Introduction to College of Semiconductor Reseach (CoSR)

National Tsinghua University (NTHU)

Chih-Huang Lai (賴志煌)

NTHU CoSR 國立清華大學 半導體研究學院 College of Semiconductor Research

Strategic Location

NTHU is located in Hsinchu City, which is located in the northern Taiwan with an hour drive to Taipei, is surrounded by world-class national laboratories and industries. Hsinchu is also referred to as the science city, the high-tech hub, and the Silicon Valley of Taiwan.

CoSR Half Funded by Government & Half by 12 Semiconductor Companies (2022/4)

tsmc PSMC VIS 世界先進 TEL TOKYO ELECTRON Micron GlobalWafers Co., Ltd. 環球晶圓股份有限公司

Unimicron 欣興電子 UMC 聯華電子 MEDIATEK FocalTech 敦泰電子 NANYA NOVATEK

CoSR Organization Structure

Dean
Burn J. Lin (林本堅)
NAE, IEEE fellow,
Academia Sinica
Acadmician

Associate Dean
C.H. Lai(賴志煌)
Chair Professor
IEEE fellow

4 Departments

Device	Design	Material	Process
			
C.J. Lin 林崇榮	J.J. Liou 劉靖家	S.Y. Chang 張守一	T.S. Gau 高蔡勝

Student Numbers

PHD	Applied		Admitted		In CoSR
	Early Selection	Exam	Screen	Exam	
2022	20	9	14	6	14
2023	10	7	7	4	15
2024	11		7		-

Master	Applied	Admitted	In CoSR
2022	408	80	64
2023	602	80	77
2024	561	80	-

International	Applied		Admitted		In CoSR
	P	M	P	M	
2023(1st half)	3	8	1	0	1 (P)
2023(2nd half)	1	7	1	0	0
2024(1st half)	4	4	3	2	-

1. PHD Students 29
   (1 international)

2.Master Students 141
   (0 international)

Faculty

	Full-time Professors	Joint Professors in NTHU	Joint Professors from Industry
Numbers	6	93	9
Remarks	Majority from retired experienced experts (20+ yrs) from industry (TSMC, Synopsys)	From other departments, Electronic Eng, Materials Sci, Chemical Eng, Physics, Chemistry,…etc	From NTU, NSYU, TSRI, ITRI, SRRC, …. University or research organization

Education Guideline :
Training Semiconductor Leaders

CoSR : Basic Scientific Training + Device Design Process Materials + Device Design Process Materials + 

Specialist Generalist Dynamic Innovator

Problem Solving !

Course Structure

Required

Design	Device	Material	Process
Introduction	Introduction	Introduction	Introduction
Device	Design	Design	Design
Material	Material	Device	Device
Process	Process	Process	Material

Required & Selective

Design specific	Device specific	Material specific	Process specific
Digital	Device Physics	Material Kinetics	Process integration
EDA	MEMS	Material Analysis	Lithography
Analog, RF, Mix-Signal	Memory	Polymer	Module Technology
AI & Signal Processing	Sensors	Functional Material	Packaging
	Power devices	Material Analysis	
	Devices Exp.		
	High Freq.		

Course-Industry Professors

TSMC VP
Michael Wu (吳顯揚)
Advanced Device

ASML VP
Anthony Yen(嚴濤南)
「EUV Principle」

TSMC VP
Doug Yu(余振華)
「 Nanometer Packaging 」

PSMC CTO
SZChang(張守仁)
「Process Integration」

TSMC Director
KCYee(余國寵)
「Nanometer Packaging」

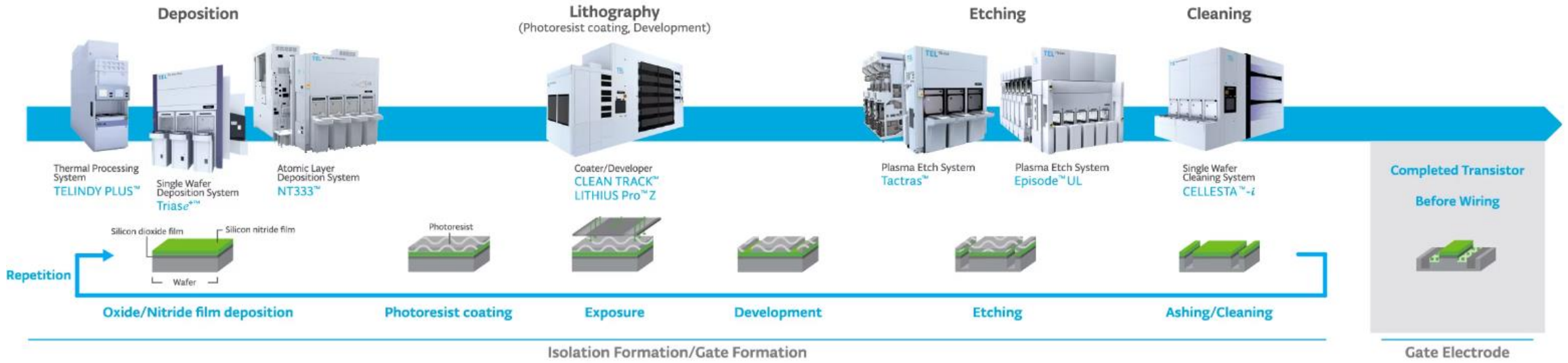
KLA Director
Q. Zhao(趙強)
「Advanced Metrology」

TEL Senior VP
Peter Loewenhardt
「Litho、Etch、Film、Clean、Tool & Control」

ASML Senior Director
CKChang(陳俊光)
「Litho、Etch、Film、Clean、Tool & Control」

Hand-on Education

Pictures from TEL website



Practical course of FinFET Process Fabrication – TSRI 8" production line

DRAM Theory, Practice and Manufacturing – Micron Taiwan FAB

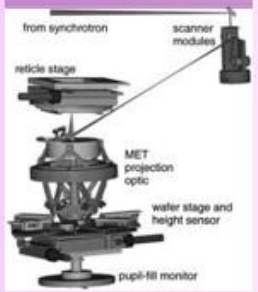
Internship to industry FAB – TSMC, PSMC, UMC, ….

RESEARCH HIGHLIGHTS OF FOUR DEPARTMENTS

Process Department

Burn J. Lin, Dean of CoSR
Academician, Academia Sinica
US NAE Member,
IEEE Fellow, SPIE Fellow
Nanolithography

Berkeley EUV



Layout Design
e-beam process
3D simulation
OPC

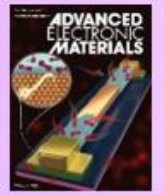
ASML

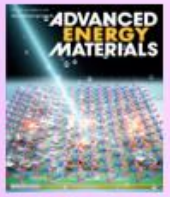
Mask scheme optimization
Mask blank acquisition

Goal: Patterning world smallest logic contact-hole pitch (< 30nm)

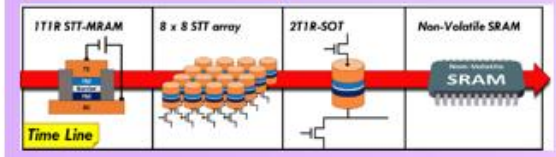
Materials Department

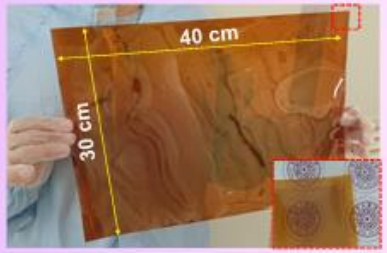
MRAM RAMA memory cells
2D materials
High-k and interconnect
Packaging





nature materials

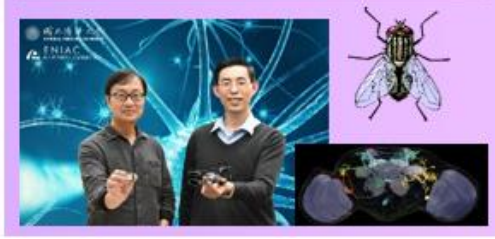


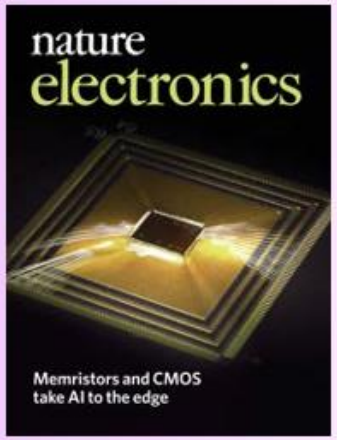


Design Department

CMOS-integrated compute-in-memory based on RRAM for AI edge devices.

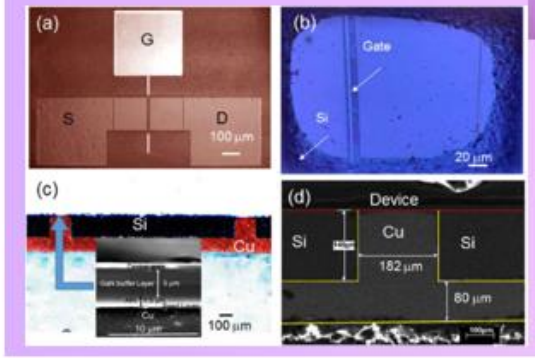
Artificial Intelligence (AI) Chips





Device Department

Power Semiconductor
Advanced VLSI devices
Memory Technology
MEMS Chips

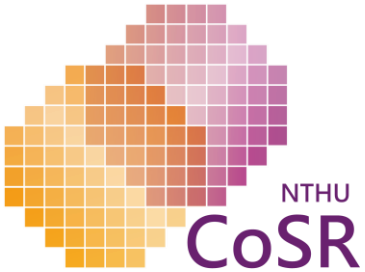


Possible Collaboration

1. Exchange of students and faculty members

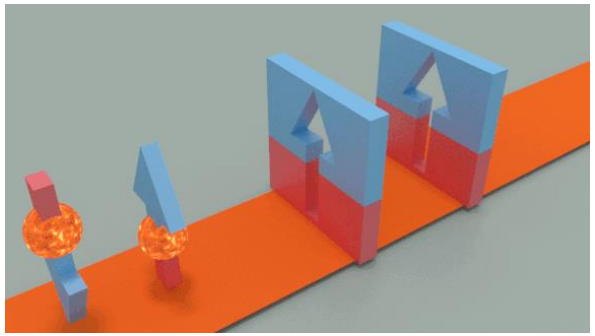
2. Co-advising graduate students with scholarship

3. Special programs on specific topics (HsinChu and Kaohsiung)

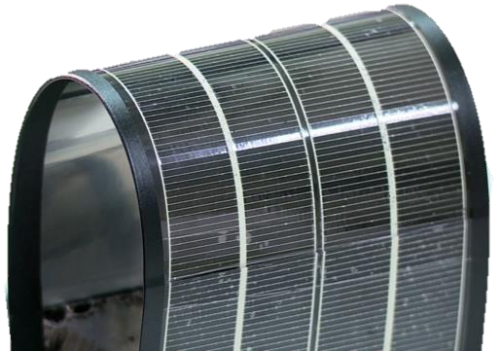


Thank you !

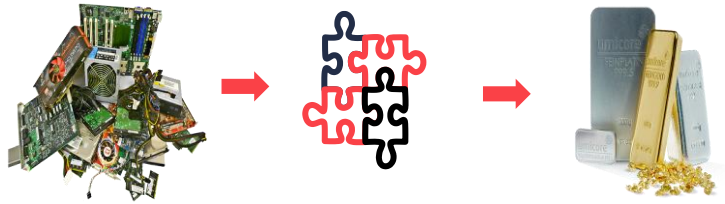
Research in Lai's group



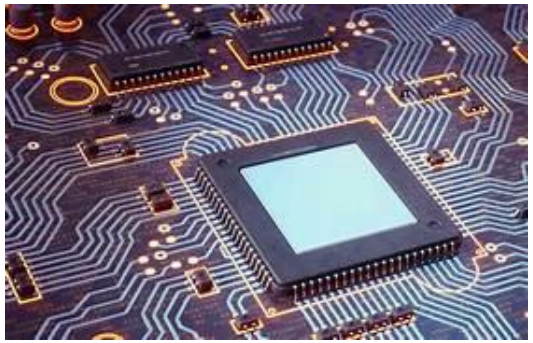
Spintronics (MRAM)



Solar cells



Material sustainability



Semiconductor materials

2 post-docs, 12 Ph.D. students, 12 master students (total 7 international members)

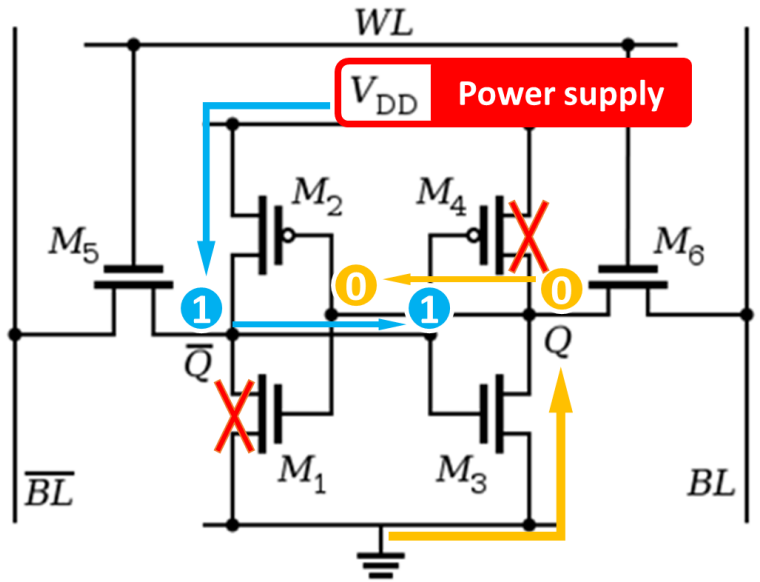
Memory unit cell

- **DRAM:**

DRAM

Charge leakage, more power consumption

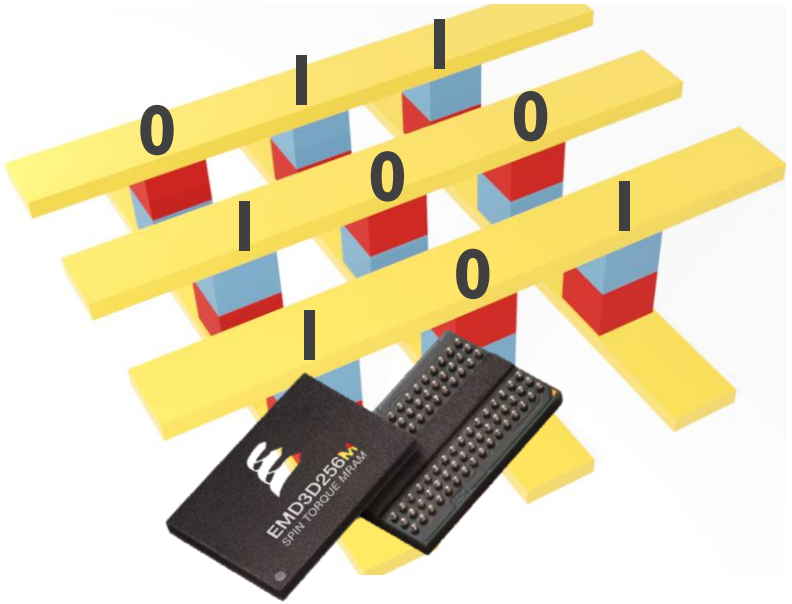
- **SRAM:**



SRAM

Need continuous power supply

- **MRAM:**

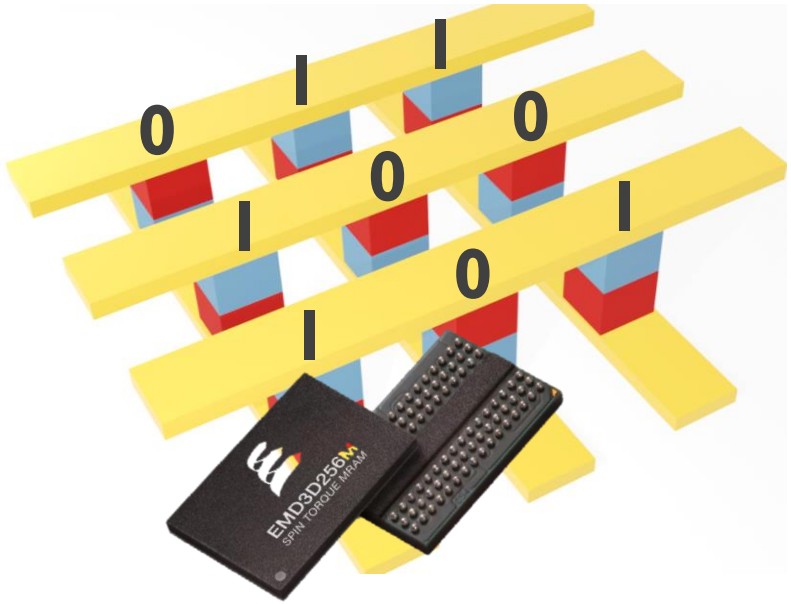


MRAM

*Stable polarity ,"**non-volatile**".*

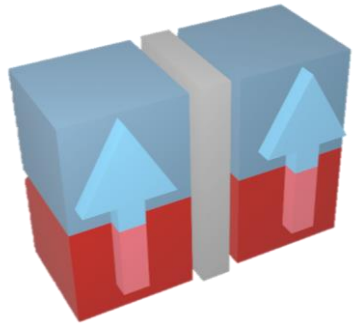
Memory unit cell

- **MRAM:**

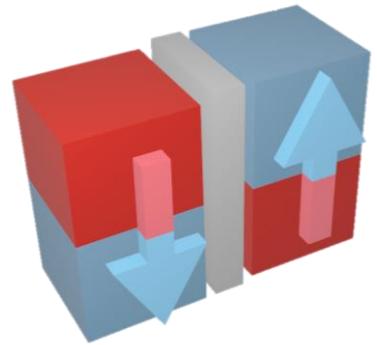


MRAM

Unit cell:
Magnetic Tunneling Junction



1

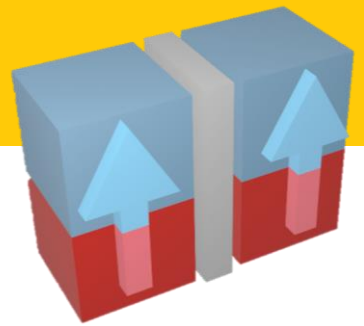


0

Magnetic Tunnelling Junction

MRAM

MTJ: use Spins, instead of Charges



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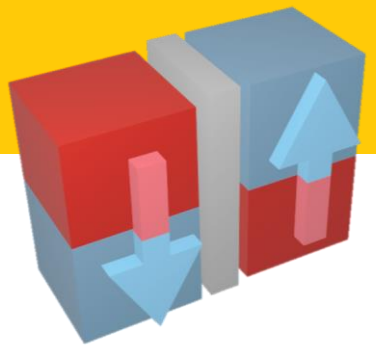

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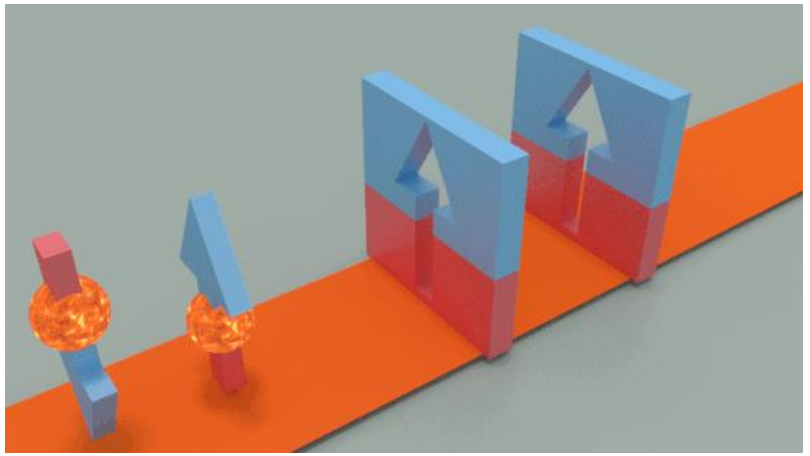
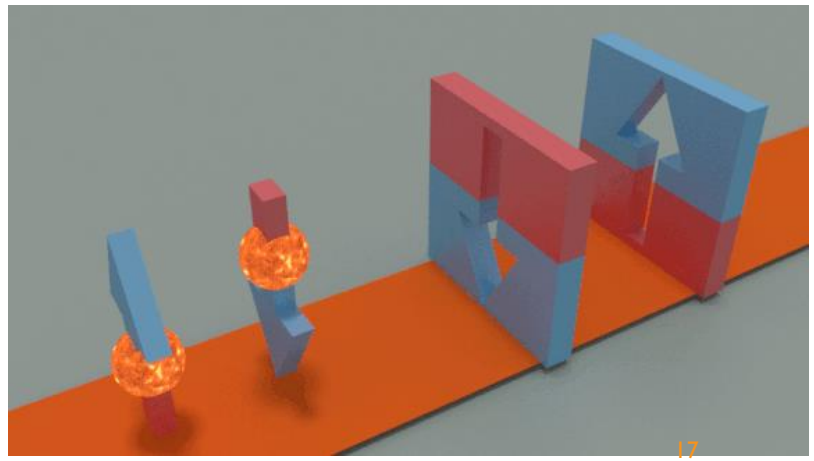


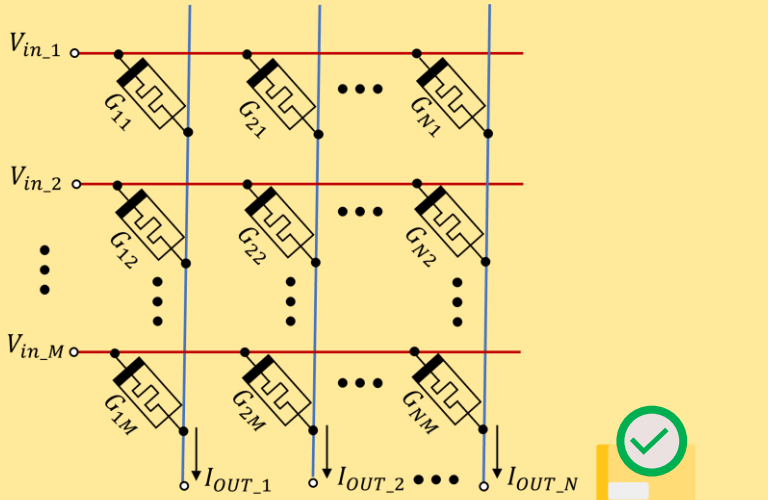


MRAM-CIM

CIM (Computing In Memory), A new computing concept inspired by human brain cells, was proposed to address Von Neumann bottleneck.

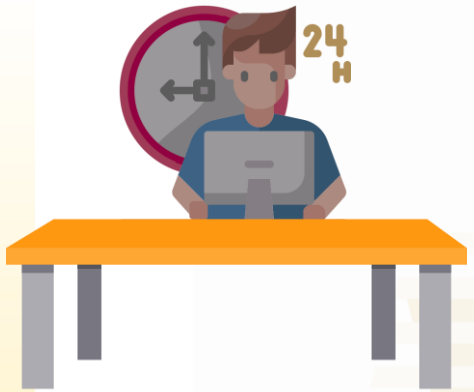
It saves time by minimizing data transit and significantly reduces power consumption.

CIM device



$$I_{OUT\_N} = \sum_{i=1}^{M} (G_{Ni} \times V_{in\_i})$$

Memory | Data trans | Processor

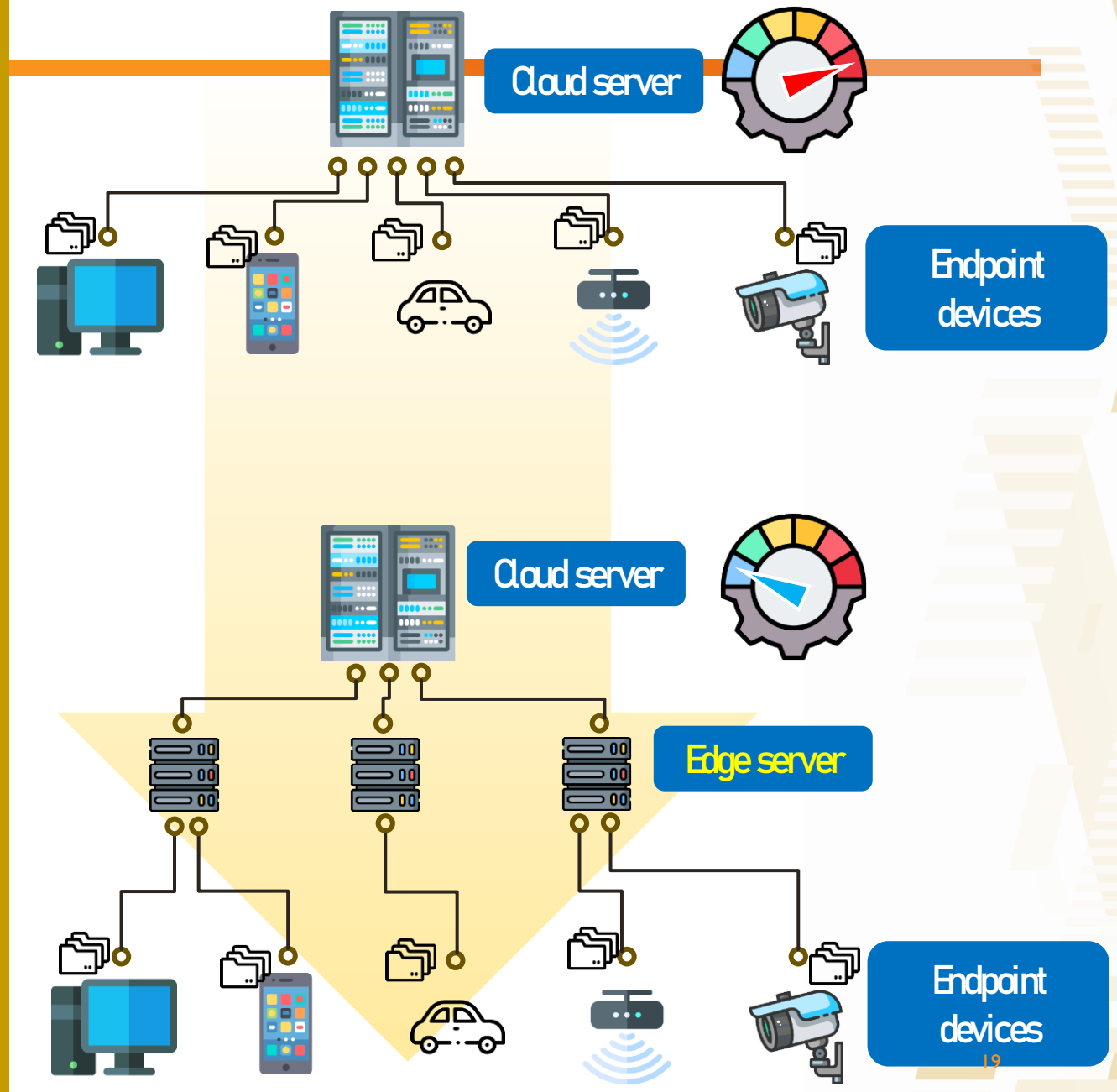


CIM | Data trans | Processor

Edge computing

Endpoint devices produce huge amount of data
→ cloud server unable to sustain computing workload

Edge servers help to share the workload and return non-immediacy data to cloud servers



Memory for Edge Server

- High speed
- Low energy consumption
- Endurance
- Non-volatile

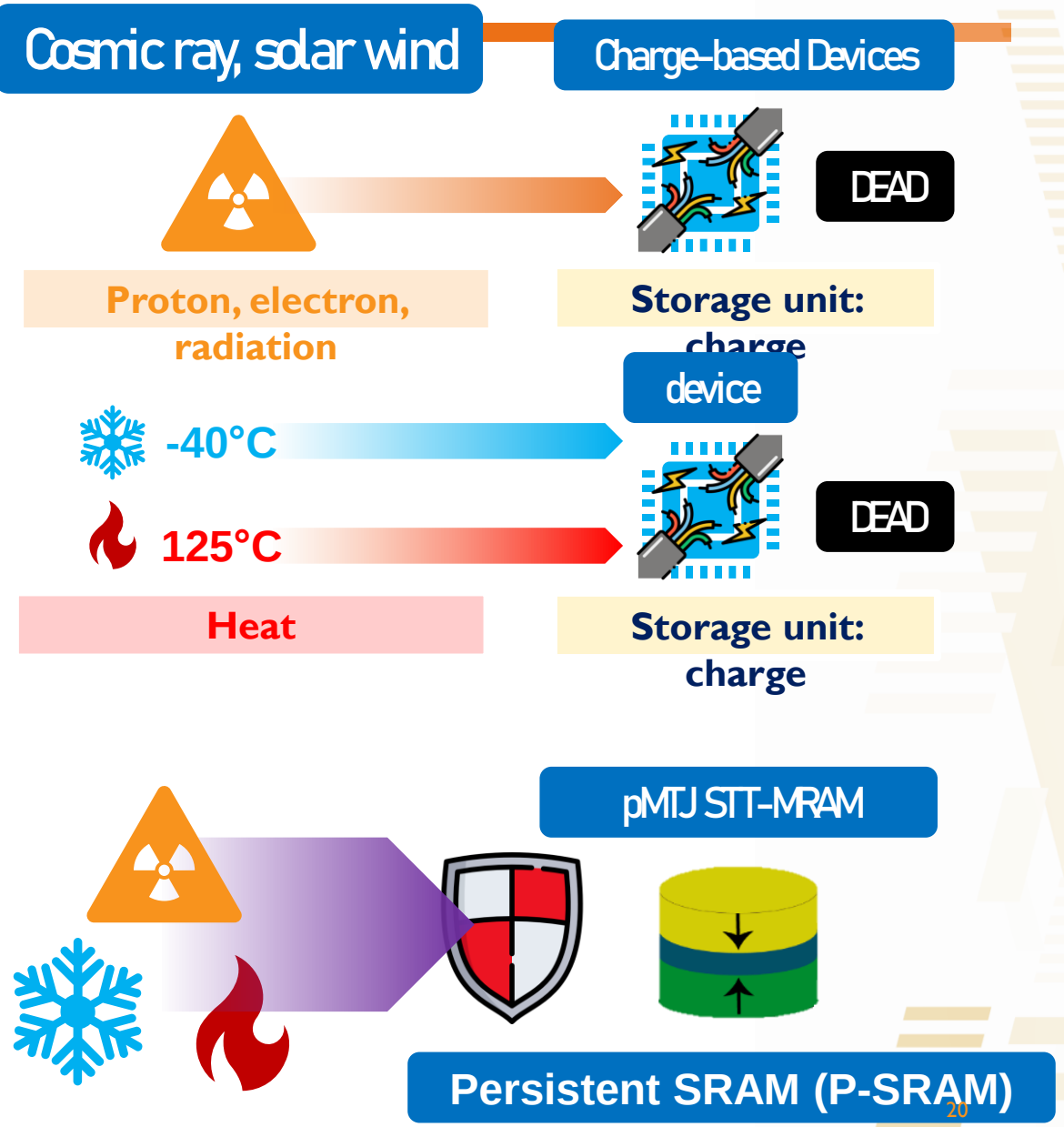
Application

- *IoT*
- *AR/VR*
- *Autonomous vehicle*
- *Intelligent factory*
- *Sensor*

MRAM-Avionics

Avalanche Technology's Persistent SRAM is a type of MRAM that can operates successfully in harsh environments.

P-SRAM (MRAM)	Parallel x32 (Gen 3)	Serial D-QSPI (Gen 3)
Densities	1Gb, 2Gb, 4Gb, 8Gb	1Gb, 2Gb, 4Gb, 8Gb
Voltages	3.0V (2.70V to 3.60V)	3.0V (2.70V to 3.60V)
Package	142-ball FBGA	96-ball FBGA
Temperature Ranges	Space-Grade (-40°C to 125°C)	Space-Grade (-40°C to 125°C)

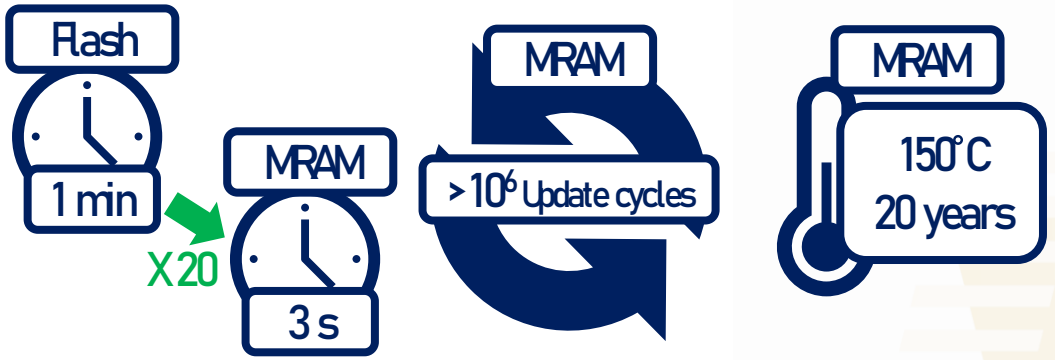


MRAM-Automobiles

MRAM will bring revolution to memory and advanced processors of automobile.

Memory

Hgh speed	Long cycle life	Endurance



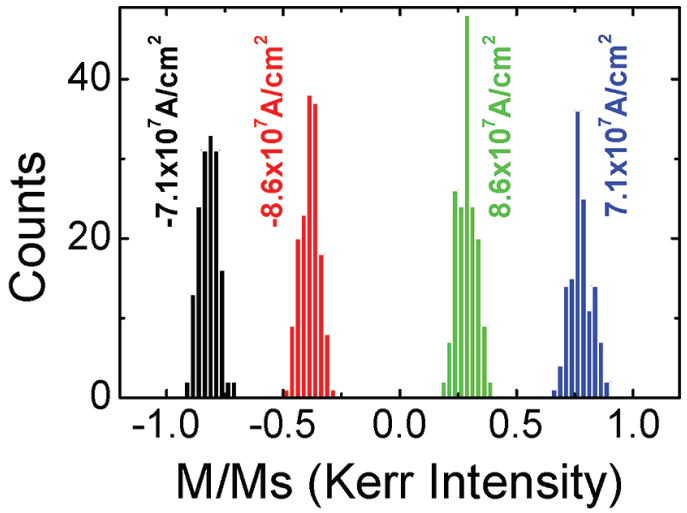
Level 3 Cache

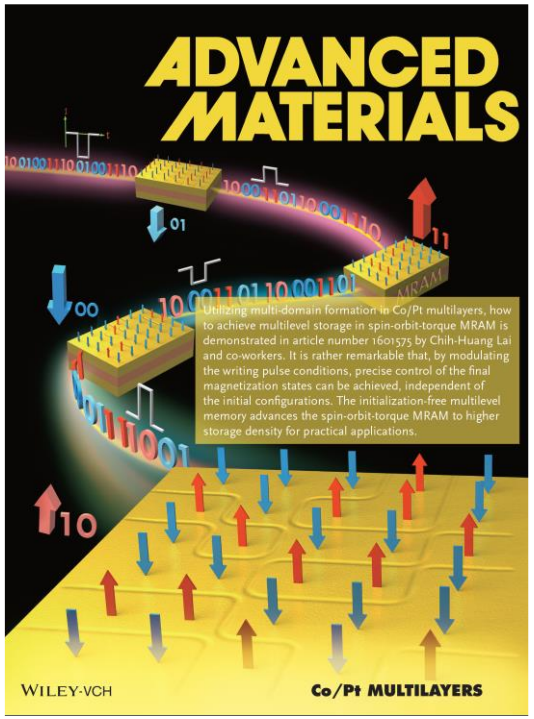
SRAM

- Low bit density
- Power consumption

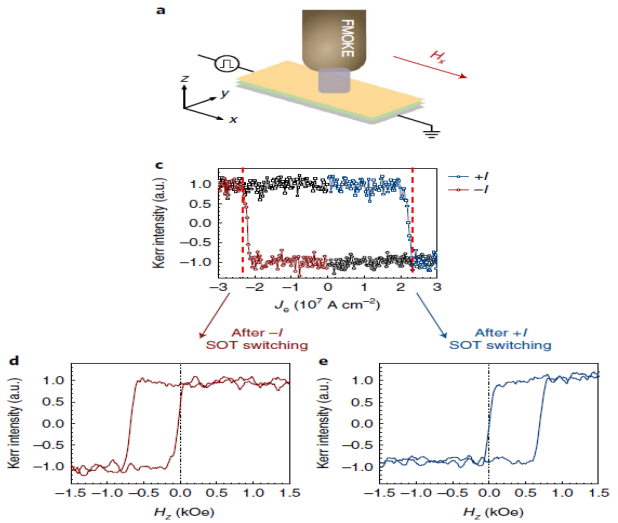
MRAM

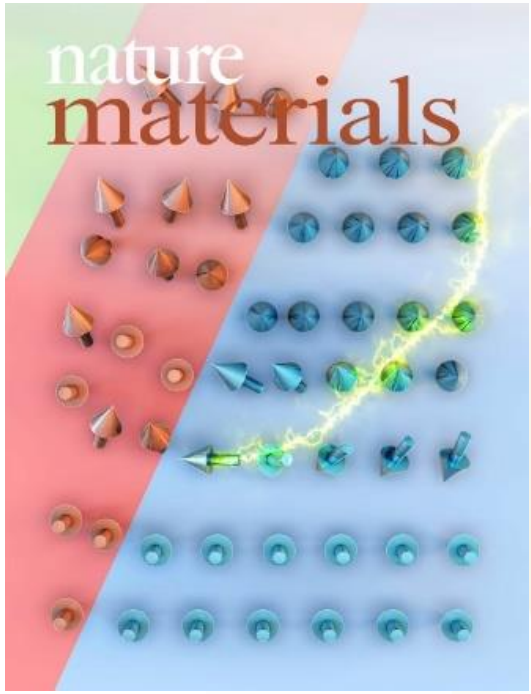
- Hgher bit density
- Non-volatile





Advanced Materials, 2018



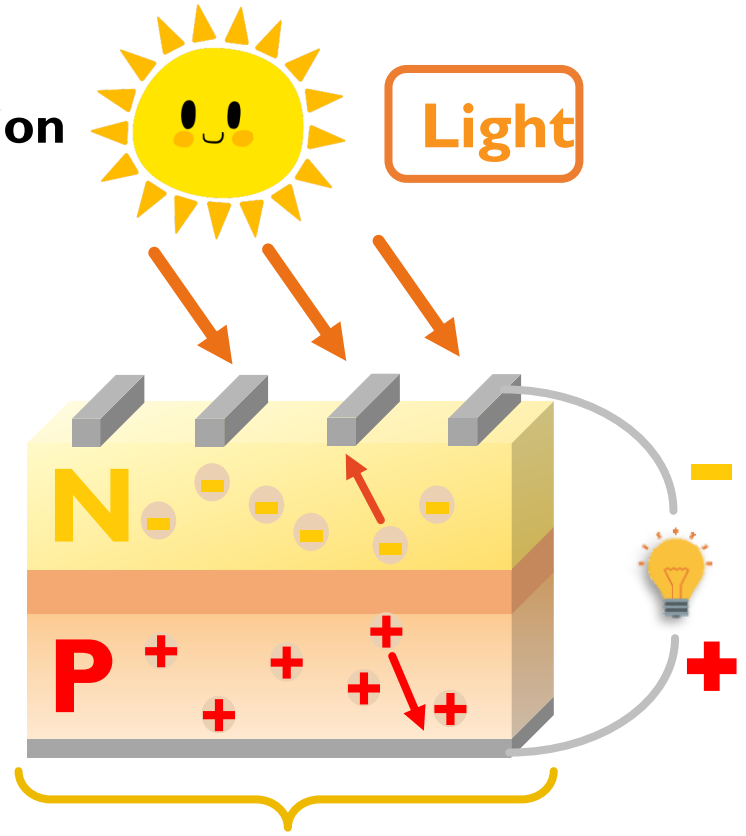


Nature Materials, 2019

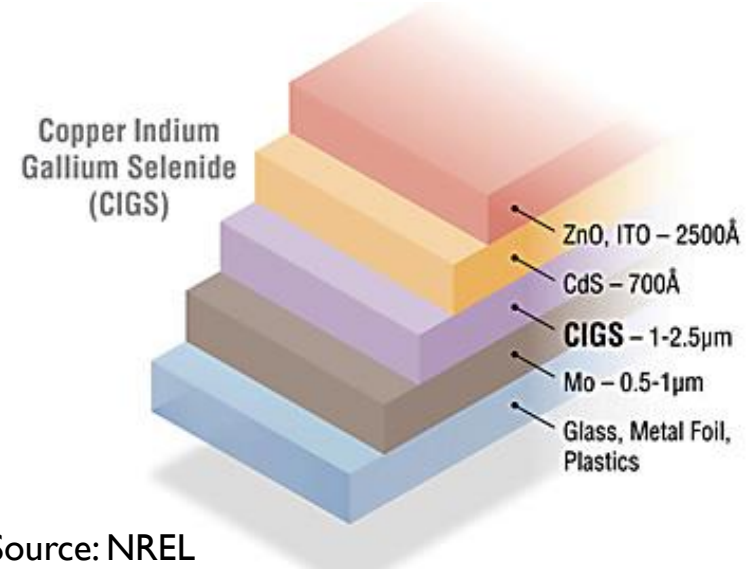
$Cu(In,Ga)Se_2$ (CIGS) Thin Film Solar Cell

What is Solar Cell?

- **Conversion efficiency, η**
  →Indicator of power generation



☐Structure of solar cell

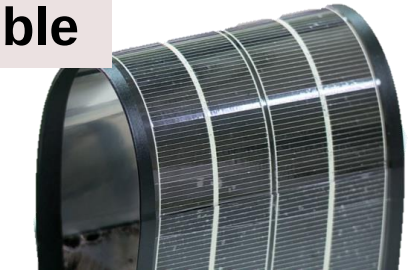


Source: NREL

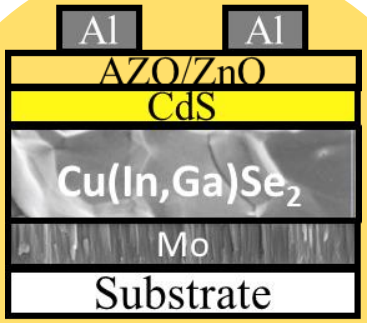
CIGS Solar Cell

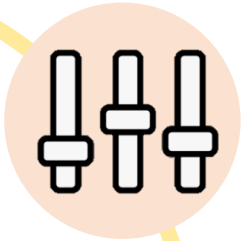
☐ Why we choose $Cu(In,Ga)Se_2$ (CIGS) solar cell ?

Thin and flexible

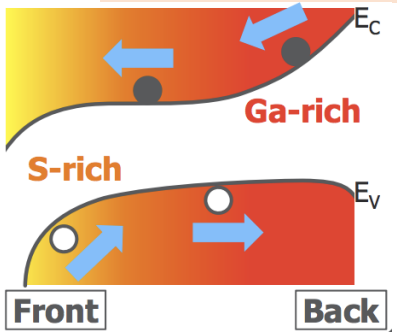


Solar Frontier

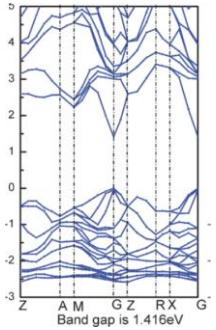




Tunable band structure



Energy Environ. Sci., 2017, 10, 1306-1319

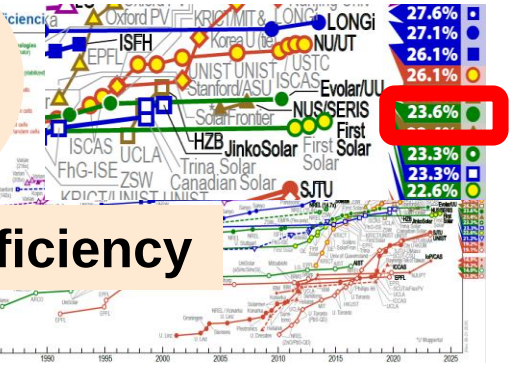


AIP ADVANCES 4, 087118 (2014)

Direct band gap

Si：26.7%

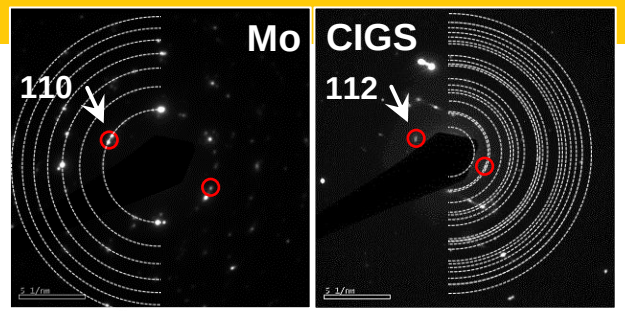
CIGS：23.6%

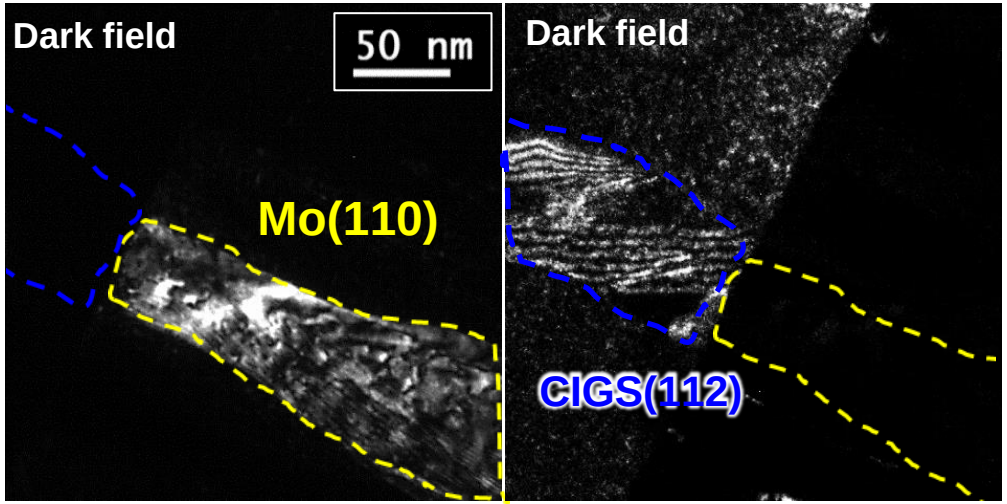


High efficiency

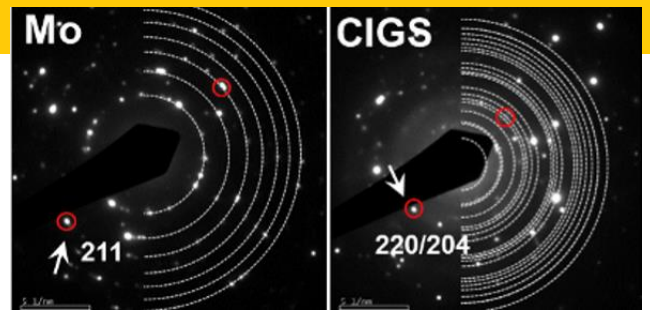
NREL

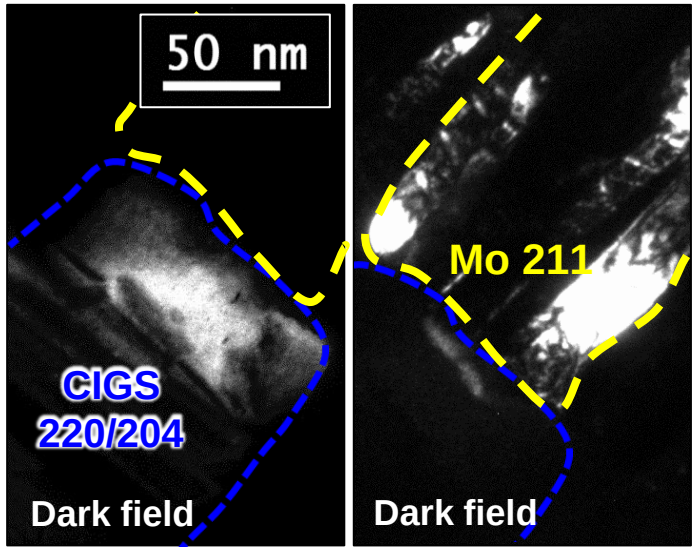
EPITAXIAL GROWTH BETWEEN CIGS & MO





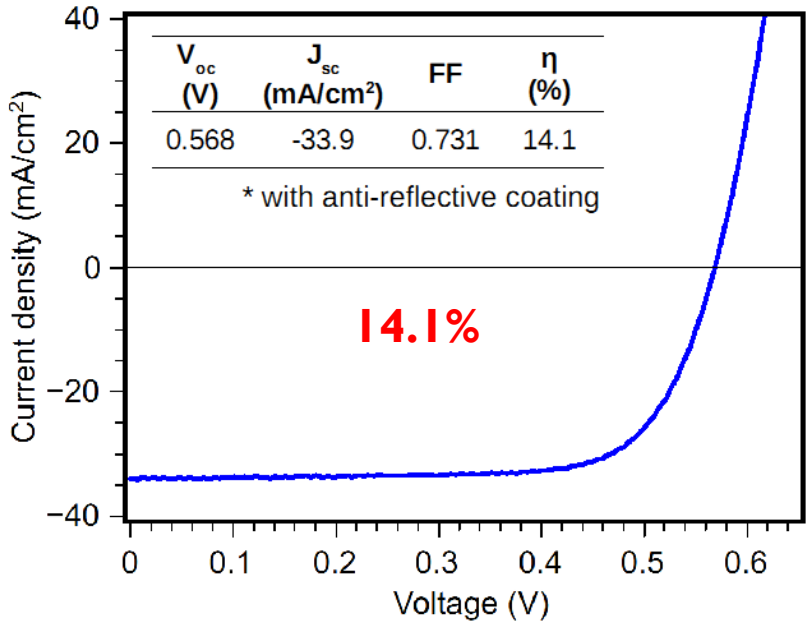
Mo: 3 mtorr

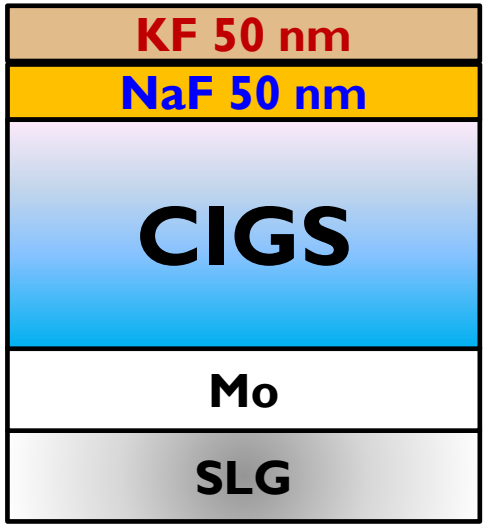


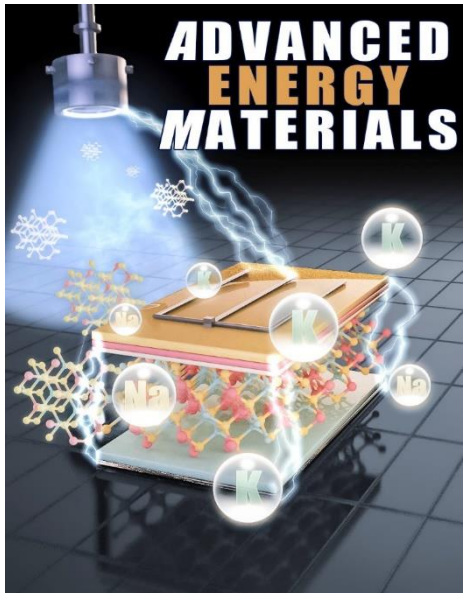


Mo: 7 mtorr

COMBINATION OF NAF AND KF







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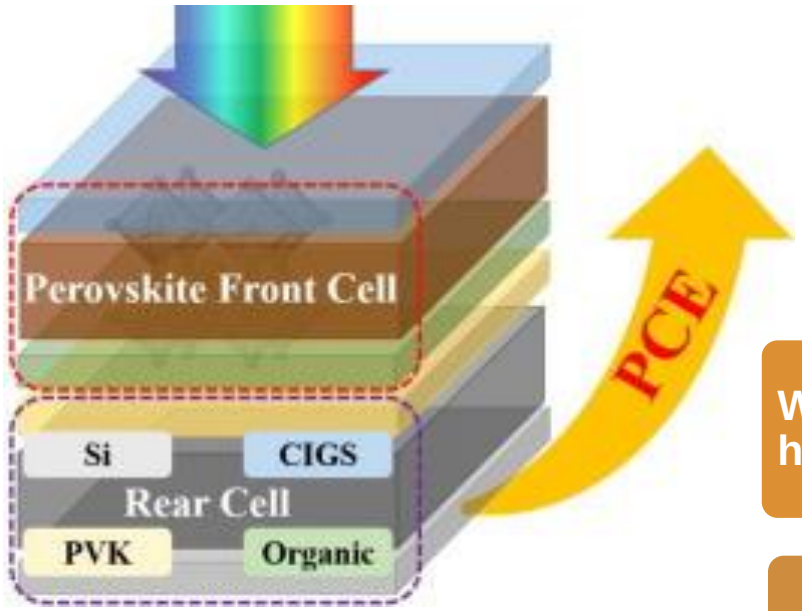
Hsu & Lai, Adv. Energy Mater. DOI: 10.1002/aenm.201602571 (2017)

Multi-junction (Tandem) Solar Cell

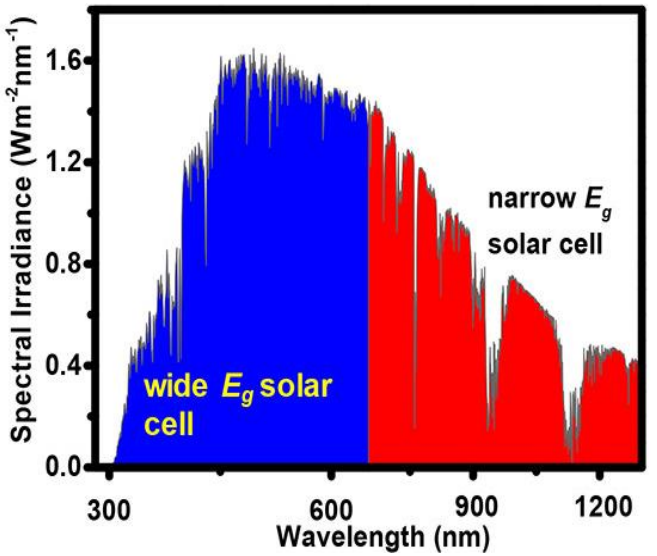


To further increase the PCE of solar cells beyond Shockley-Quiesser limit

Combine different absorbers with complementary bandgaps

Wide-bandgap active layer harvests high-energy photons

narrow-bandgap active layer captures low-energy photons



Development of Recycling Technologies for Net Zero Emission and Resource Sustainability

Recycling Technologies

Hydrometallurgy

- Lithium-ion batteries

Electrometallurgy

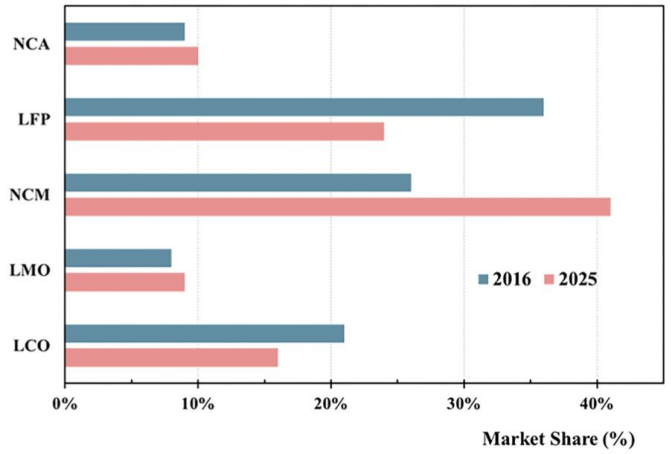
- Rare-earth magnets
- Tungsten alloys

Pyrometallurgy

- Liquid crystal displays

Hydrometallurgy for Lithium-ion batteries

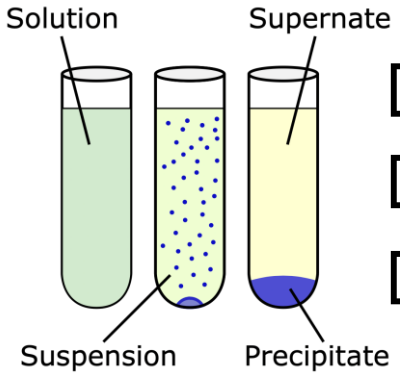
- **For all types LIBs**



Chem. Rev. 2020, 120, 7020-7063.

LIBs Recycling

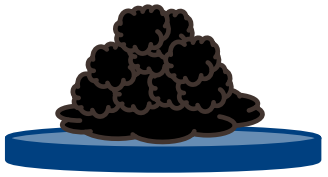
- **Absolute chemical precipitation**



- ☑ Easy
- ☑ Cheap
- ☑ Mn, Co, Ni separation

- **High purity Li & Co products**

99.77 wt%
Li_2CO_3



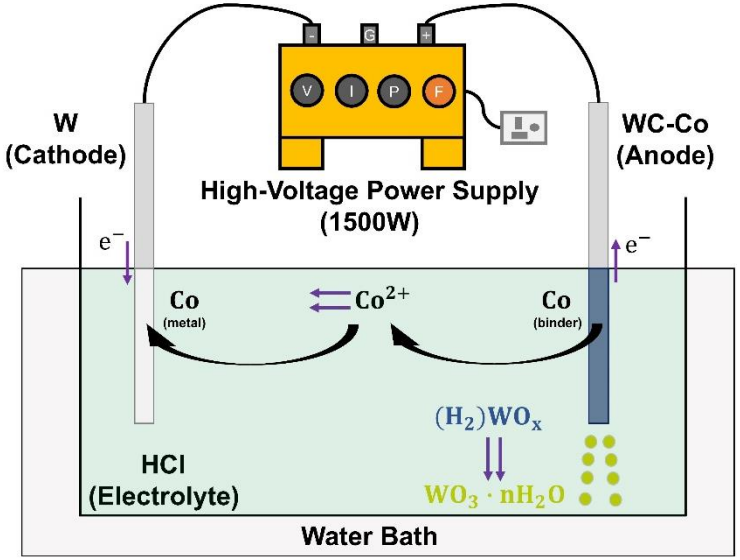
99.55 wt%
$Co_2O_3 \cdot 3H_2O$

- **Low cost**

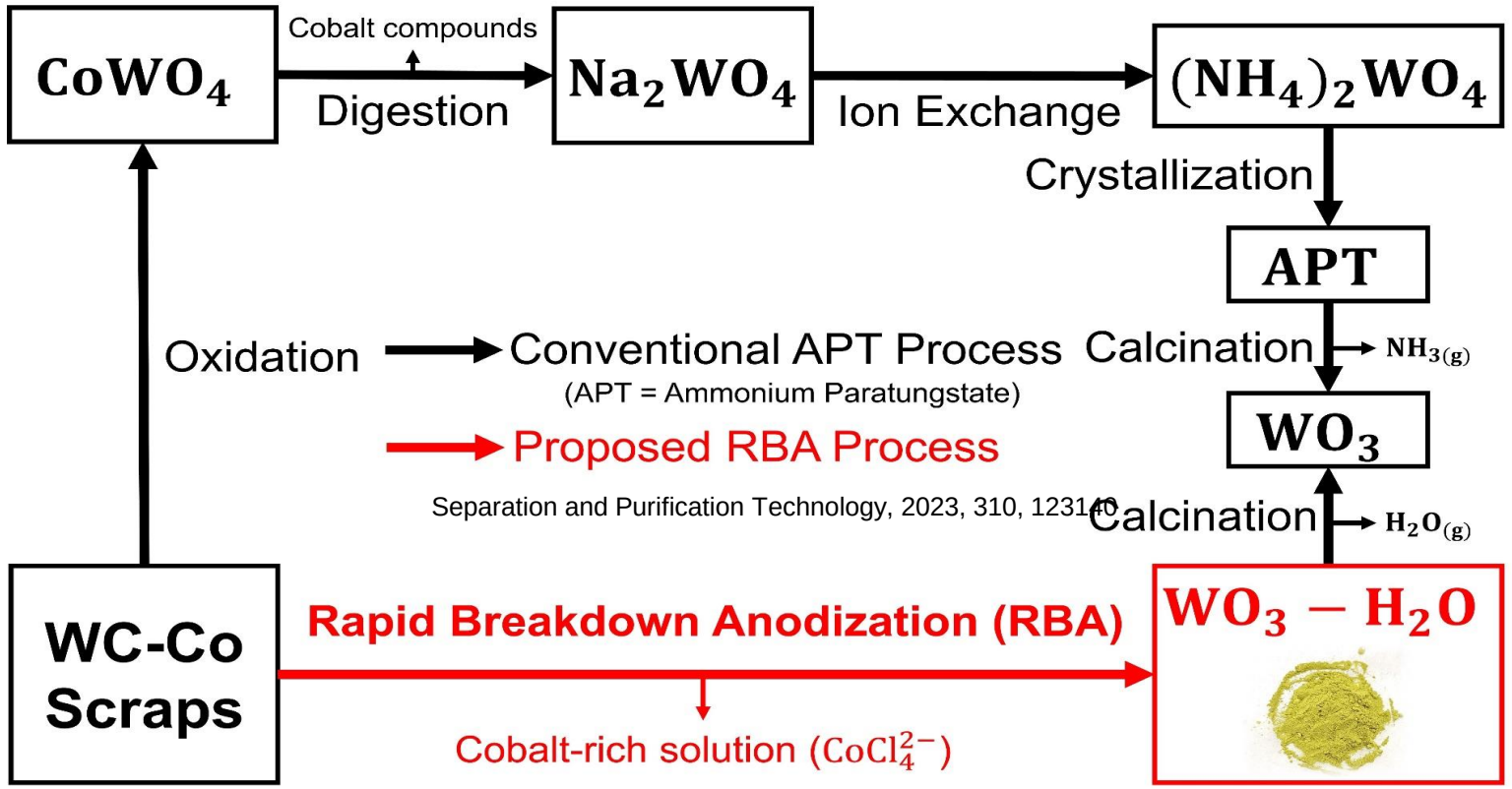
*LIBs = lithium-ion batteries

Electrometallurgy for Tungsten alloys

Tungsten Alloys (WC-Co, W-Ti…)



Electrometallurgy (ex. RBA)

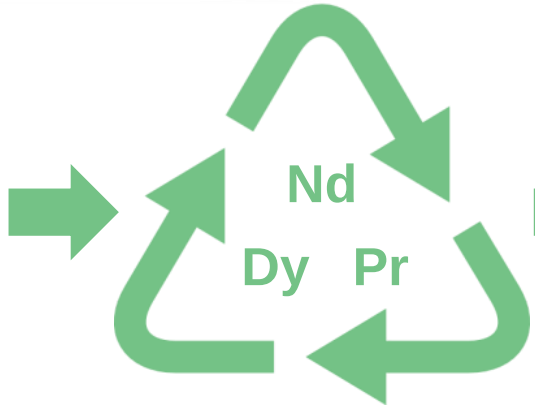


High Purity, High Efficiency, High Flexibility

Electrometallurgy for Rare-earth magnets

Permanent Magnets (NdFeB, SmCo…)

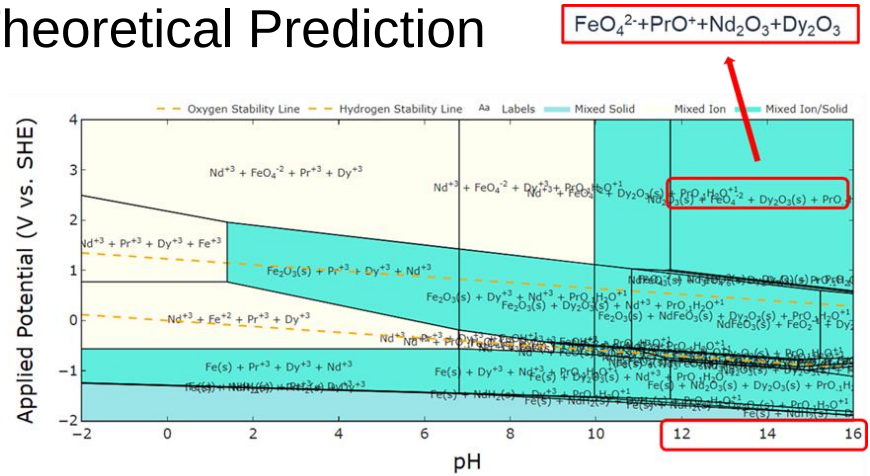
Commercial Magnets (NdFeB)



Electrometallurgy

Rare-earth Oxides ($Nd_2O_3, Dy_2O_3, Pr_2O_3$)

Theoretical Prediction

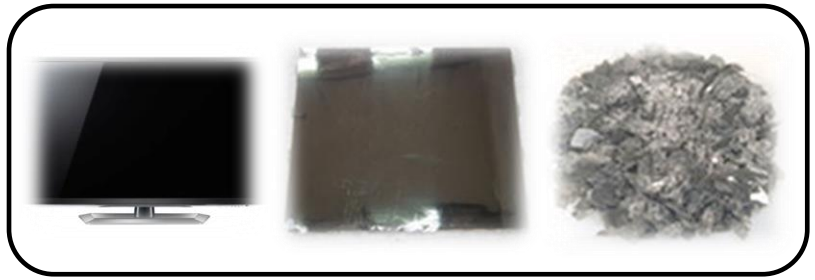


Advantages:

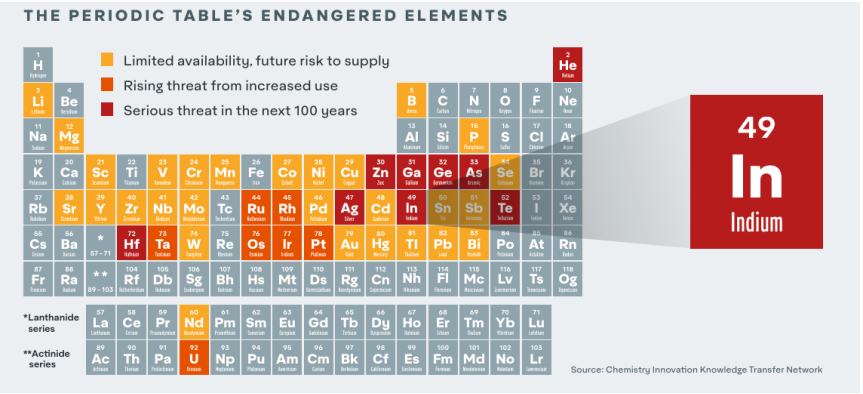
- ✓ Low-Carbon Materials
- ✓ Cut Costs of Recycling
- ✓ Process Time Reduction

Pyrometallurgy for Liquid crystal displays

Liquid crystal displays (ex. In-Sn oxide, ITO)



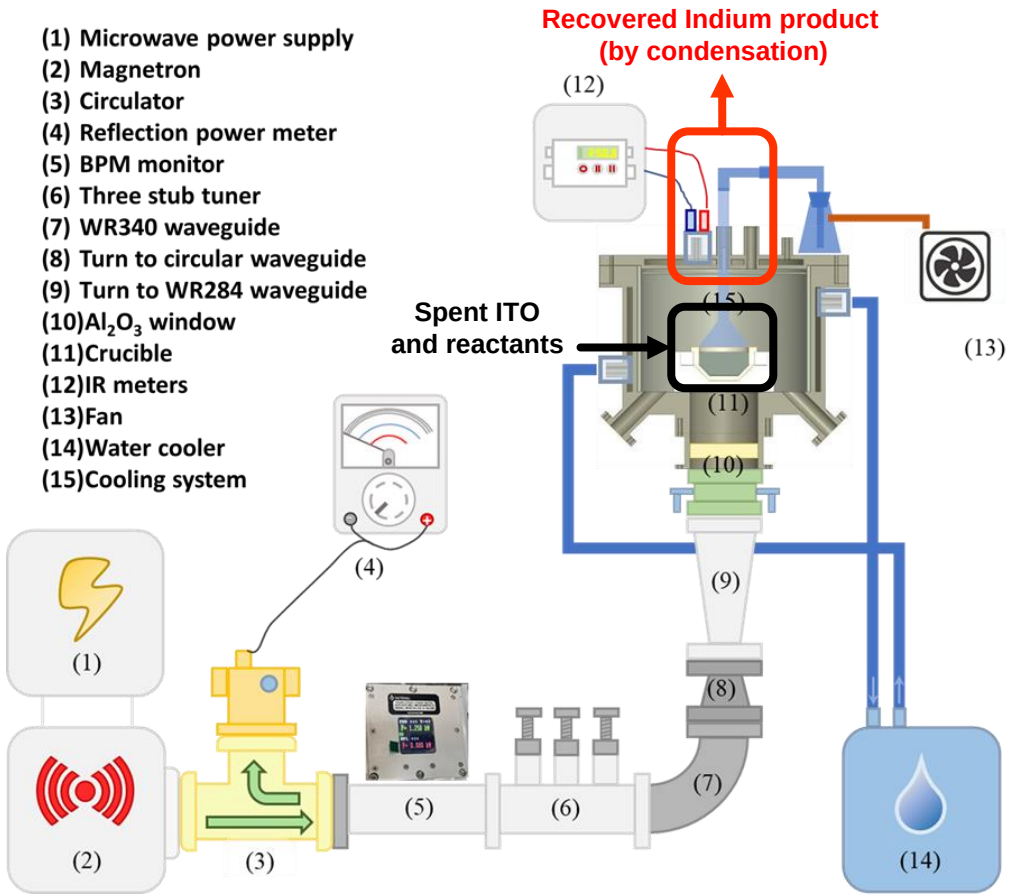
♣ Endanger elements



Chemistry Innovation Knowledge Transfer Network

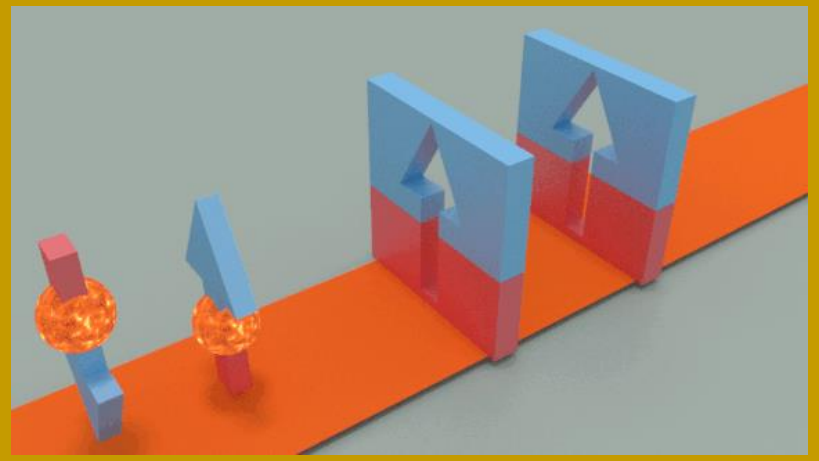
♣ Microwave-assisted approach

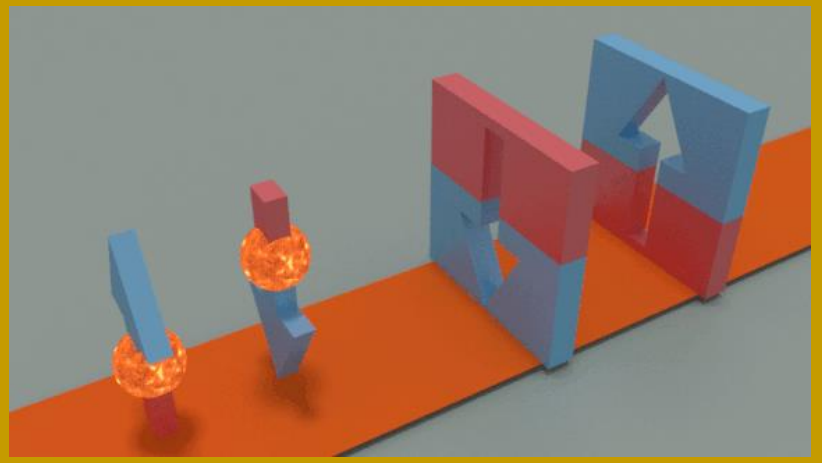
(1) Microwave power supply
(2) Magnetron
(3) Circulator
(4) Reflection power meter
(5) BPM monitor
(6) Three stub tuner
(7) WR340 waveguide
(8) Turn to circular waveguide
(9) Turn to WR284 waveguide
(10) Al_2O_3 window
(11) Crucible
(12) IR meters
(13) Fan
(14) Water cooler
(15) Cooling system



Advantages:

- ✓ Fast and Selective heating
- ✓ Enhanced reactivity
- ✓ High energy efficiency
- ✓ Overall cost effectiveness





Thank you

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