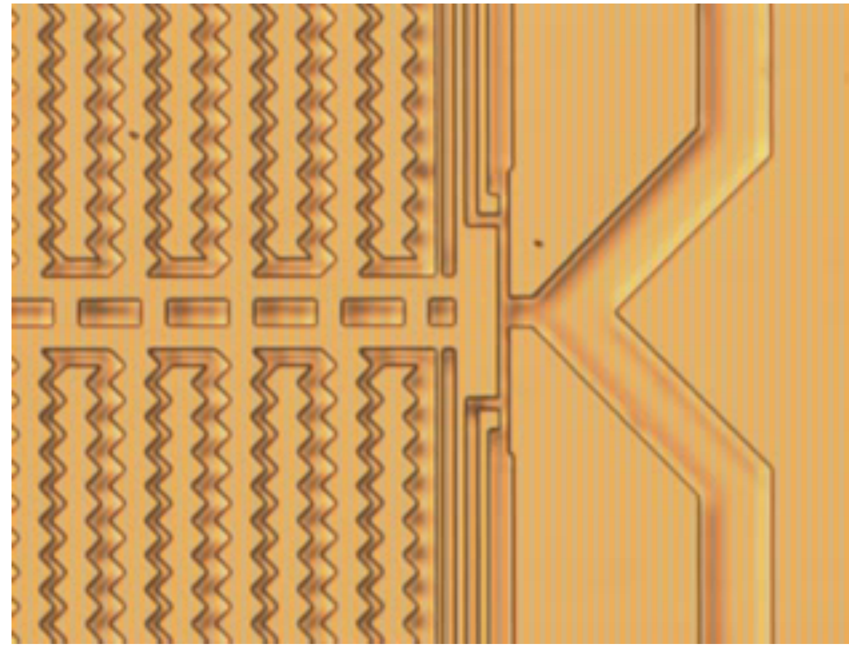


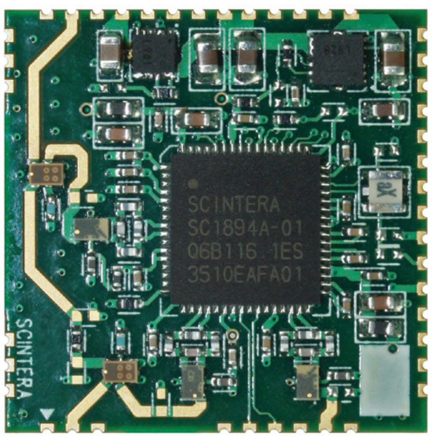
INAOE MEM's-based RF switch design and fabrication

A joint INAOE-Team Technologies, Inc. $ 10 million USD MEMs-based RF switch.









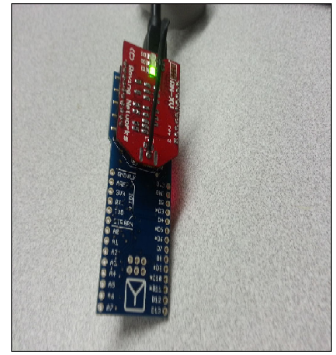
RF power amplifier for small celluar base stations

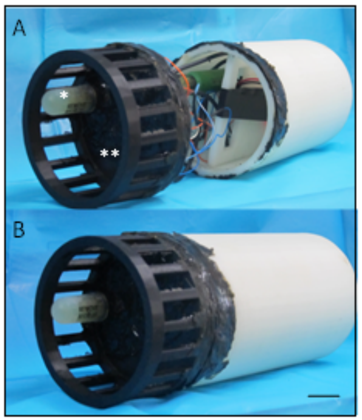
Contacto: Alfonso Torres, atorres@inaoep.mx

INAOE develops the full fabrication process and will do the 10 GHZ characterization, de-embedding and modeling.

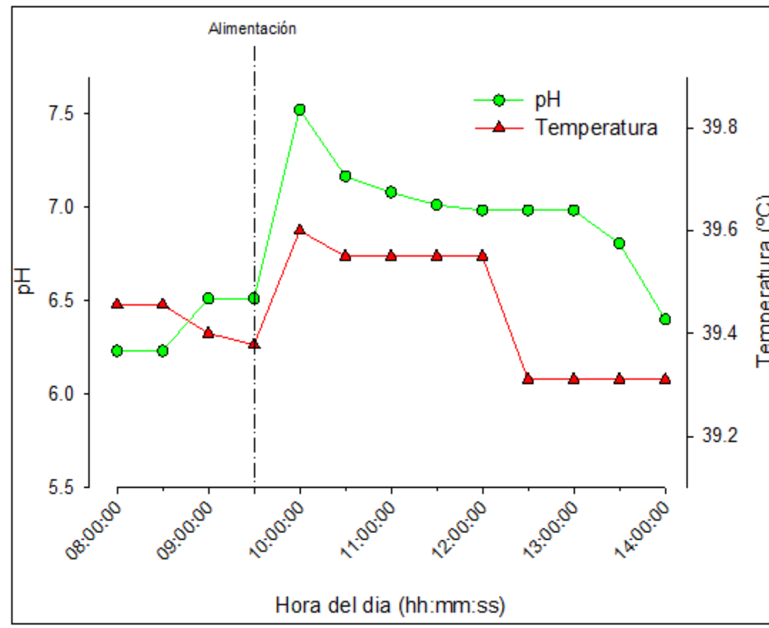
Hardware and software used for remote bio-sensing

- ISFET-based PH sensor
- Silicon-based temperature sensor
- ZigBee (IEEE 802.15.4), 2.4 GHz





Design, fabrication, and test of the in-rumen device. Instituto Tecnológico de Veracruz, México.

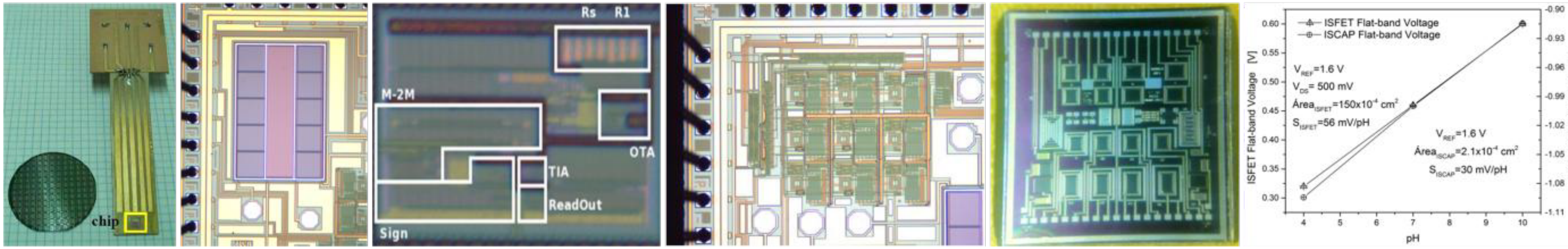


CO_2 emissions have been correlated to PH, temperature and associated to a diet model that reduces milk acidity and CO_2 emission.

Desarrollo y evolución de ISFETs (detectores de iones)

Contacto: Joel Molina, jmolina@inaoep.mx

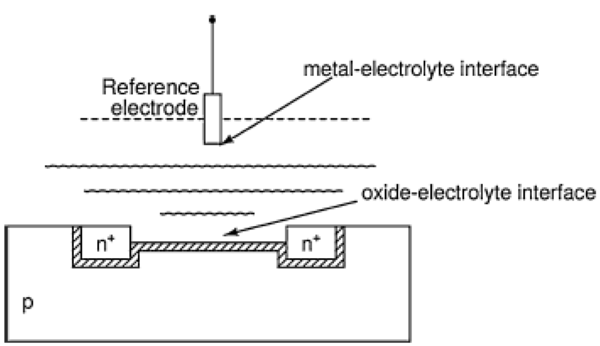
2000 … 2012 2013 2014 2015 2016



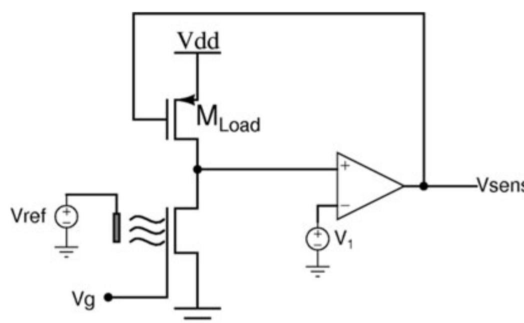
Detección de iones (H^+, Na^+, K^+, Ca^+, etc) presentes en soluciones biológicas.

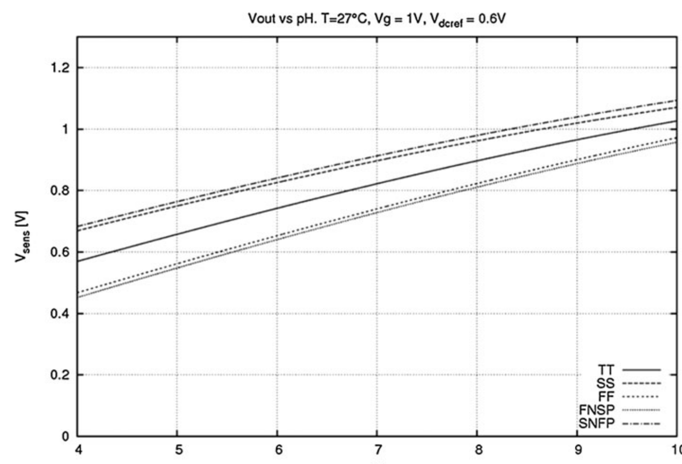
- Primera etapa: ISFETs fabricados en INAOE y combinados con MOSIS
- Segunda etapa: ISFETs combinados con pre-amplificadores básicos en INAOE
- Utilizados para medir pH. Fabricados en INAOE con Al_2O_3 ALD, portables y de bajo costo.

Esquemático del IFET



0.18 µm OTA+ calibración





LAEDC

Latin.American Electron Devices Conference
Armenia, Quindio, Colombia
February 24-27, 2019

Deadline paper submission:
September 14, 2018

laedc.cinvestav.edu

LAEDC is a conference cosponsored by the IEEE Electron Device society. Its main goal is to bring together specialists from all Electron Device related fields. It will take place in Armenia, Colombia, and it will be co-located with LASCAS.

Proceedings will be published by IEEE and will be available on IEEE Xplore.

Social Activities: Besides the technical program, a welcome reception and a gala dinner are planned. Visitors will have the opportunity to visit several tourist attractions.

Topics of Interest:

All electron based devices

- Semiconductor-, MEMS- and Nano-technologies
- Packaging, 3D integration,
- Sensors and actuators
- Display technology
- Modeling and simulation
- Reliability and yield
- Device characterization
- Energy harvesting
- Biomedical Devices
- Circuit-device interaction
- Novel materials and process modules
- Technology roadmaps
- Electron device engineering education
- Electron device outreach
- Optoelectronics, photovoltaic and photonic devices and systems

Armenia City is the capital of the department of Quindio. It is located in the Colombian region known as the coffee triangle. Since 2011, this region is recognized by the UNESCO as a world cultural heritage due to its exceptional landscapes that are the mixture of natural beautifulness and cultural traditions around the coffee growing. Different theme parks related to cultural and agricultural traditions are also located in the department of Quindio, which turns out the LAEDC an opportunity not only for academic exchange but also for knowing and enjoying the traditions around the coffee growing.

Program chairs:

Arturo Escobosa (escobosa@cinvestav.mx), Lluis Marsal (lluis.marsal@urv.cat)

Muito Obrigado!