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Is Hardware Security prepared for unexpected discoveries?

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Purpose

- Remind about the importance of Hardware Security
  - Growing number of devices being used in critical and sensitive applications
  - Have we learned from history of attacks?
- Highlight that mitigation is not developed in time to defeat attacks
- Present some new attacks
- Discuss predictability of attacks

Outline

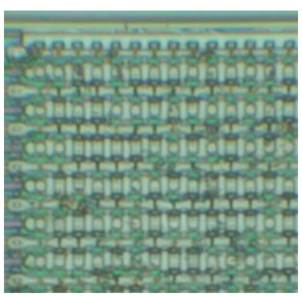
- Introduction
- History of attack technologies
- New attacks
- Discussions
- Challenges and Future work
- Conclusion

Introduction

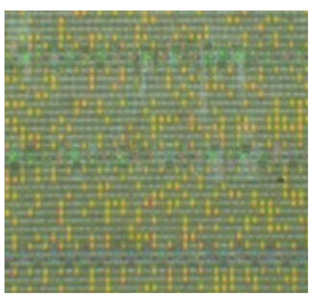
- History of disturbing physical attacks
  - Mask ROM visibility
  - Power analysis
  - Optical fault injection
  - Data remanence in Flash/EEPROM
  - Combined attacks
  - Optical emission analysis
  - Flash/EEPROM imaging under SEM
  - CPU speculative execution bug

History of disturbing physical attacks

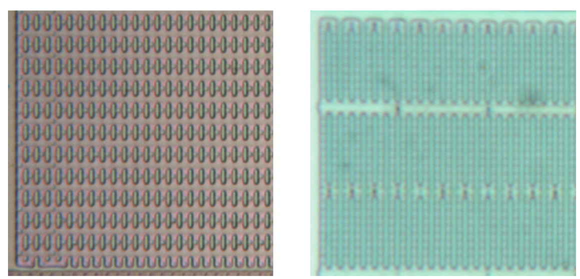
- Mask ROM “invisibility” in 1990s
  - Information is encoded with doping level
  - Impossible to see under optical microscope
  - Failure Analysis helps with defects etching
  - Countermeasures at silicon level



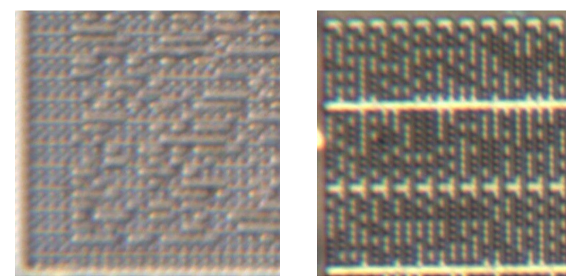
encoding by presence of transistors



encoding by shorts in metal layer



encoding by doping concentration

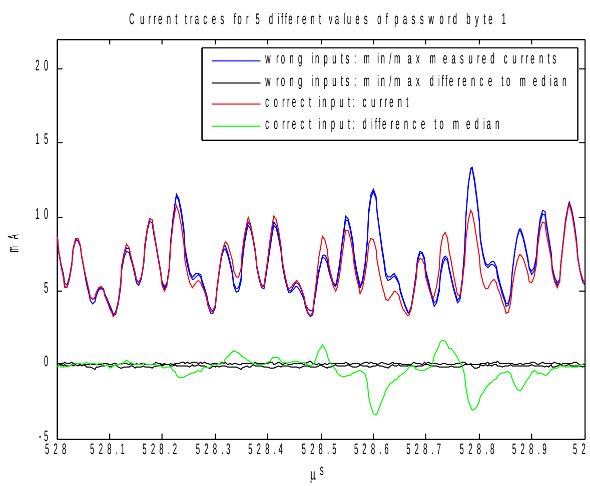


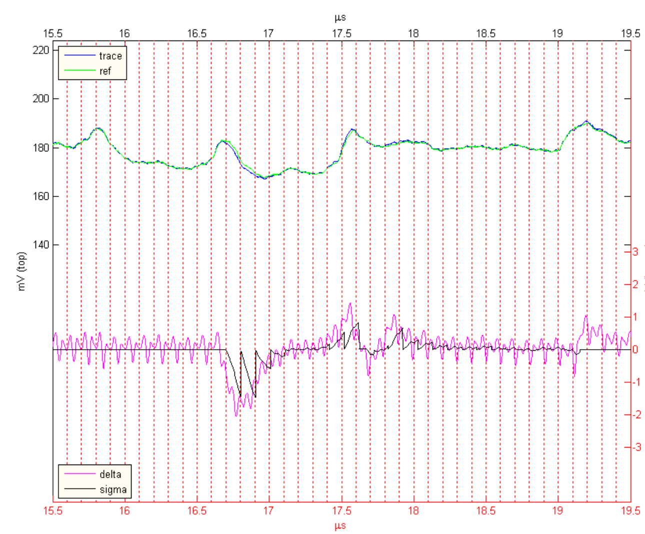
after selective dash etching

O. Kömmerling, M. Kuhn: Design Principles for Tamper-Resistant Smartcard Processors. USENIX 1999

History of disturbing physical attacks

- Power analysis reveals deep secrets
  - Leakage from switching CMOS transistors is correlated with processed data
  - Can break passwords and crypto keys
  - Countermeasures are very sophisticated

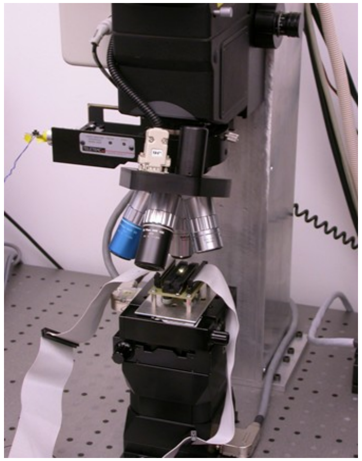


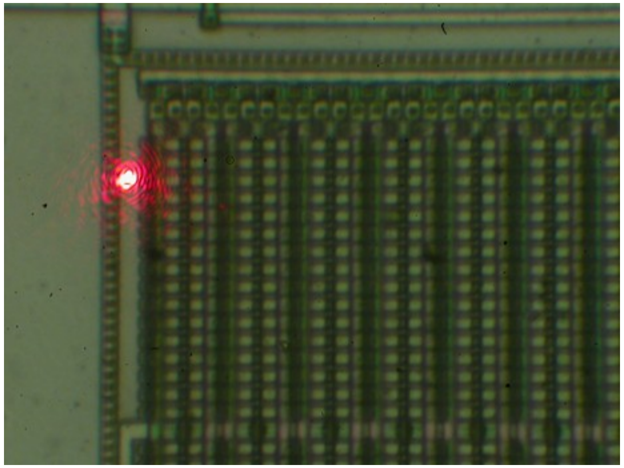


P. Kocher: Differential Power Analysis. Crypto 1999

History of disturbing physical attacks

- Optical fault injection
  - CMOS transistors and memory cells can be controlled with a laser beam
  - Confirmed down to 28nm devices
  - Countermeasures at silicon level

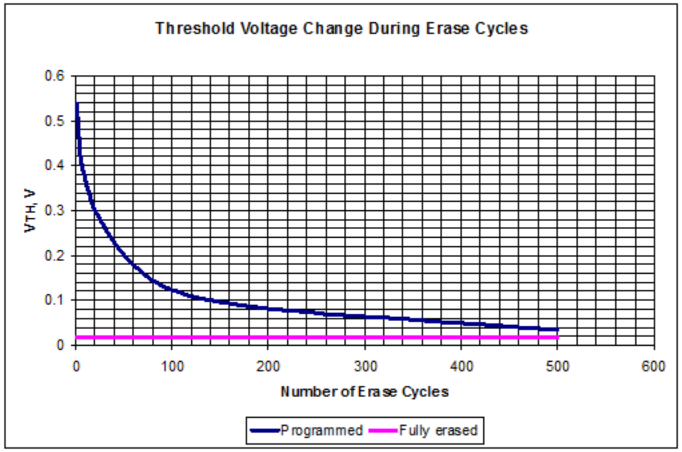


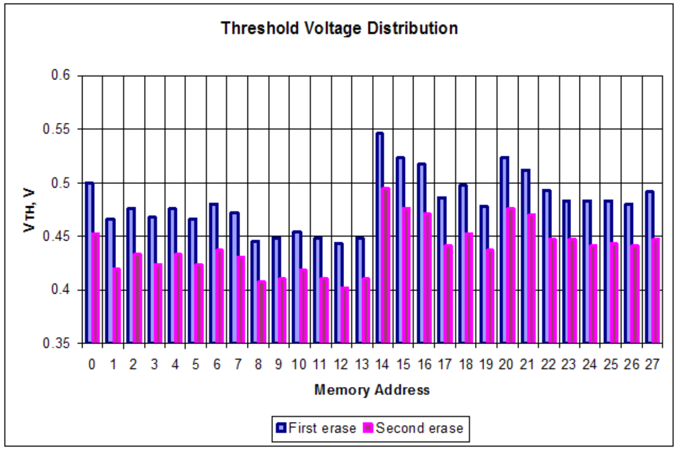


S. Skorobogatov, R. Anderson: Optical Fault Induction Attacks. CHES 2002

History of disturbing physical attacks

- Data remanence in Flash/EEPROM
  - Residual information present after Erase
  - Could lead to recovery of sensitive data
  - Once learned can be easily defeated

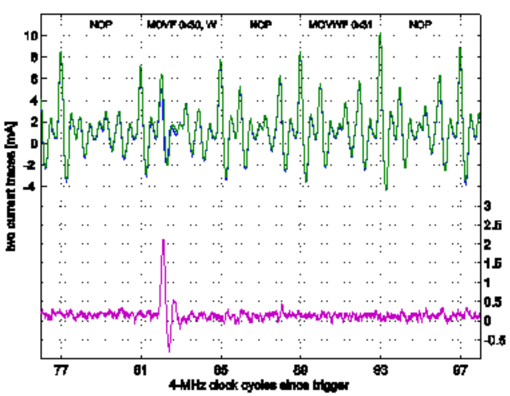




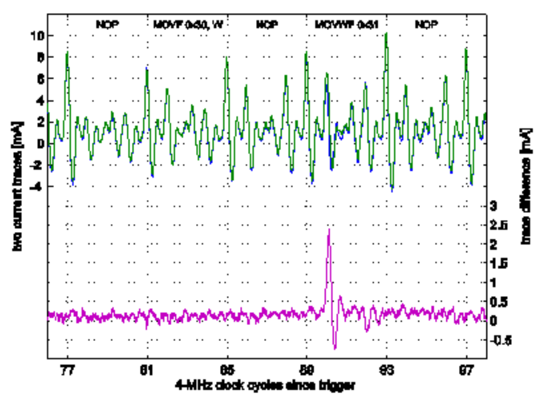
S. Skorobogatov: Data Remanence in Flash Memory Devices. CHES 2005

History of disturbing physical attacks

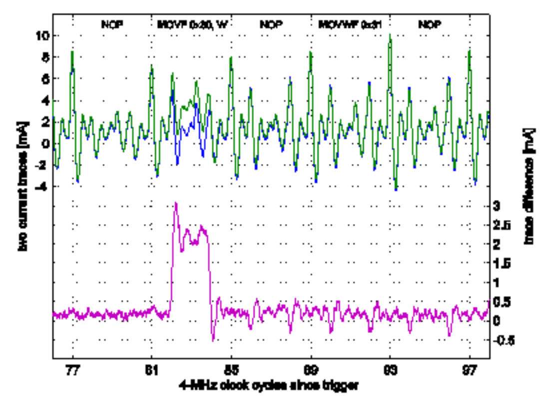
- Combined attacks
  - Power analysis + Fault injection
  - More powerful and localised
  - Countermeasures are hard to implement



read memory location (laser Off - On)



write memory location (laser Off - On)



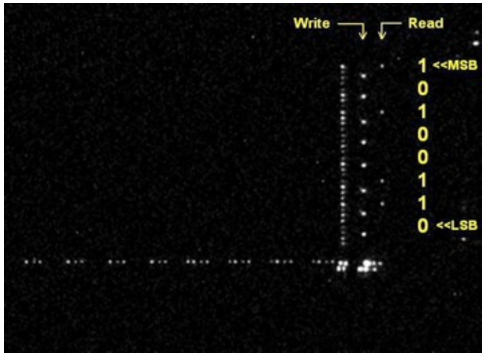
read memory location (laser Off – On)
contents of memory changed by laser

S. Skorobogatov: Optically Enhanced Position-Locked Power Analysis. CHES 2006

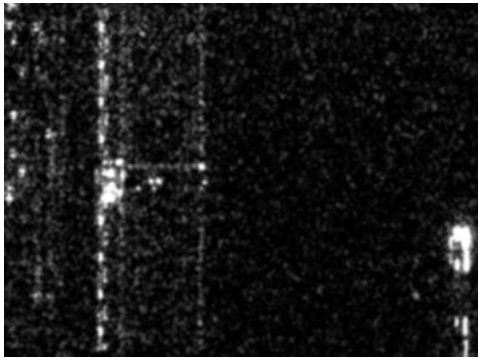
History of disturbing physical attacks

- Optical emission analysis
  - Switching CMOS transistors emit photons
  - Can be detected with CCD cameras (2D) and photomultiplier tubes (time resolved)
  - Countermeasures are hard to implement

PMT response over large area



CCD image acquired on SRAM

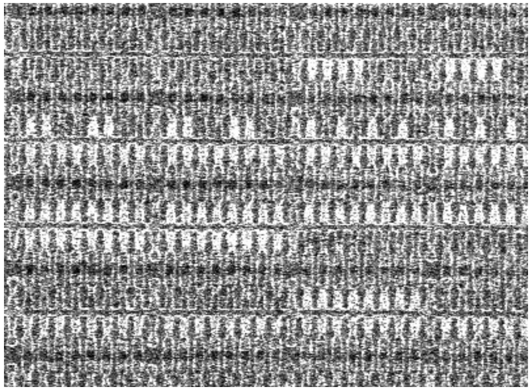


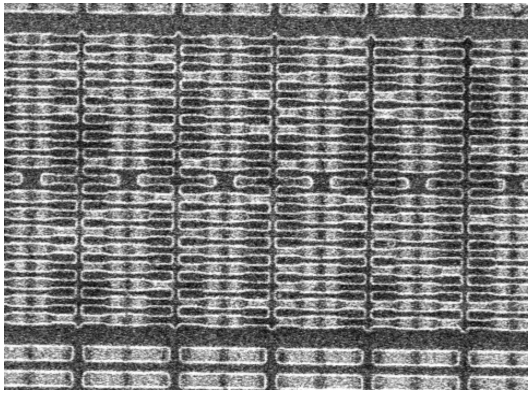
CCD image acquired on AES, 130nm

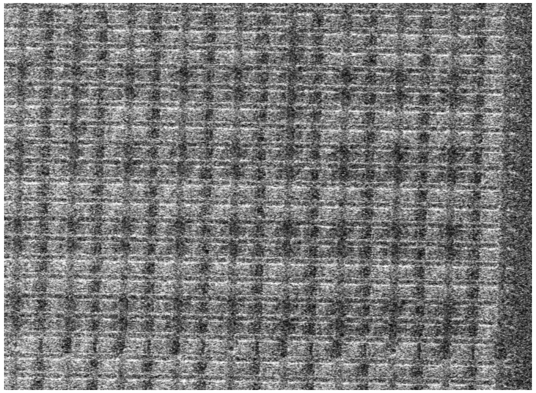
S. Skorobogatov: Using Optical Emission Analysis for Estimating Contribution to Power Analysis. FDTC 2009

History of disturbing physical attacks

- Flash/EEPROM imaging under SEM
  - More efficient and faster than SPM
  - Destructive to memory cells
  - Physical limits for detectable charge
  - Countermeasures are hard to implement







F. Courbon, S. Skorobogatov, C. Woods: Direct charge measurement in Floating Gate transistors of Flash EEPROM using Scanning Electron Microscopy. ISTFA 2016

History of disturbing physical attacks

- CPU speculative execution bug
  - Design flaw in most modern CPUs
  - Attack names: Meltdown, Spectre
  - Allows eavesdropping on internal CPU data from independent processes
  - Countermeasures at OS and silicon level

M. Lipp et al: Meltdown. USENIX 2018
P. Kocher et al: Spectre. S&P 2018

History of attack technologies

- Did all those attacks came unexpected or they could have been predicted?
  - Mask ROM visibility
    - manufacturers new what they were doing
  - Power analysis
    - standard tool to calculate power dissipation
  - Optical fault injection
    - radiation causes circuits to malfunction
  - Data remanence
    - was known for magnetic media

History of attack technologies

- Did all those attacks came unexpected or they could have been predicted?
  - Combined attacks
    - were not considered as simpler attacks existed
  - Optical emission analysis
    - was known for many years and is used in LEDs
  - Flash/EEPROM imaging under SEM
    - was not considered until latest SEMs with PVC
  - CPU speculative execution bug
    - possible to predict if you have security review

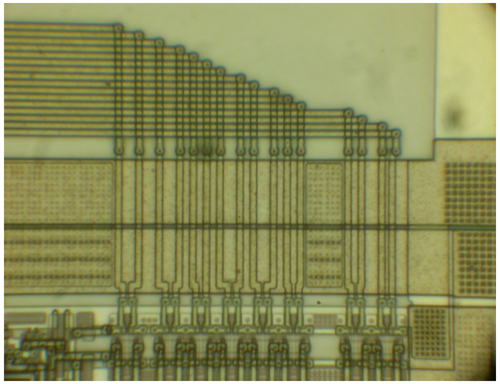
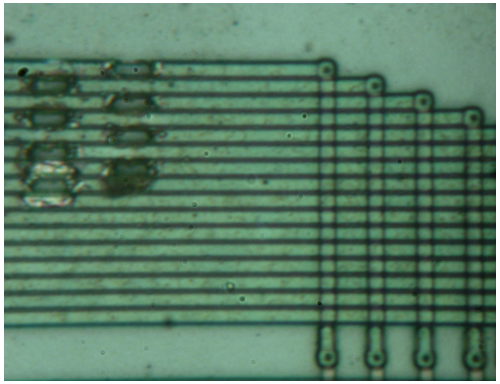
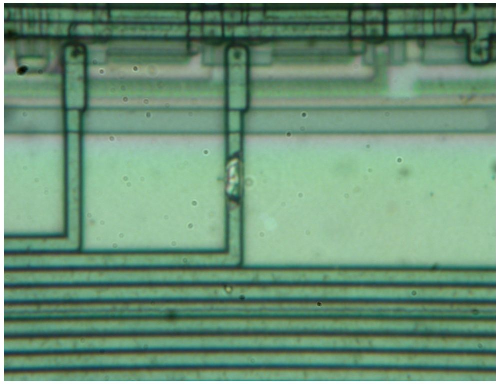
Impossible attacks – very high drive

- Reading data if there is no readback
  - Devices were considered secure by design
    - bypassed with bumping attacks
- Accessing data through backdoor
  - Was considered to be impossible by design
    - proved to work via undocumented debugging
- Reset passcode attempt counter in iPhone
  - FBI claimed that NAND mirroring will not work
    - proved to work with hardware cloning prototype

S. Skorobogatov: Flash Memory 'Bumping' Attacks. CHES 2010
S. Skorobogatov, C. Woods: Breakthrough silicon scanning discovers backdoor in military chip. CHES 2012
S. Skorobogatov: The bumpy road towards iPhone 5c NAND mirroring. arXiv 2016

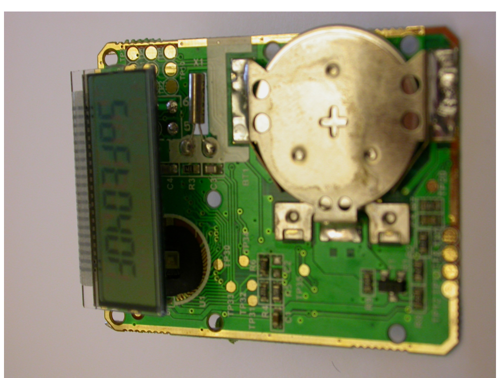
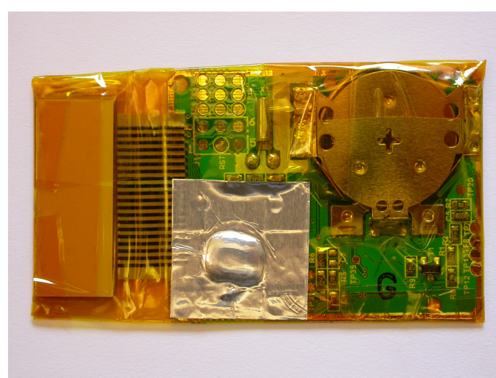
New attacks

- Microprobing CPU data bus
  - Hitachi HD6483102 smartcard controller
  - 16-bit Von-Neumann RISC CPU
  - Cutting bus line bit-15 will inject permanent '1'
    - CPU will execute non-branch 1-cycle instructions
  - Full memory extracted using one microprobe

New proof of concept attack

- Decapsulation on live circuits
  - Vasco Digipass 270 authentication token
  - Battery-backed SRAM storage for keys
    - on losing power or if Reset stops working
  - Sample preparation involves tape insulation, applying hot 100% Nitric Acid via stencil and washing with Acetone

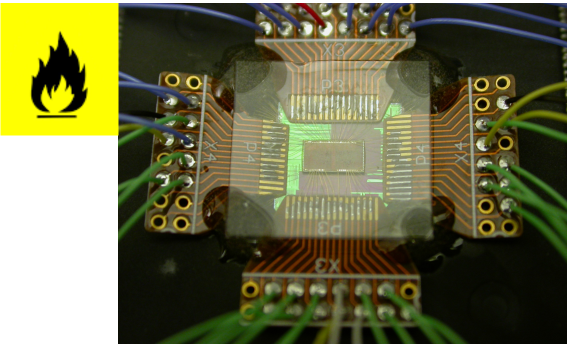



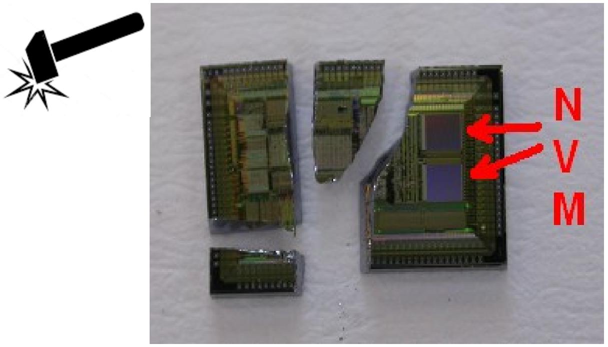

Discussions

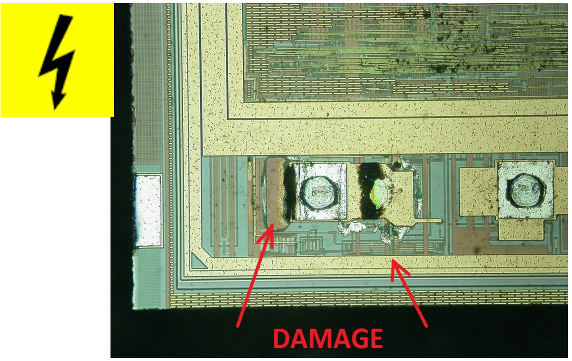
- Is it possible to predict new attacks?
  - Hardware security educated engineers
  - Open mind design reviewers
- Unexpected attack: bad or good
  - Helps in understanding the nature
  - What is bad for chip manufacturers might be good for technological progress
    - new materials could be created
    - new processes could be developed
    - new solutions to problems found

Challenges and Future Work

- Mechanical damage
  - Restore challenging packages (QFN, BGA)
  - Recovering information from shattered dies
- Electrical damage
  - Recovering information with burned I/O
  - Recovering information if logic is burned







Conclusion

- Many new attacks are based on well known facts and phenomena
- Instruction set in many CPUs is highly orthogonal, hence, susceptible to fault attacks
- Battery backed devices can be decapsulated without losing power
- New attacks are likely to emerge in the future
  - Are we ready to defeat?
- Collaboration between Industry and Academia
  - Implementing 'impossible' attacks
  - Coming up with new solutions and 'crazy' ideas