Material Efficiency: The case of devices for IoT

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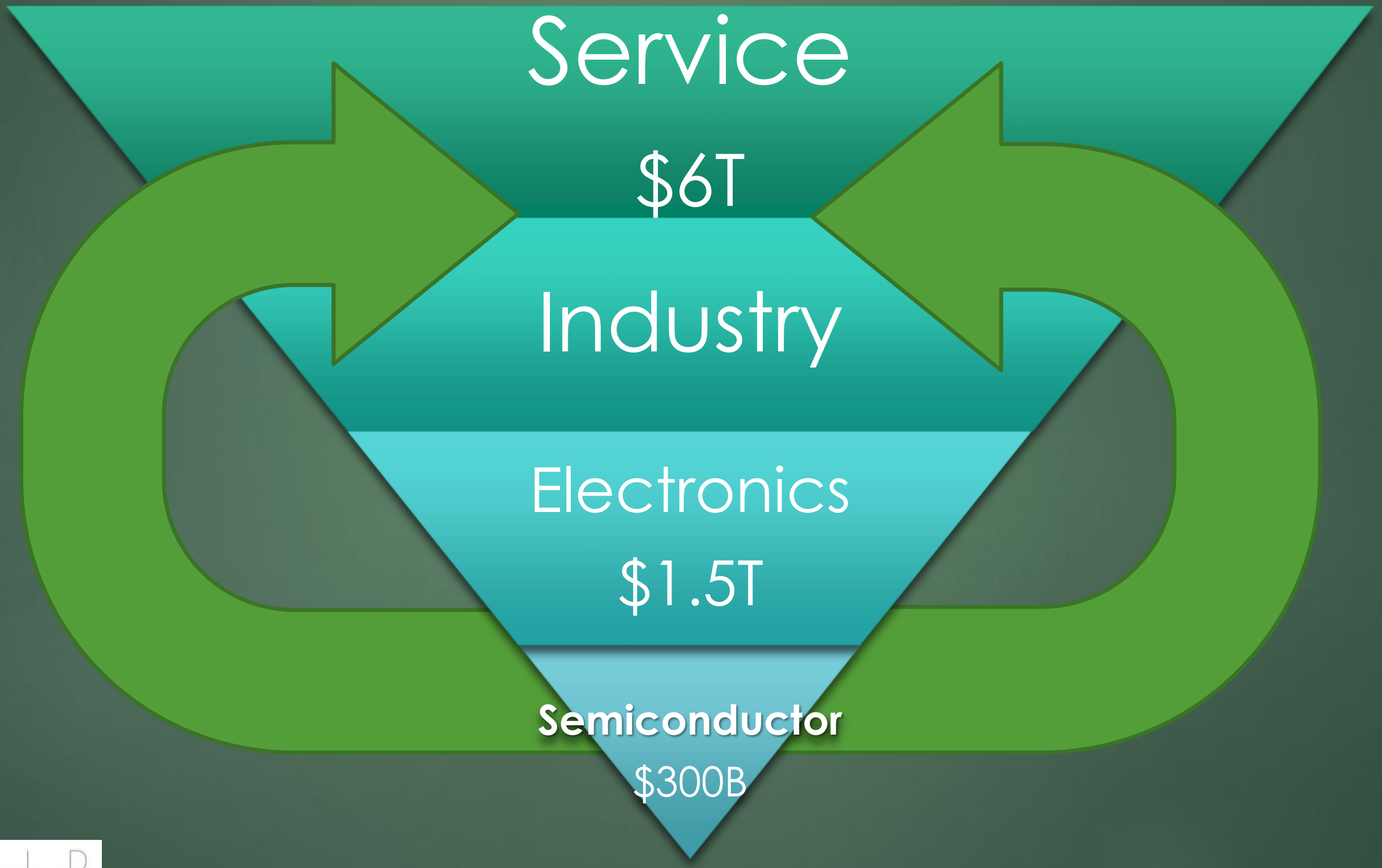
WORLD MATERIALS FORUM

WORK SUPPORTED IN PART BY FIRST, JSPS AND IMPACT, JST

Market (a university professor's view)



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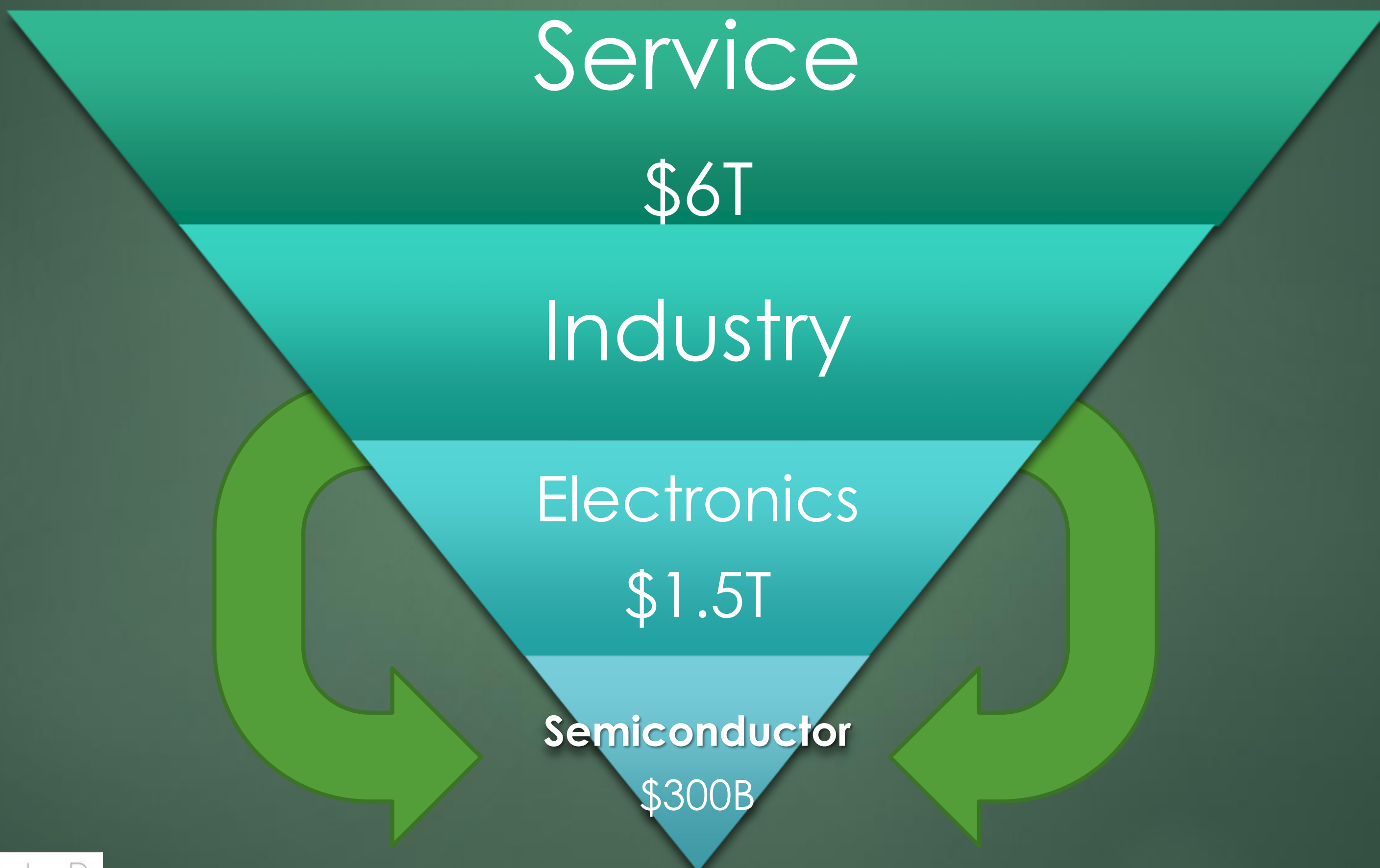

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IoT Devices

Sensors

Communication

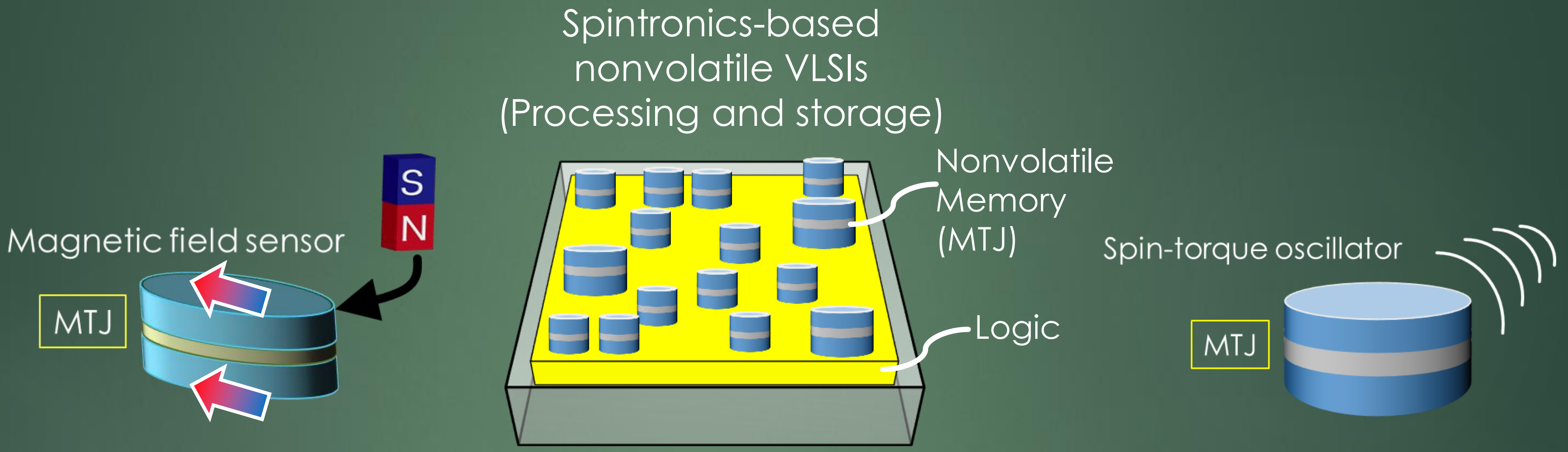
Storage

Processing

- ► Limited bandwidth: processed data for upload
- ► Maintenance free: energy efficiency

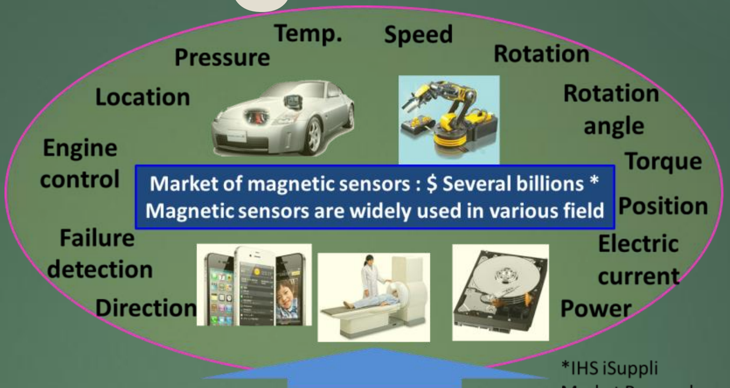
► IoT devices have to be
- small = material efficient
- smart = information processing capability
- energy efficient = low power/standby power free

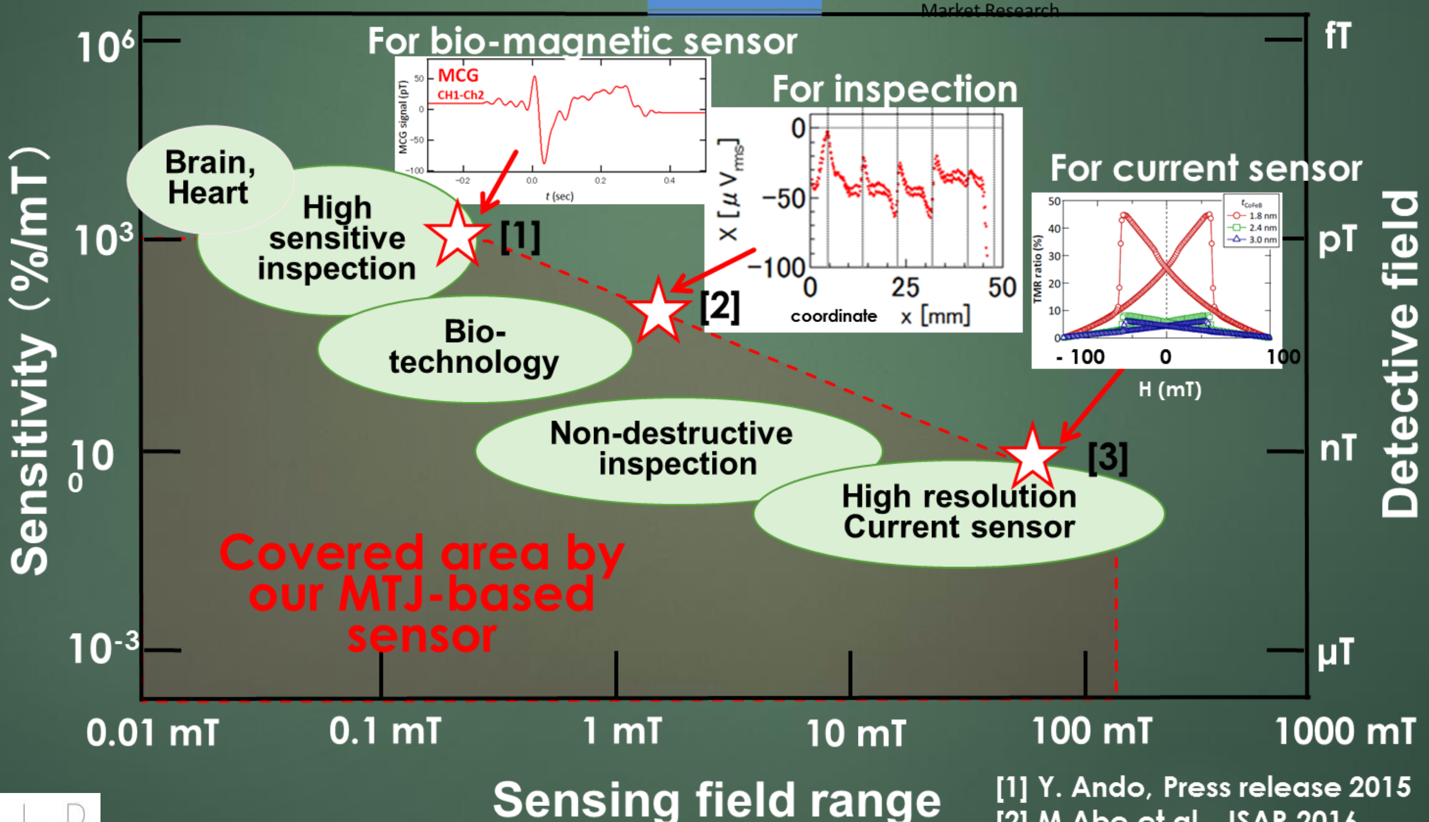
Spintronics does it all
(Magnetic Tunnel Junction: MTJ)



- Spintronics devices can
  - ✓ sense magnetic fields,
  - ✓ generate high frequency for communication, and
  - ✓ provides nonvolatile low-power processing
- They are ***small*** and can be made ***nonvolatile***
- Magnetic Tunnel Junction (MTJ): key spintronics device

MTJ-based magnetic sensors



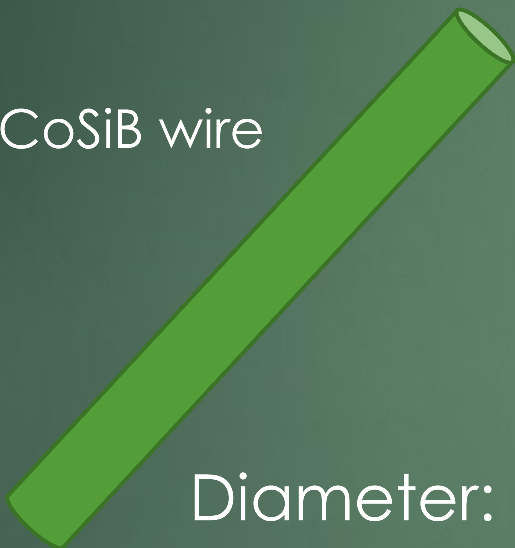


[1] Y. Ando, Press release 2015
[2] M.Abe et al., JSAP 2016
[3] T. Nakano et el., MMM 2016

Courtesy of Yasuo Ando

MTJ based field sensor vs. MI sensors

FeCoSiB wire

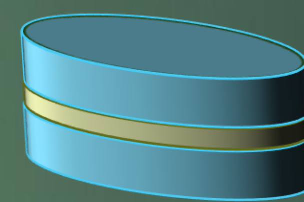


Diameter: ~20 μm

Taken from http://www.aichi-mi.com/mi-technology/%E5%8E%9F%E7%90%86/ (Japanese)

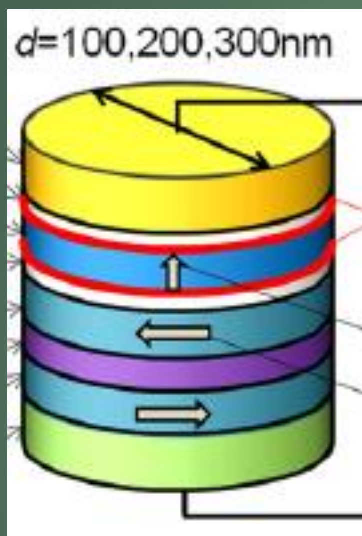
versus

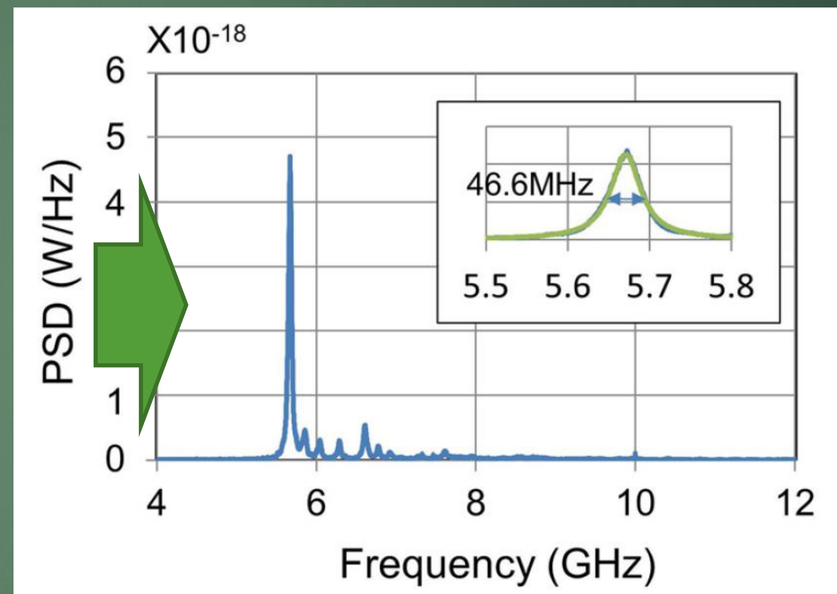
MTJ based magnetic field sensor



Size: ~μm^2

High Frequency Generation and detection by Magnetic Tunnel Junction





Taken from S. Tamaru *et al.*, J. Appl. Phys. **115**, 17C740 (2014).

Crystal oscillator

Size: ~ mm

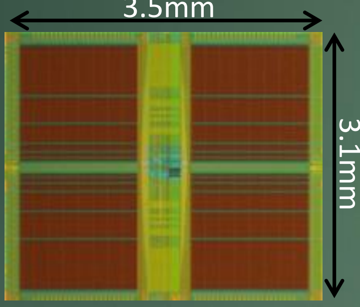
https://en.wikipedia.org/wiki/Crystal_oscillator

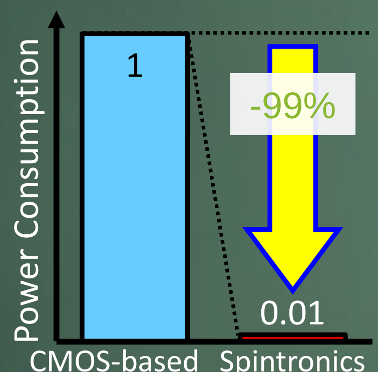
MTJ/CMOS Nonvolatile VLSIs

2013 Symposium. On VLSI Circuits

NV-TCAM

Non-volatile VLSIs for search engine for big data





$$1 \times \frac{1}{100} \times 1 \leqq \frac{1}{64}$$

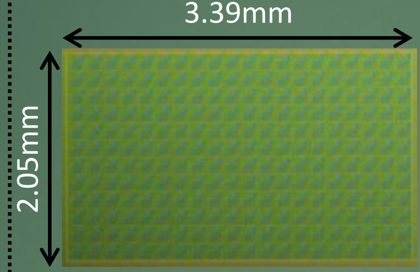
(delay) (power) (area)

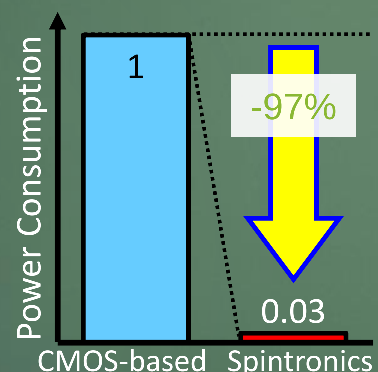
※in case of used for full text search system

2013 IEICE Electronics Express

NV-FPGA

Non-volatile field programmable gate array (FPGA)





$$1 \times \frac{1}{32} \times \frac{1}{2} \leqq \frac{1}{64}$$

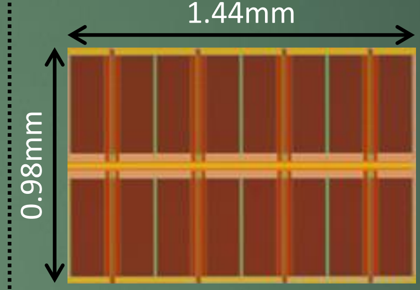
(delay) (power) (area)

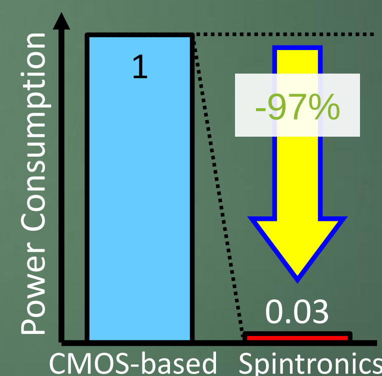
※ in case of implementation to a typical application

2012 Symposium. On VLSI Circuits

STT-MRAM

Non-volatile cash memory embedded in high speed CPU





$$\frac{1}{1.5} \times \frac{1}{29} \times \frac{1}{1.7} \leqq \frac{1}{64}$$

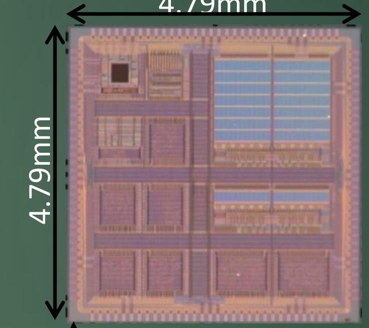
(delay) (power) (area)

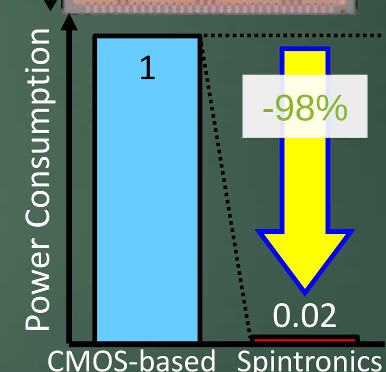
※in case of typical cash operation

2014 IEEE ISSCC

NV-MPU

Non-volatile microcontroller for battery-driven sensor device





$$1 \times \frac{1}{80} \times 1 \leqq \frac{1}{64}$$

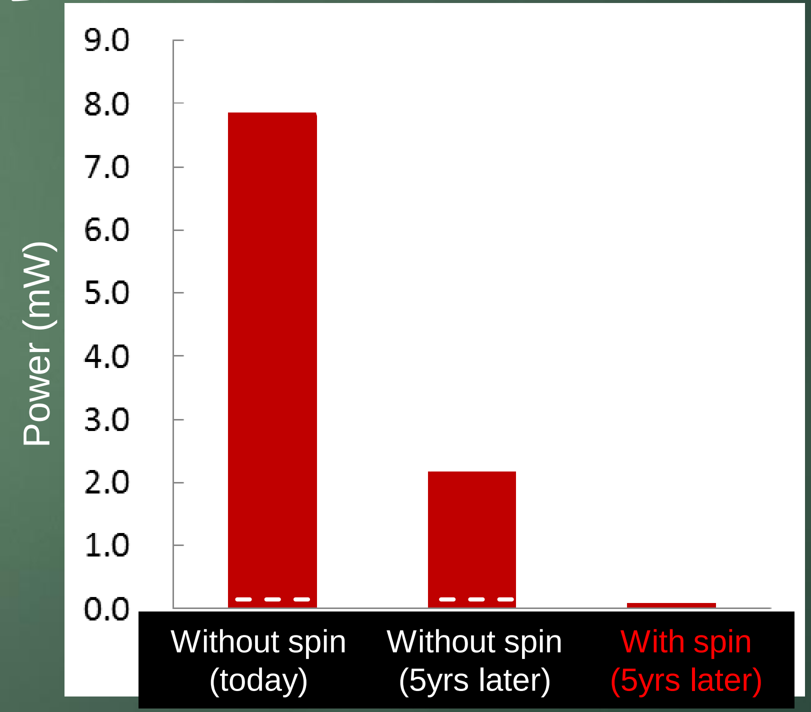
(delay) (power) (area)

※in case of use in a wireless sensor device

Battery-free: Can we get there?

- Energy Harvesting
  - 300 μW: Solar cell with room light
  - 100 μW: Vibration
- Intermittent Sensing
  - 10×10 sec-sensing a day
- Distribution of Power
  - 200 μW
    - Sensing: 20 μW
    - RF: 80 μW
    - Microcontroller: 100 μW

} 200 μW



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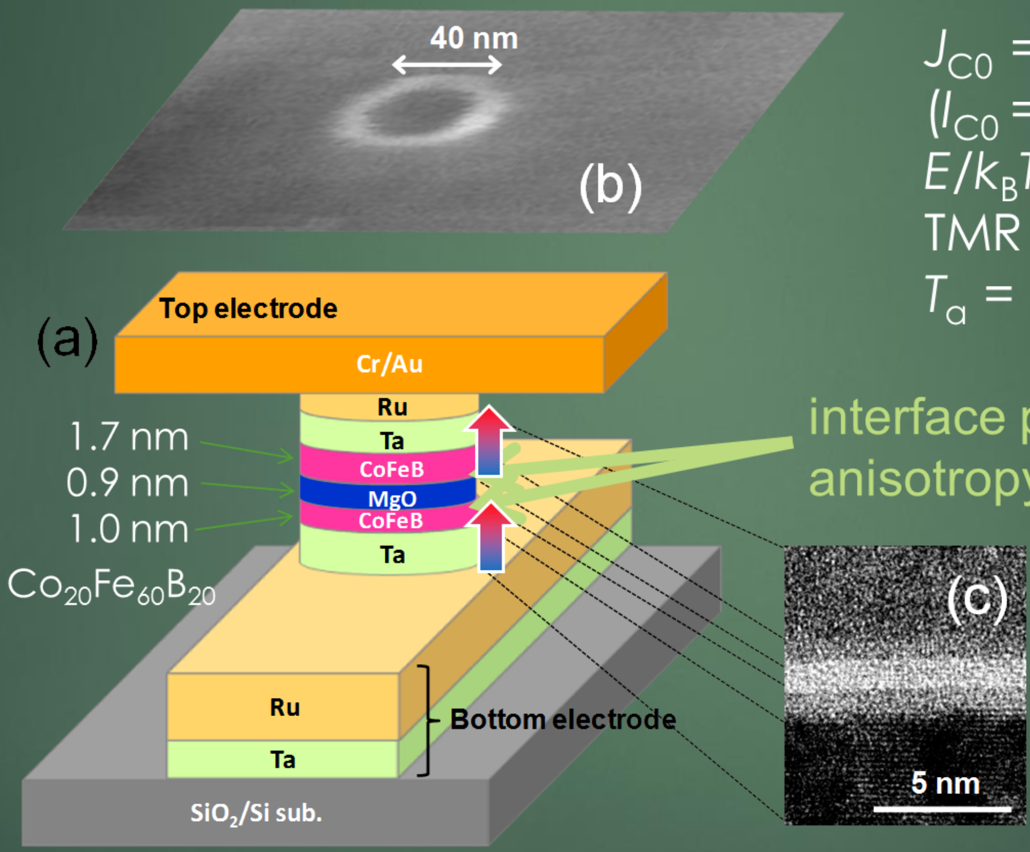
High performance nonvolatile memory element:

Perpendicular MgO-CoFeB MTJ



J_{C0} = 3.8 MA/cm^2
(I_{C0} = 48 μA)
E/k_BT ~ 40
TMR ratio = 110%
T_a = 350°C

interface perpendicular anisotropy

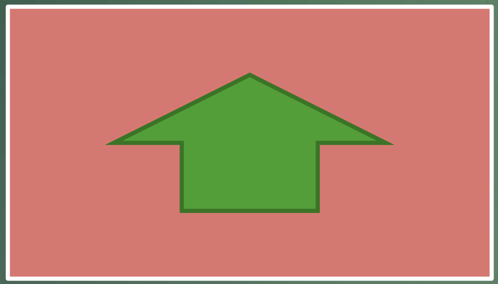
Interface!

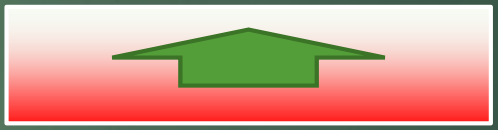
S. Ikeda *et al.*, *Nature Mat.* **9**, 721 (2010)

Magnetic Tunnel Junction - bulk versus interface -

FePt (bulk)

CoFeB (interface)





Materials Efficiency (Cost of material)

10 :1

Recycling at the level of manufacturing tool: efficiency

MTJ Material

Target

300 mm wafer

~3%

MTJ Product

97% left in the chamber

http://www.tel.co.jp/news/2014/1201_001.htm

SUMMARY

- **Spintronics device** (Magnetic Tunnel Junction) provides key functionalities required for IoT: sensing, communication, and information processing/storage
- It is material efficient and becoming more so with newly developed device structure (**interface**)
- **Retrieving unused materials** from manufacturing tools under development for further increasing the material efficiency

Next: Wireless Passive Sensor Technology, Donald C. Malocha