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Modulated CMOS Static Power is Data Dependent and Observable

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Motivation

Novel Threats Using Well Established Methods

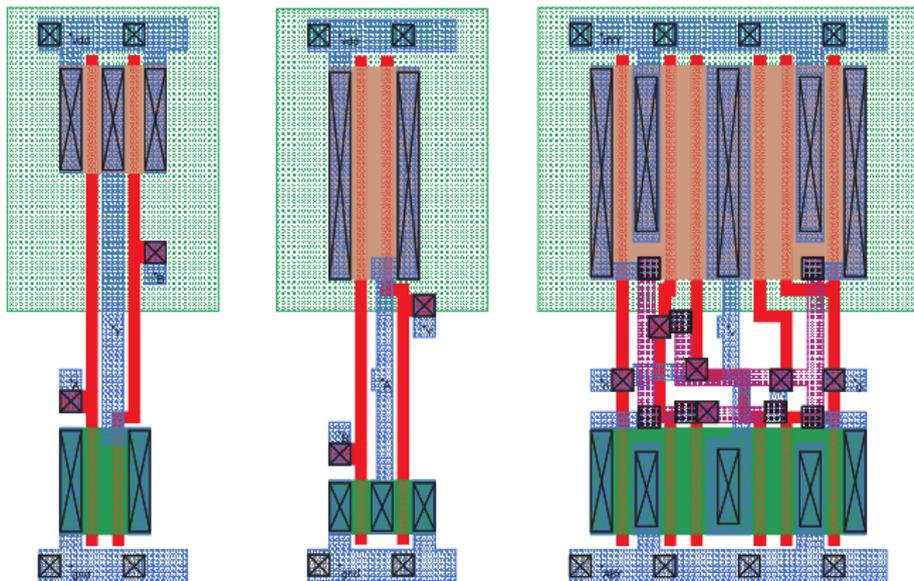
We analyze the data dependence of the photocurrent induced by a laser beam in the illuminated CMOS device:

- lasers are often used to induce faults into registers
- we analyze static current of **combinational circuits** modulated by illumination (a laser beam)
- + 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

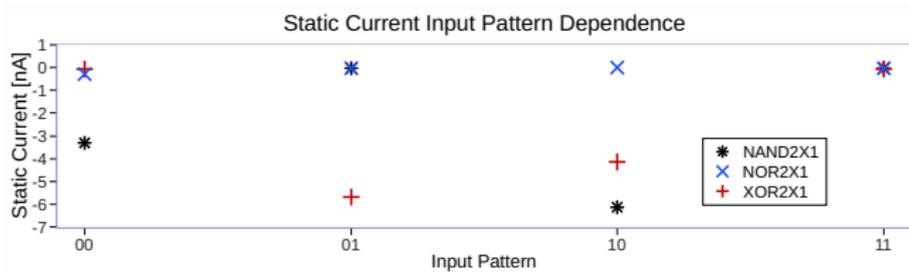
Conductivity is Influenced by Geometry



Layout of NAND2X1 ($4 \times 10.8 \mu\text{m}$), NOR2X1 ($4 \times 10.8 \mu\text{m}$) and XOR2X1 ($7.2 \times 10.8 \mu\text{m}$) cells in 180nm TSMC technology



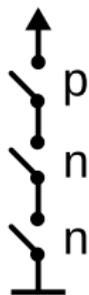
Data Dependence in CMOS



The data dependence of the static current on the input pattern for three standard cell SPICE models – namely NAND2X1, NOR2X1, and XOR2X1 – in 180nm TSMC technology



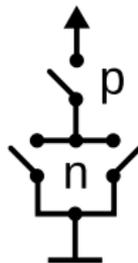
Data Dependence in CMOS Serial/Parallel Transistor Structures



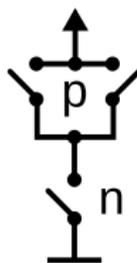
(a)



(b)



(c)

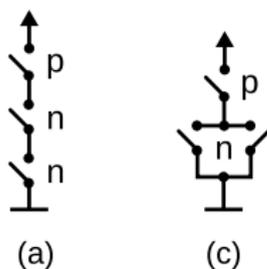


(d)

Simulated transistor structures displayed as serial/parallel switches. Note, that these structures are not included in the standard cell library: SPICE models were derived from standard cells with equal geometry of NMOS/PMOS parts



Data Dependence in CMOS Serial/Parallel Transistor Structures



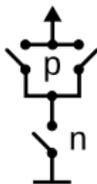
- in structures (a) and (c), the static current is influenced (mainly) by the state of the PMOS transistor – the dependence on any combination of NMOSes is distinctly less significant;
- for NMOSes, it holds, that the serial structure (a) introduces a stronger data dependence than the parallel structure (c). Naturally, there is a difference in the static current when opening (only) the *top* or (only) the *bottom* transistor because of induced drain/source voltage differences;



Data Dependence in CMOS Serial/Parallel Transistor Structures



(b)



(d)

- for structures (b) and (d), we observed very little (almost none) data dependence on the (single) NMOS transistor state;
- for PMOSes, in contrast to NMOSes, the parallel structure (d) introduces (a bit) stronger data dependence than the serial structure (b). This is apparently caused by lower hole mobility in PMOSes.

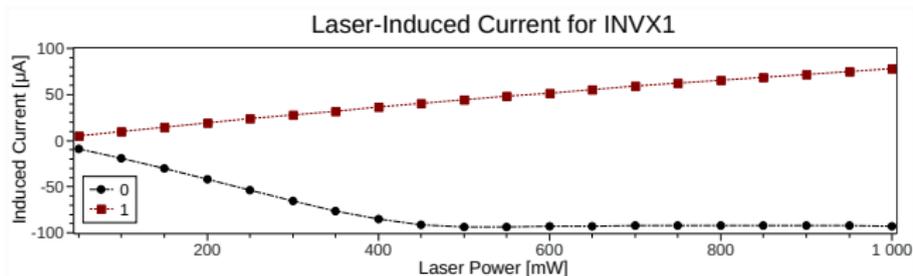


Data Dependence in CMOS Influence on Standard Cells

- the NAND2X1 cell is the most asymmetric one, which is caused by the NMOS serial arrangement;
- the XOR2X1 cell power imprint allows a clear distinction of the XOR output state, which demonstrates the symmetry of the XOR gate;
- the NOR2X1 power imprint is very narrow compared to the other two gates, which is apparently caused by the serial arrangement of PMOSes (introducing low conductivity when one of them is closed).



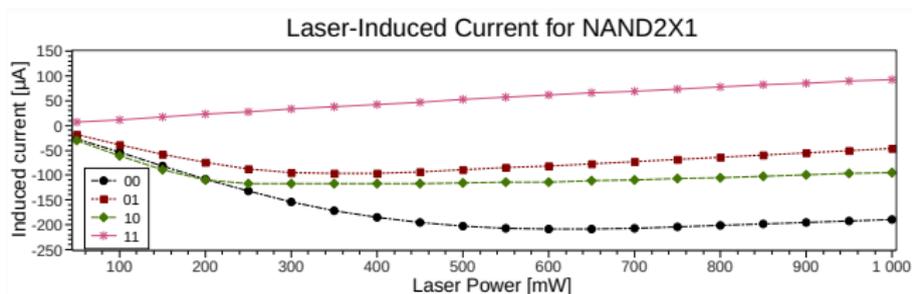
Standard Cell Illumination INVX1



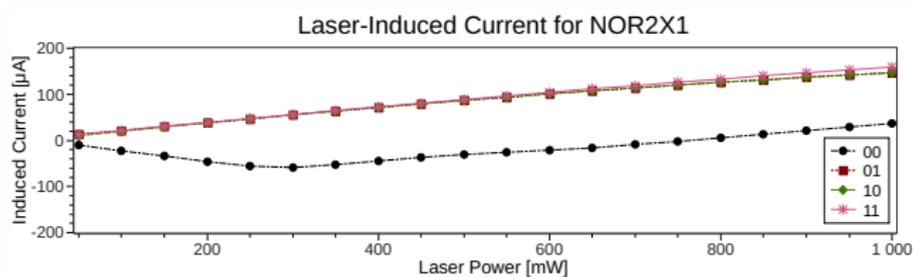
The photocurrent for INVX1 for different input patterns and increasing laser power. The 0 and 1 input patterns are easy to distinguish



Standard Cell Illumination NAND2X1



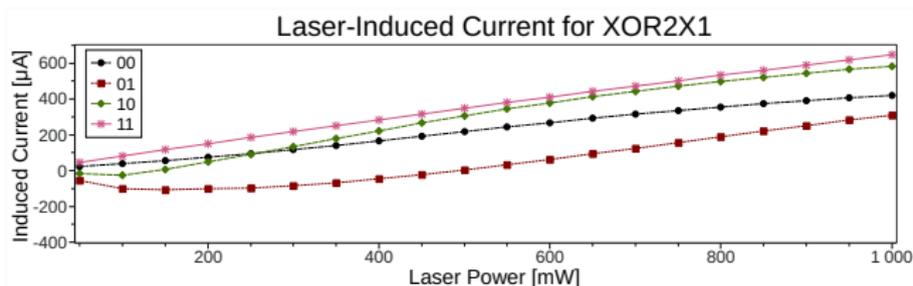
The photocurrent for NAND2X1 for different input patterns and increasing laser power. The 00 and 11 input patterns are easy to distinguish; patterns 01 and 10 cause similar currents, although the $20\mu\text{A}$ difference (for 100mW and above) is still distinguishable



The photocurrent for NOR2X1 for different input patterns and increasing laser power. The (00) and (11, 01, 10) input pattern subsets are easy to distinguish



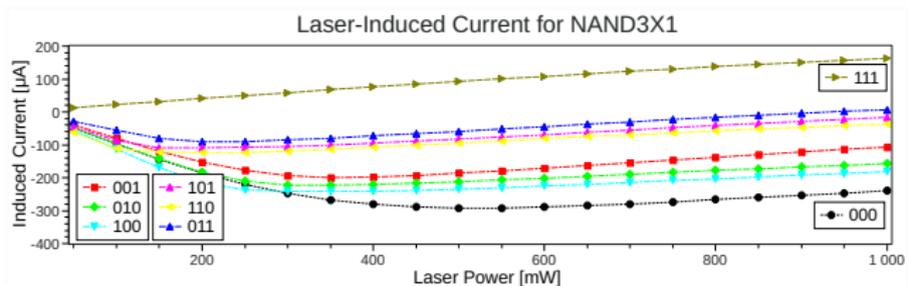
Standard Cell Illumination XOR2X1



The photocurrent for XOR2X1 for different input patterns and increasing laser power. The 00 and 11, 01 and 10 input patterns can be distinguished



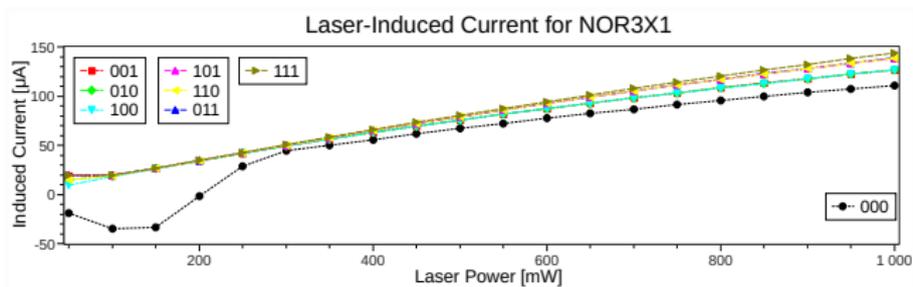
Standard Cell Illumination NAND3X1



The photocurrent for NAND3X1 for different input patterns and increasing laser power. The four sets of input patterns are easy to distinguish: these sets of input patterns distinguished by the Hamming Weight (HW): 000 with HW(0); 001, 010 and 100 with HW(1); 011, 101 and 110 with HW(2) and 111 with HW(3)



Standard Cell Illumination NOR3X1

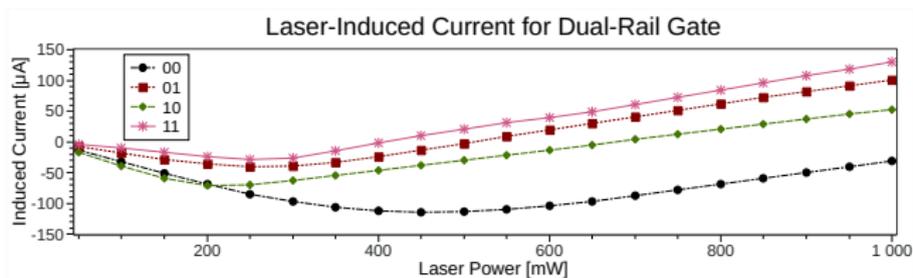


The photocurrent for NOR3X1 for different input patterns and increasing laser power. It is simple to distinguish the 000 input pattern. Additionally, it is possible to distinguish 4 sets of input patterns: these sets of input patterns distinguished by Hamming Weight (HW): 000 with HW(0); 001, 010 and 100 with HW(1); 011, 101 and 110 with HW(2) and 111 with HW(3)



Dual-Rail is Not Safe

- dual-rail encoding-based methods were introduced (into security area) to balance the **dynamic power**
- our method exploits the differences in the geometry and the data dependence of the (modulated) **static power**



The photocurrent for the conventional WDDL NAND gate composed of NAND2X1 and NOR2X1 gates for different input patterns and increasing laser power. The 00 input pattern (logical inputs) is easy to distinguish; other patterns (11, 01 and 10) are also distinguishable



- the “cocktail effect” is the situation, when the (modulated) static currents of many gates are mixed together
- the in depth research of the “cocktail effect” influence is currently work-in-progress
- we have already shown, that there are special cases, where “cocktail effect” has, in fact, positive influence – voters may behave as amplifiers¹

¹Bělohoubek, J.; Fišer, P.; Schmidt, J.: Using Voters May Lead to Secret Leakage. In: 22nd International Symposium on Design and Diagnostics of Electronic Circuits and Systems (DDECS 2019). April 24-26, 2019.



- static power of a selected CMOS sub-circuit can be modulated by a laser beam (the sub-circuit area is “selected”)
- visibility of the processed data in the device’s power trace
- laser beam may be used to obtain potentially sensitive data processed by a combinational sub-circuit targeted by the laser beam
- the method has strong requirements
- approaches based on dual-rail logic cannot be used to fight against the potential attacks based on the presented method



Thank You!

Work-In-Progress and Future Work

- 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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