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Low-Cost CMOS Power Consumption Data Dependency Demonstrator Concept

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Motivation – Novel Vulnerabilities Originating in the Modulated Static Power

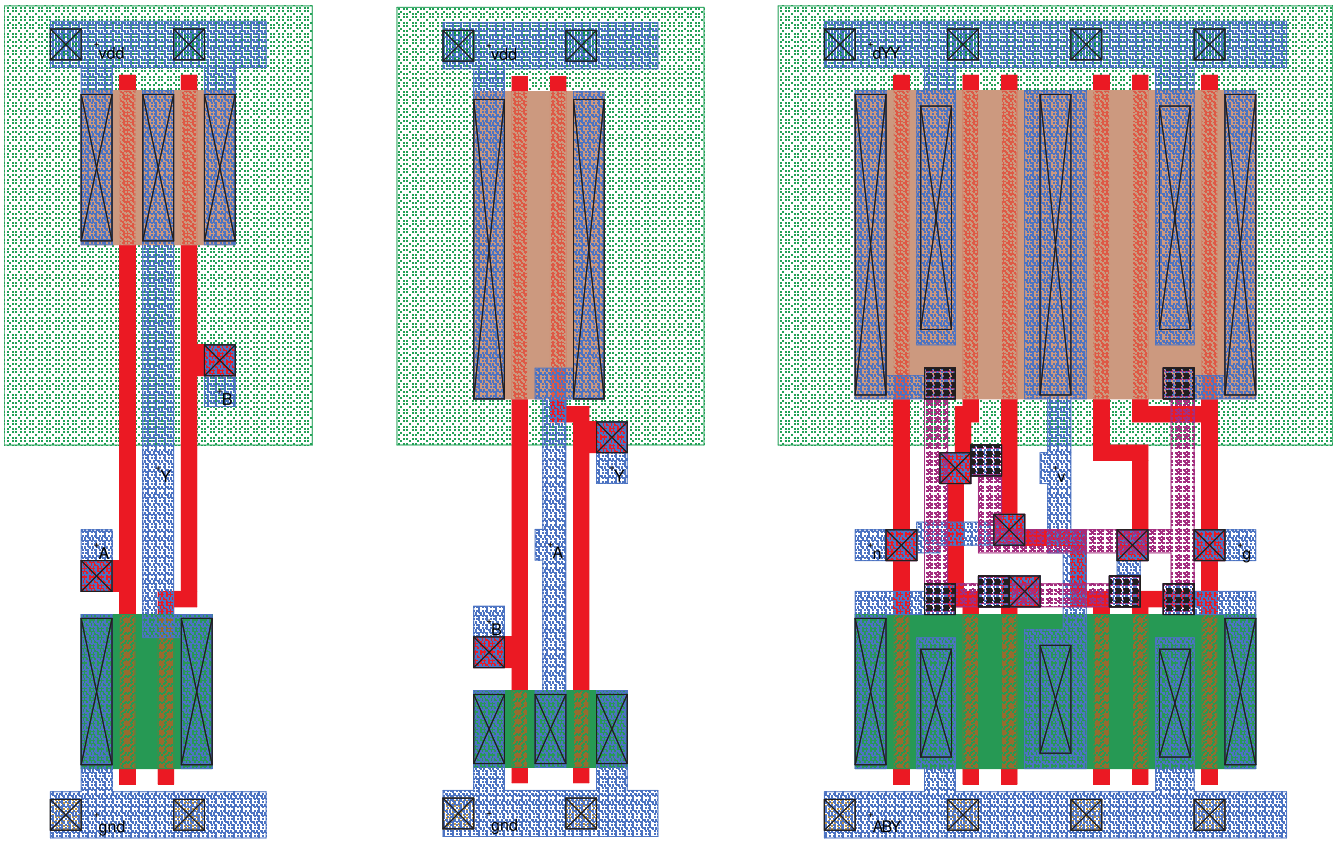
We analyze the data dependency of the photocurrent induced by a laser beam in the illuminated CMOS device:

- → it's like *amplified static power*
- → lasers are often used to induce faults into registers
- → we analyze static current of **combinational circuits** modulated by illumination (a laser beam)

Pros and Cons:

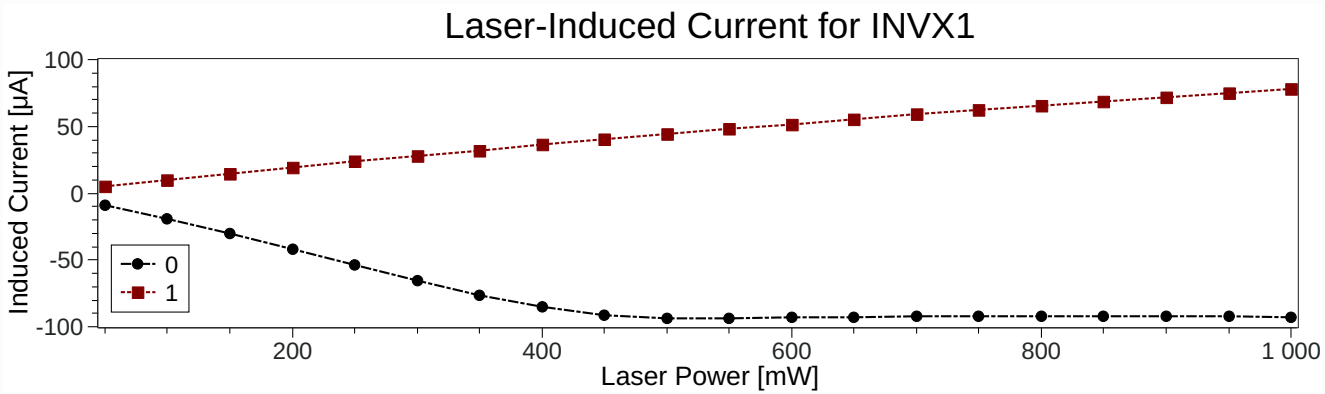
- \+ combinational logic provides **sufficient area** (to target laser beam) even in recent technology nodes
- \+ stored **values remain unaltered**
  - → error detection may not be raised
  - → measurement time may be prolonged
- – advisory values are *mixed together* → **the cocktail effect**
- – possible **attack requirements are strong** – known layout, precise laser beam localization

Data Dependence in CMOS
Conductivity is Influenced by Geometry



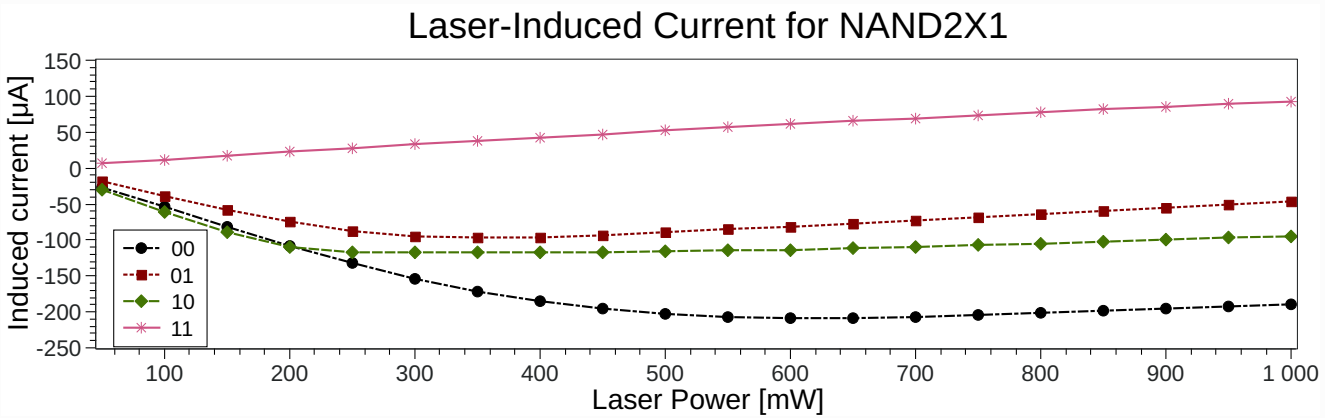
Layout of `NAND2X1` (4 x 10.8 μm), `NOR2X1` (4 x 10.8 μm) and `XOR2X1` (7.2 x 10.8 μm) cells in 180nm TSMC technology

Standard Cell Illumination
INVX1 @ TSMC 180nm (SPICE)



The photocurrent for `INVX1` for different input patters and increasing laser power. The 0 and 1 input patterns are easy to distinguish

Standard Cell Illumination
NAND2X1 @ TSMC 180nm (SPICE)



The photocurrent for `NAND2X1` for different input patters and increasing laser power. The 00 and 11 input patterns are easy to distinguish; patterns 01 and 10 cause similar currents, although the 20μA difference (for 100mW and above) is still distinguishable

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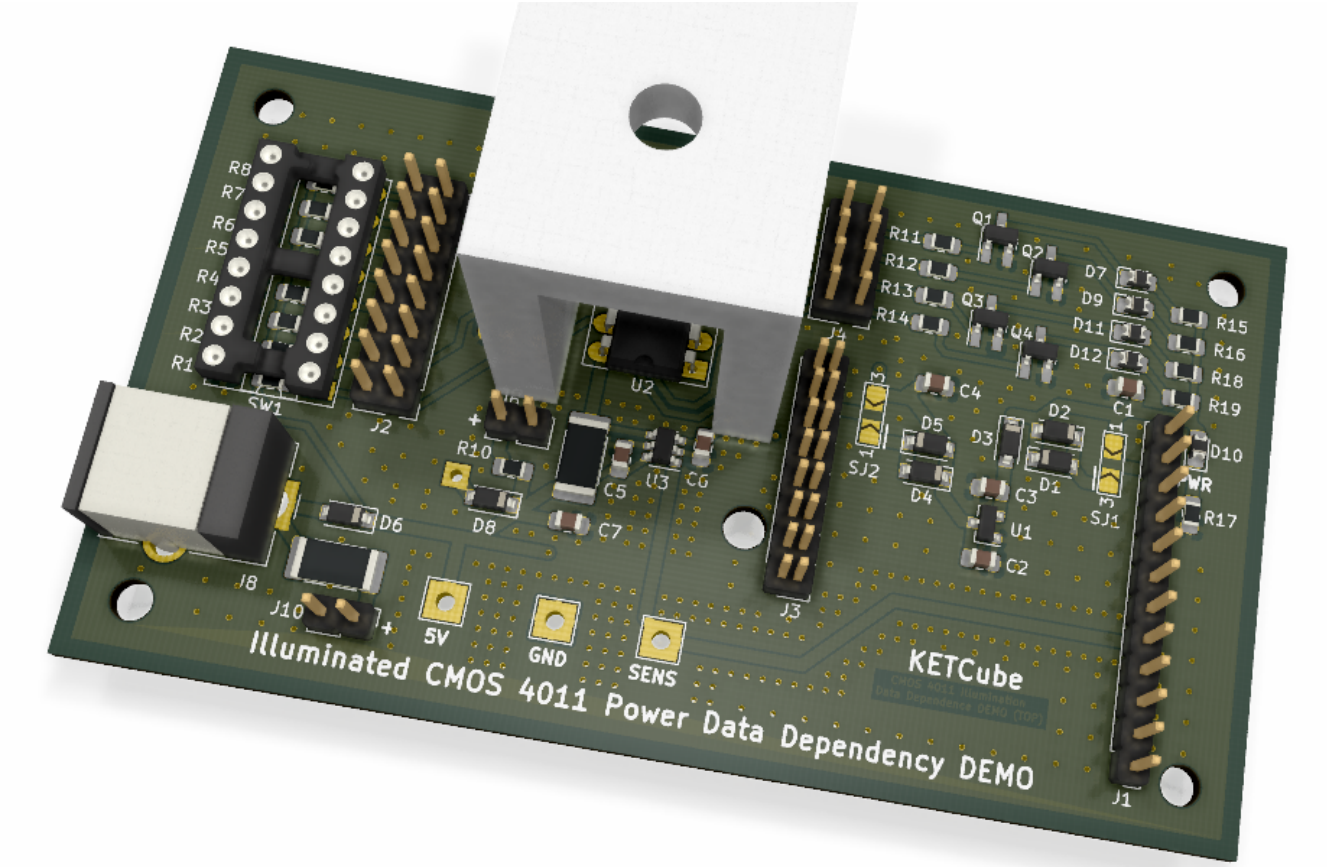
Data Dependency Demonstrator Concept
Low Cost CMOS 4011 Based Demonstrator

- Employs **CMOS 4011** by Texas Instruments
  - Low cost, well known CMOS circuit in PDIP (Plastic Dual-In-Line Package)
  - Datasheet contains design details including metal layer geometry
  - Illuminated by power diode
- Highly Configurable
  - Battery-Powered samples
  - MicroAmps are expressed as millivolts (SENS pin)
  - Measurement by MCU or by multimeter (accuracy of tens of millivolts)
- Measurements
  - Static/Leakage Power
  - Static power data dependency

Data Dependency Demonstrator Concept
Low Cost Demonstrator Visualization



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CMOS 4011 Decapsulation
Traditional Chemical Process

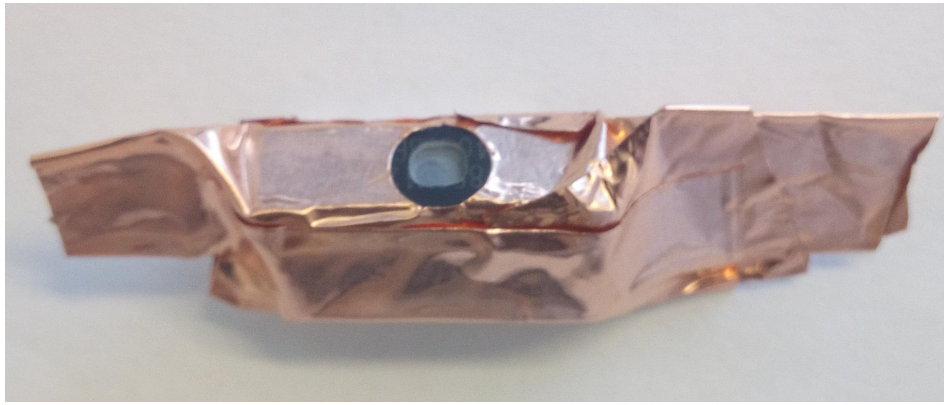
- Fuming HNO_3 is used (above 86%)
- Cu bonding was dissolved, DIE remains OK
- After bonding recovery (bonding machine), the circuit was operational

But:

- Bonding recovery takes too much time

CMOS 4011 Decapsulation
Electro-Chemical Process – Prerequisites

- Concentrated H_2SO_4 (1 part) + red fuming HNO_3 (3 parts)
- Device was milled above DIE to speed-up decapsulation
- Device was covered using conductive copper tape



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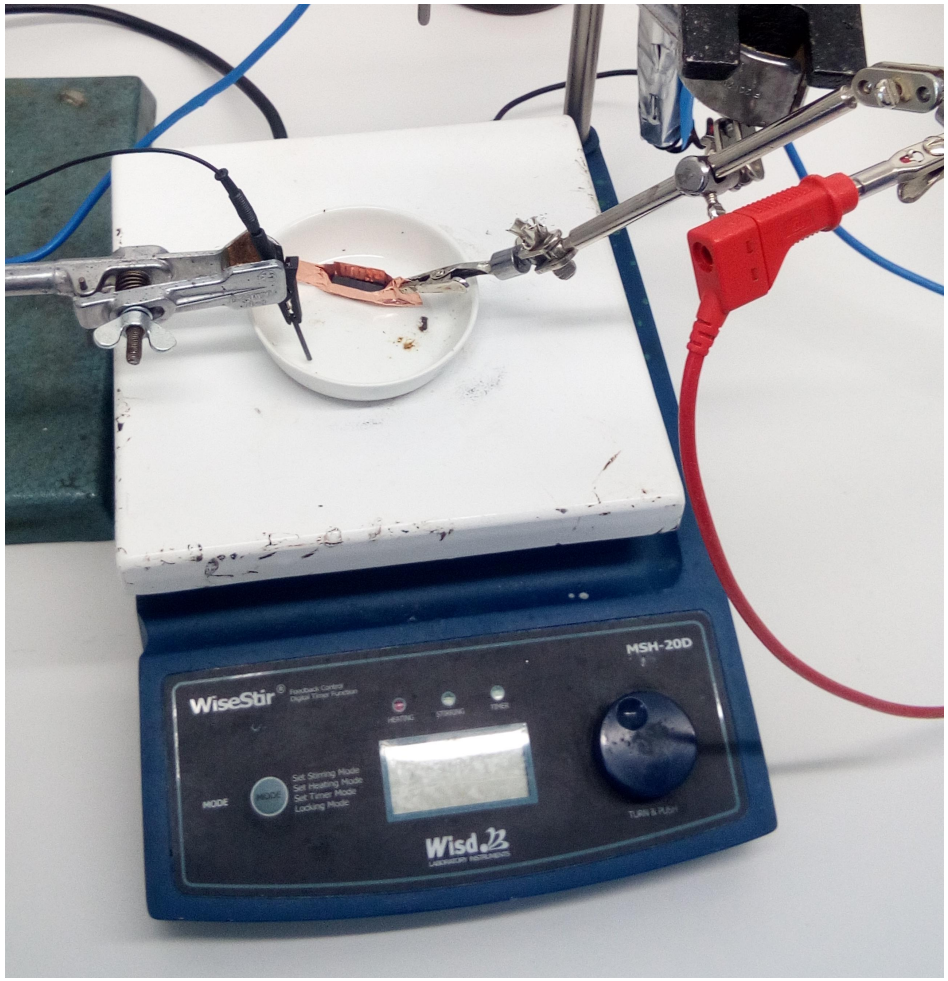
CMOS 4011 Decapsulation
Electro-Chemical Process – Setup[1]

- Positive electrode – device being decapsulated
- Negative electrode – platinum is recommended in literature
- Negative electrode – low cost alternatives:
  - Graphite electrode (originally from a pencil) – it works, but it dissolves due to fillers
  - Stainless electrode provides satisfactory results (stainless steel screw was used)
- Potential: 5V (current was about 50 - 100 mA)
- Acid temperature: 70 - 80 °C
- Decapsulation time: $>$ 1 minute

[1] Endoh, Hirohiko, and Takuya Naoe. "Copper wire bonding package decapsulation using the anodic protection method." Microelectronics Reliability 55.1 (2015): 207-212.

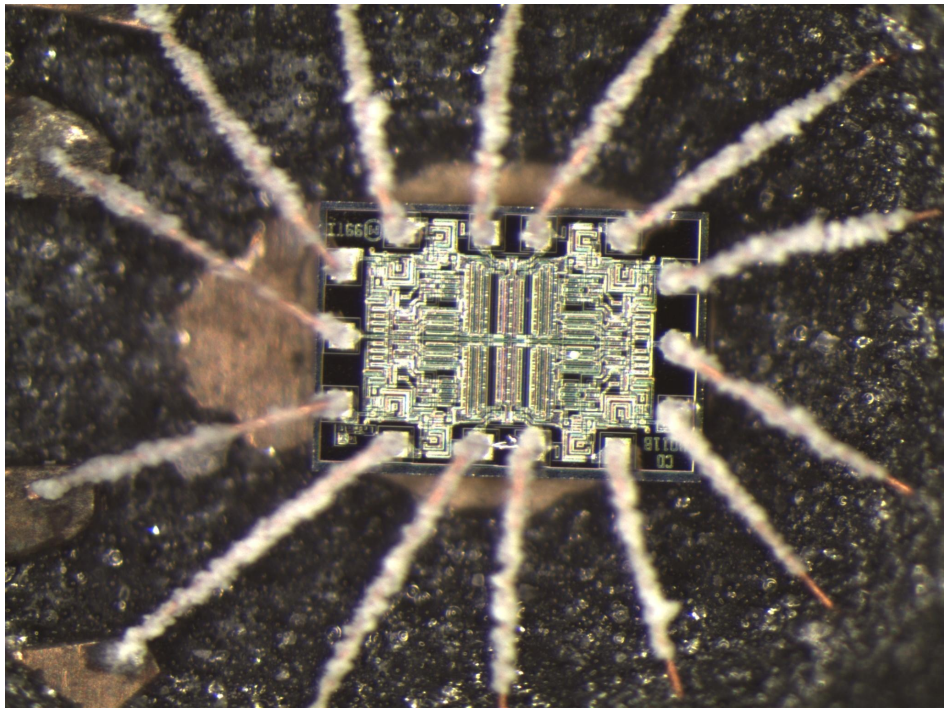
CMOS 4011 Decapsulation
Electro-Chemical Process – Illustration

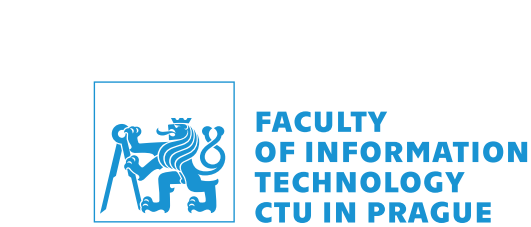


CMOS 4011 Decapsulation
Electro-Chemical Process – Postprocessing

- Decapsulated device was washed in acetone
- The process residual are the Cu^{2+} salts ($CuSO_4$, $Cu(NO_3)_2$)

→ salts were dissolved in the distilled water





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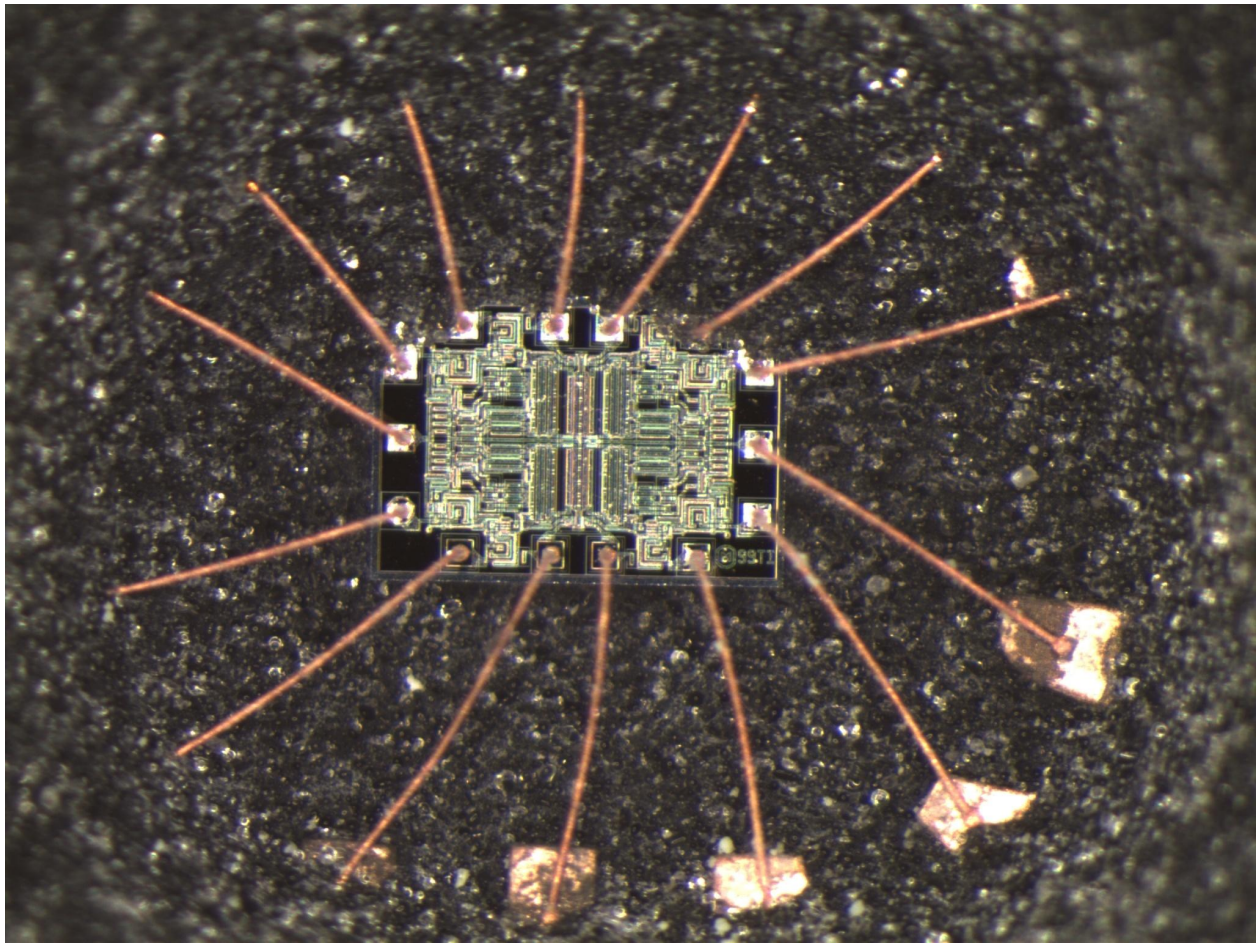
CMOS 4011 Decapsulation
Decapsulated and Operational CMOS 4011



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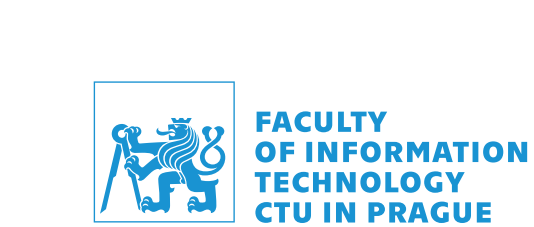
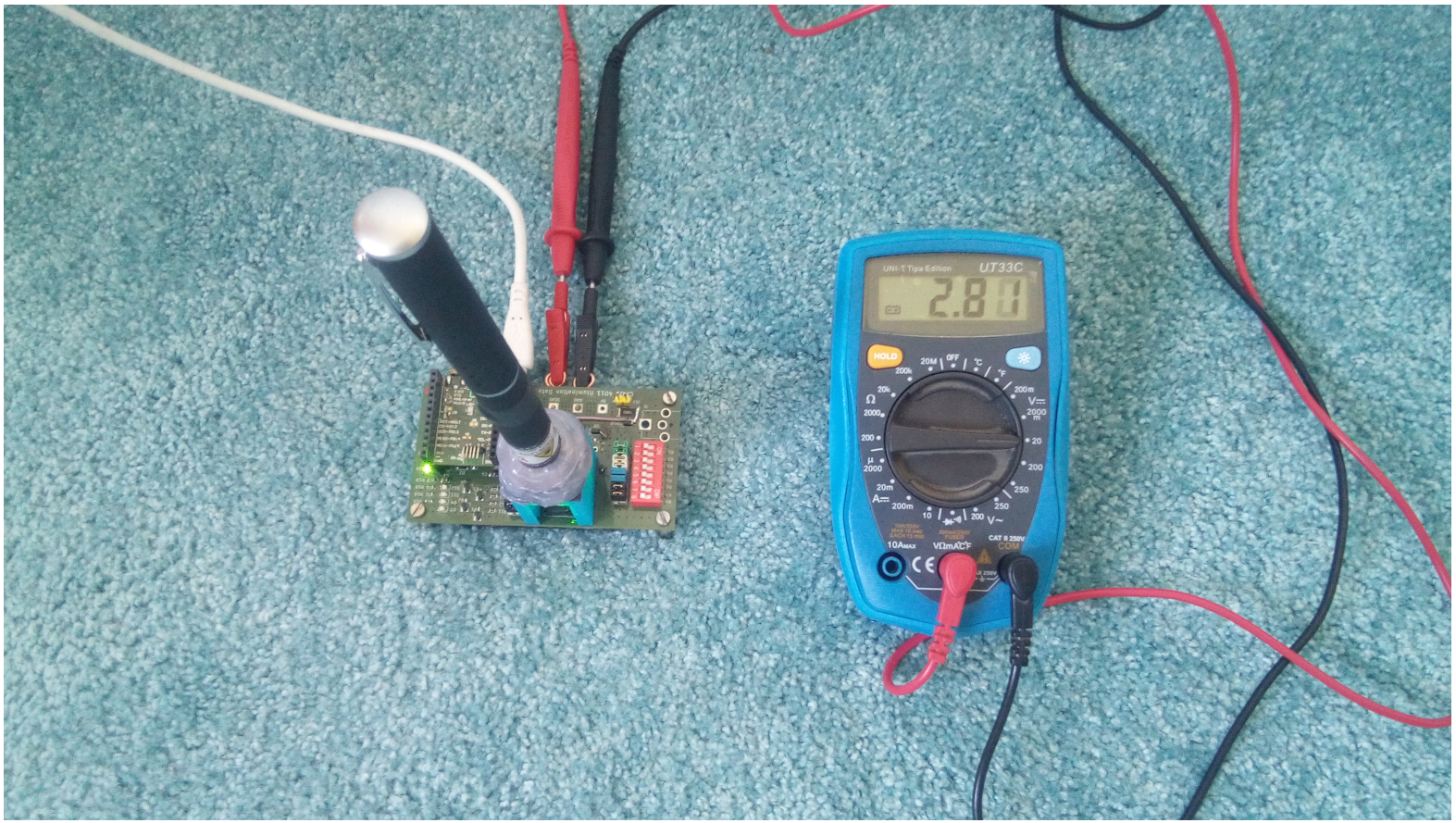
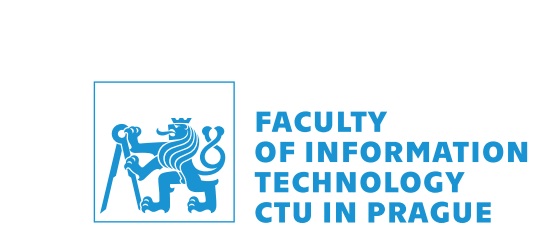
CMOS 4011 Live Demo

Live Demo . . . Later :-)



CMOS 4011 Demo – Experiments
All-1 inputs; 50mW laser: 2810 μA





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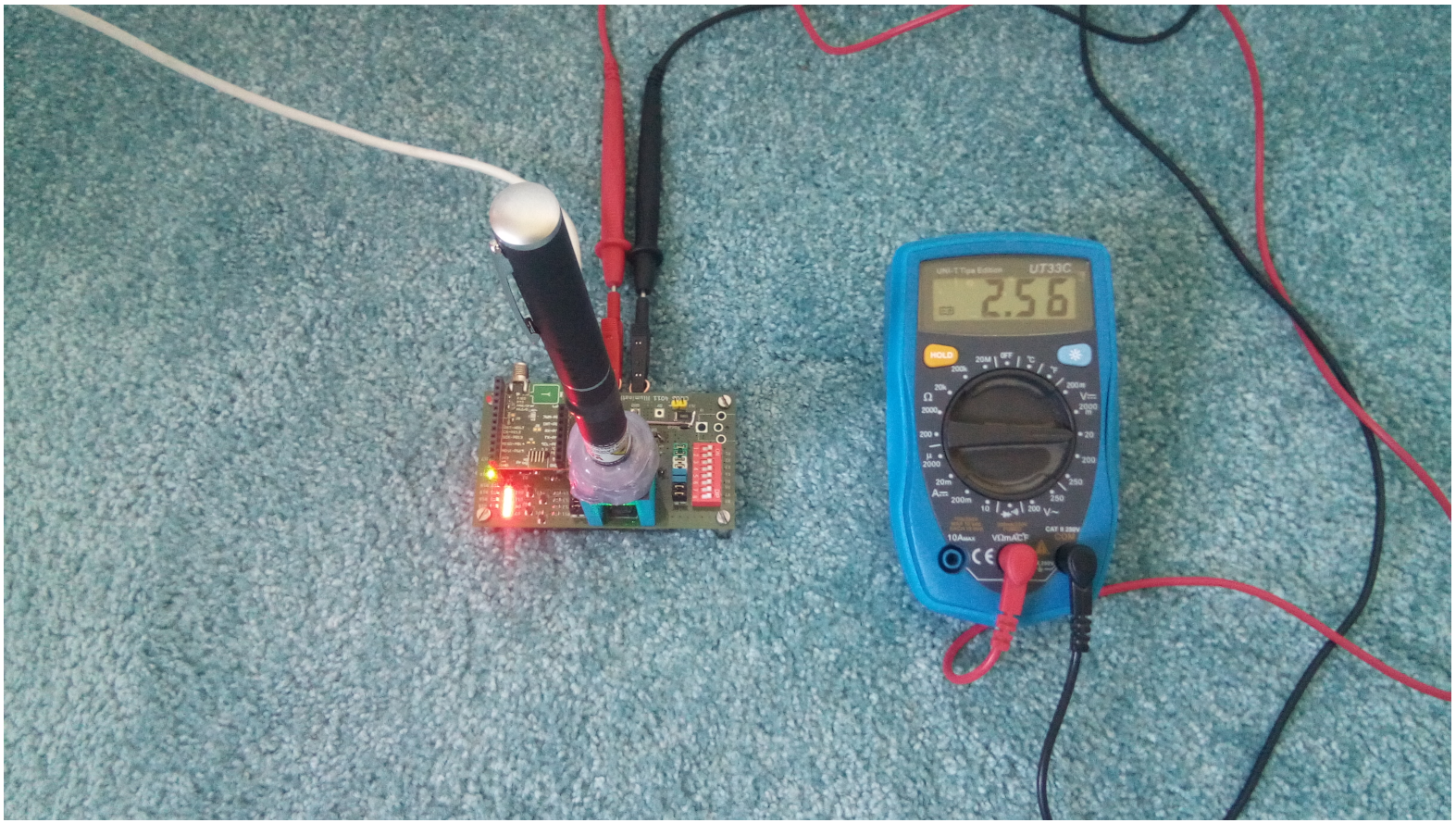
CMOS 4011 Demo – Experiments
All-0 inputs; 50mW laser: 2560 μA



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Thank You!
Work-In-Progress and Future Work

Future Work is related to submicron technology and applications of the phenomena in the security area:

- research of the "cocktail effect" influence
- modulated static current variability modeling and simulation
- measurements using devices manufactured by using corresponding (in the field) technologies
- attack scenario formulation and validation

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