Advanced Materials for next-generation Semiconductor technology

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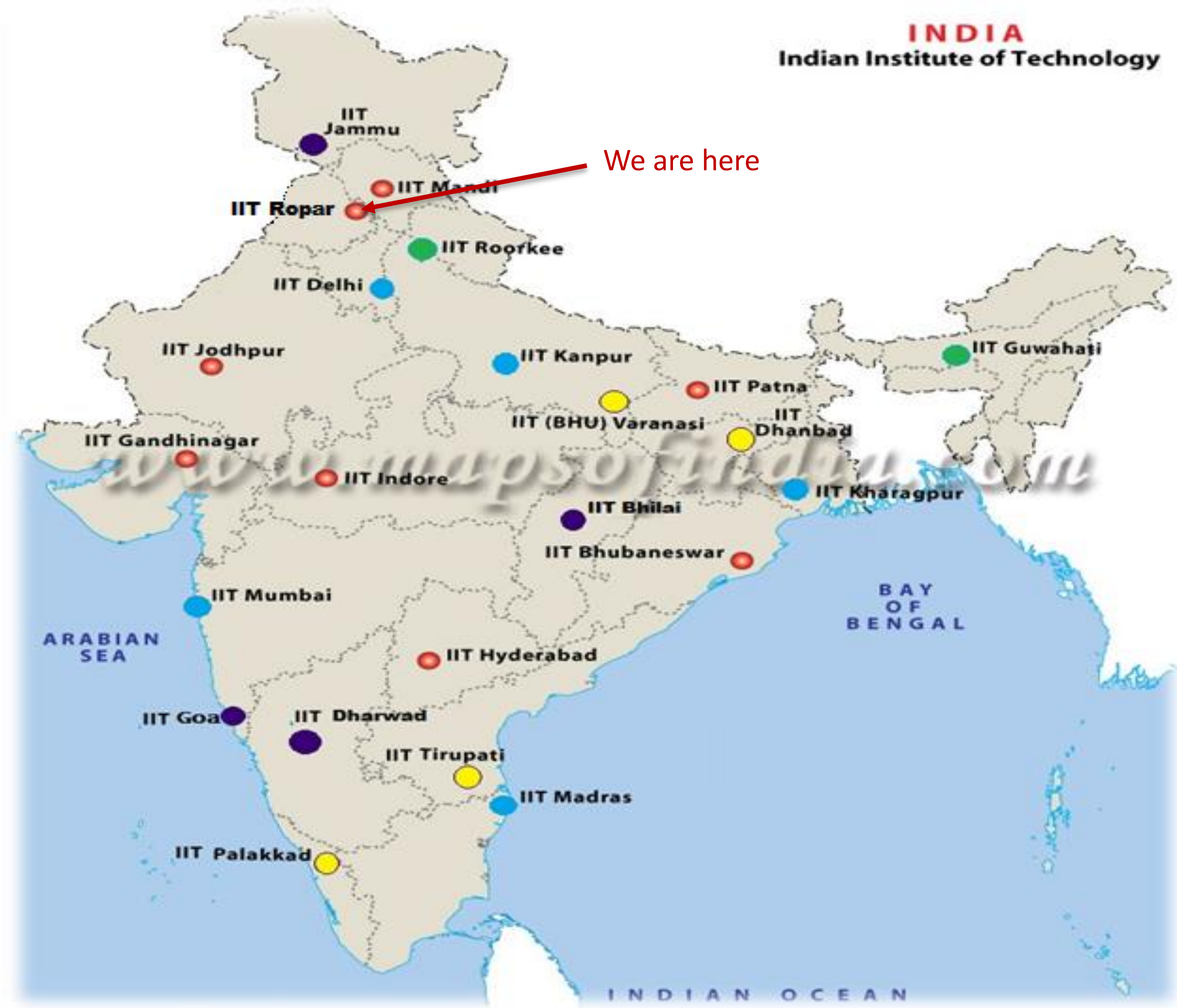
UPPSALA UNIVERSITET

As an institute of national importance, IIT Ropar embodies the original vision behind establishment of the IITs and continues to develop scientific and technological capabilities for nation-building

IIT Ropar was established in 2008 !

One of the youngest IITs and growing very fast !

Brief history of IITs



Journey of IIT Ropar

2008
- Established

2009
- Transit campus @Ropar
- 1st publication

2015
- Masters program
- New UG programs

2017
- Vision, mission & strategic plan
- New curriculum
- Permanent campus
- Phase 1B

2023
- Main Campus
- Joint degree pgm
- Several Centers
- 5470 Publications

	2008-09	2013-14	2014-15	2016-17	2017-18	2019	2021	**2024**
Departments	7	7	7	10	11	11	11	12
Centers	--	1	2	2	2	2	2	6
Faculty	13	66	84	94	115	148	167	181
Students	222	581	683	822	1116	1549	2125	2837
Publications	1	490	713	1254	1283	1808	2750+	5470

Academic Programs

B. TECH.

Artificial Intelligence & Data Engineering
Civil Engineering
Computer Science and Engineering
Electrical Engineering
Mechanical Engineering
Engineering Physics
Chemical Engineering
Metallurgical & Materials Engineering
Maths and Computing

M.TECH.

Computer Science Engineering
CSE (Artificial Intelligence)
Power Engineering
Communication & Signal Processing
Microelectronics & VLSI Design
Mechanics & Design
Manufacturing Engineering
Thermal Engineering
Civil Engineering
Biomedical Engineering
Chemical Engineering

Ph. D.

Ph.D. in all the departments & centers

M.Sc.

Physics
Chemistry
Mathematics
Data Science & Management

M.S. (Research)

Electrical Engineering
Computer Science and Engineering

UPPSALA UNIVERSITET

FOCUS…….

SUSTAINABLE DEVELOPMENT GOALS

Materials research for energy applications

- Power Generation
  - Photovoltaics for solar power
  - Wind Energy
  - Fuel Cells
  - Thermoelectrics for power generation from waste heat recovery
- Transmission
  - Superconducting power cables for congested areas, long-distance power from remote sits of solar & wind sources
- Transformation
  - Superconducting Transformers
- Consumption
  - Solid State Lighting
- Storage
  - Batteries, Supercapacitors, Superconducting magnetic energy storage
- Security/Protection
  - Superconducting Fault current limiters

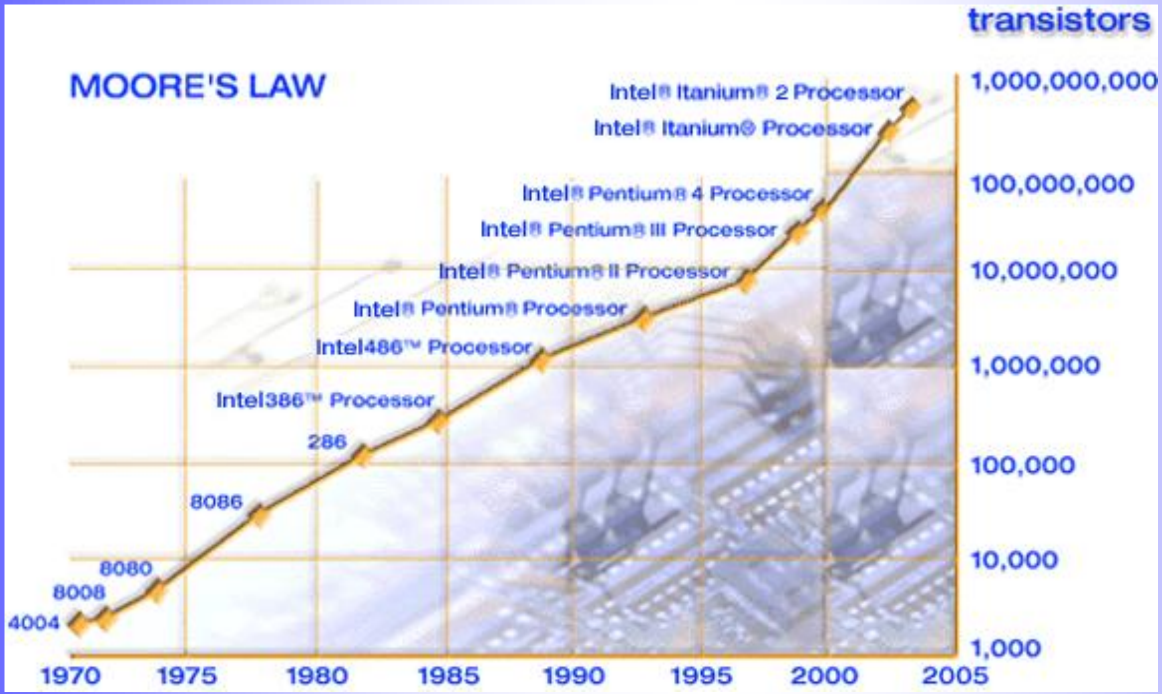
Advanced materials are useful all over the Energy landscape!
They act in the framework of sustainable development

Semiconductor Spintronics: why do we need new materials?

The number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit (1965, Gordon Moore, co-founder of Intel)

Moore predicted that this trend would continue for the foreseeable future. In subsequent years, the pace slowed down a bit, but data density has doubled approximately every 18 months

Most experts, including Moore himself, expect Moore's Law to hold for at least another two decades.



Dilute ferromagnetic semiconductors: what are they?

⇒ Electronics
- charge to process information
- spin to store information

⇒ Spintronics
- add spin degree of freedom to charge-based electronics
- use spin alone as information carrier

♦Features

.Heavily transition metal doped semiconductor (III-V, II-VI, IV)
.must be ferromagnetic at and above room temperature
.as similar as possible to a semiconductor
.Easily integrated in a semiconductor device technology

□♦Advantages

.non-volatility
.increased data processing speed
.decreased electric power consumption

♦Potential applications

.spin LEDS
.non-volatile memory
.quantum computing

♦Problems

.TM cluster, precipitates
.efficient spin injection: requires smooth interfaces
.long spin lifetime: spin must stay aligned long time to be useful

Ferromagnetism above room temperature in bulk and transparent thin films of Mn-doped ZnO

PARMANAND SHARMA[1†], AMITA GUPTA[1], K.V. RAO*[1], FRANK J. OWENS[2], RENU SHARMA[3], RAJEEV AHUJA[4], J. M. OSORIO GUILLEN[4], BÖRJE JOHANSSON[4,5] AND G. A. GEHRING[6]

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[†]Currently at: Institute of Materials Research, Tohoku University, Sendai, 980-8577 Japan

[2]Armament Research, Development and Engg Ctr, Picatinny, New Jersey 07806, USA

[3]Center for Solid State Sciences, Arizona State University, Tampe, Arizona 85287-1704, USA

[4]Condensed Matter Theory Group, Department of Physics, University of Uppsala, Box 530, SE 75121 Uppsala, Sweden

[5]Applied Materials Physics, Department of Materials Science, Royal Institute of Technology, SE 10044 Stockholm, Sweden

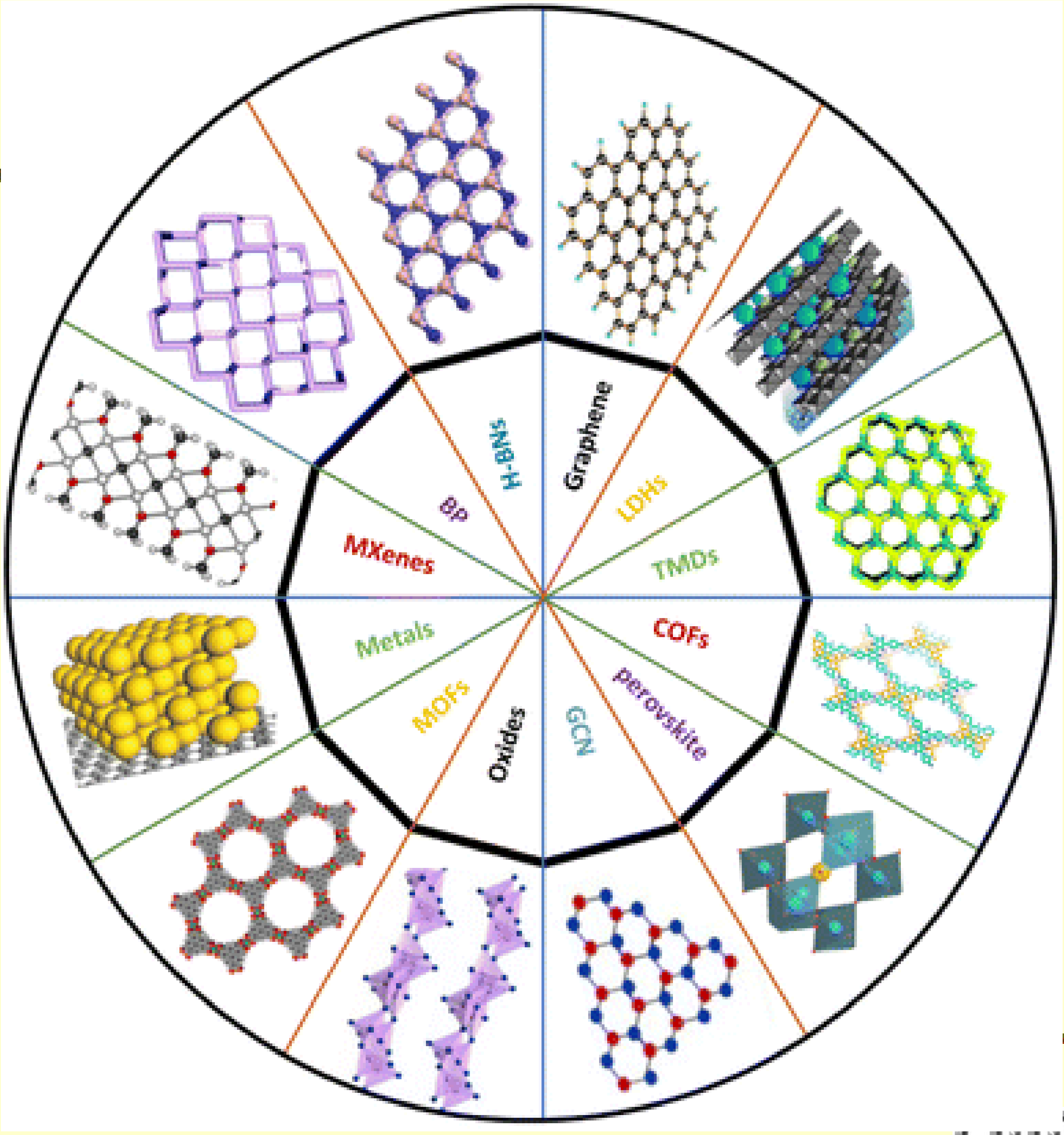
[6]Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK

*e-mail: rao@kth.se

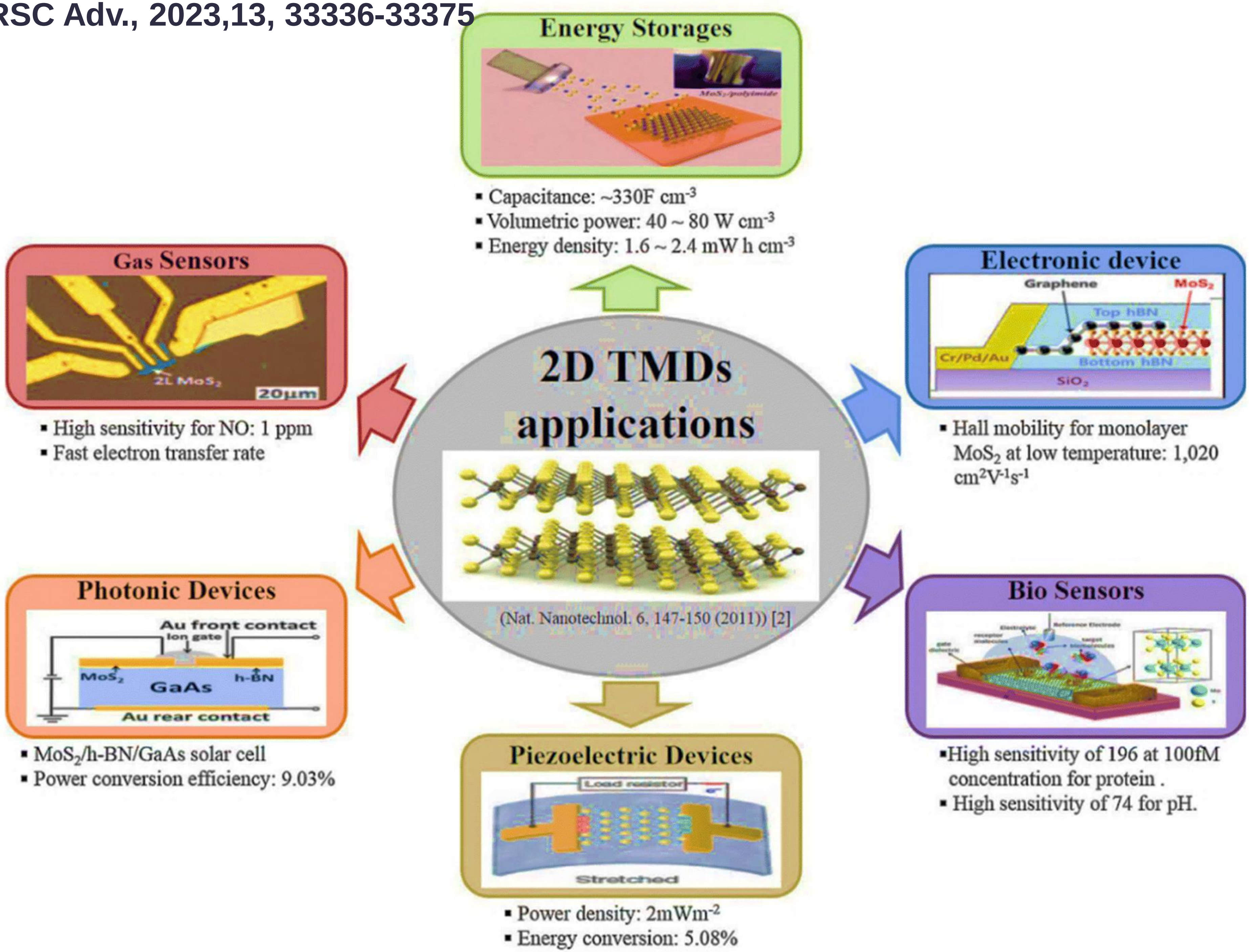
***Nature Materials* 2, 673–677**

RSC Adv., 2023,13, 33336-33375

Graphene-like emerging 2D materials:



RSC Adv., 2023,13, 33336-33375



Research in semiconductor and future goals

Indian Institute of Technology Ropar

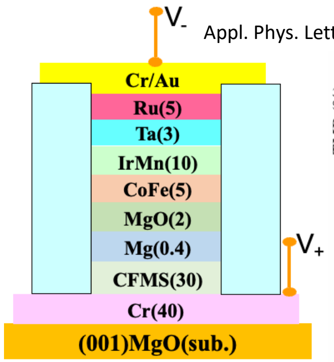
- Academic courses are aligned with Semiconductor Missions, Gov. of India
- **B. Tech. Engineering Physics**, **B. Tech. (EE), B. Tech. (Materials)** are focused academic programs to trained man power
- **State-of-the-art research facilities**
- Research training of the faculty members in diverse area of semiconductors fabrication, TRL-4 and beyond
- Departments involved: Electrical, Physics, Mechanical and Materials Engineering.

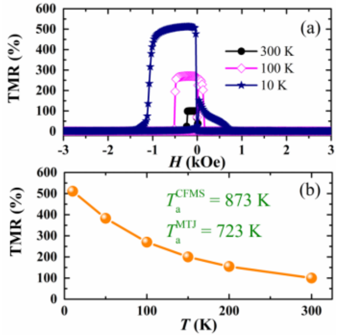
Need of the hour

- Semiconductors is a focus area from both academic and industrial areas and is a mission for Government of India
  - ISM aims at establishing Indian semiconductor leadership and onboarding
- The AI and Quantum missions will further bolter activities in this area due to greater impetus on innovative hardware design for AI powered systems
- Acute shortage of skilled workforce in semiconductors in India
- IIT can play a pivotal role in filling the gap in workforce development in partnership with government (eg. SCL Mohali) and/or private industry
- We aim to develop an industry-academic framework for system driven design and aggregation, which is clearly lacking in India.

Micro-electronic devices and applications

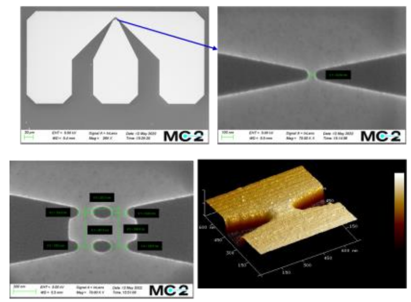
Appl. Phys. Lett. **112**, 052403 (2018)



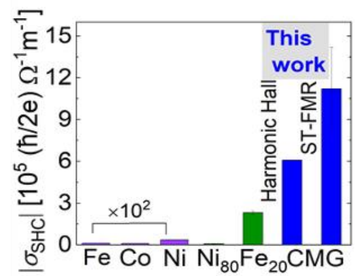


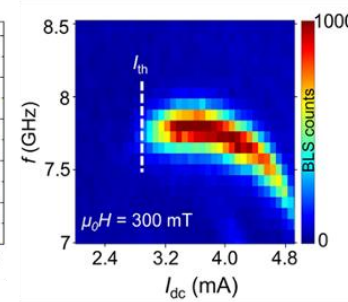
Magnetic tunnel junctions (MTJs) using spin gapless semiconductors

arXiv:2311.08145v2



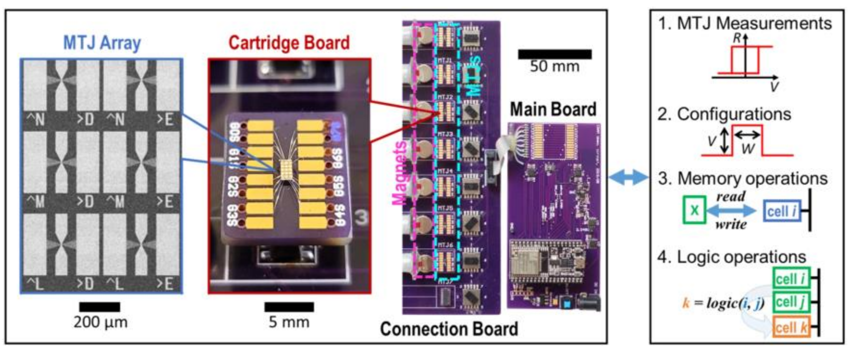
Spin Hall nano-oscillators (SHNOs)





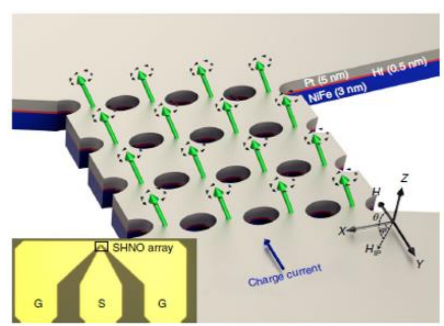
Spin Hall conductivity and auto-oscillation in SHNOs

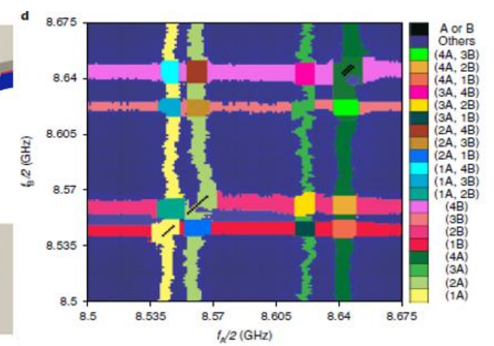
Experimental demonstration of MTJ-based computational random-access memory



npj Unconv. Comput. **1**, 3 (2024)

Neuromorphic computing using 2D array of SHNOs

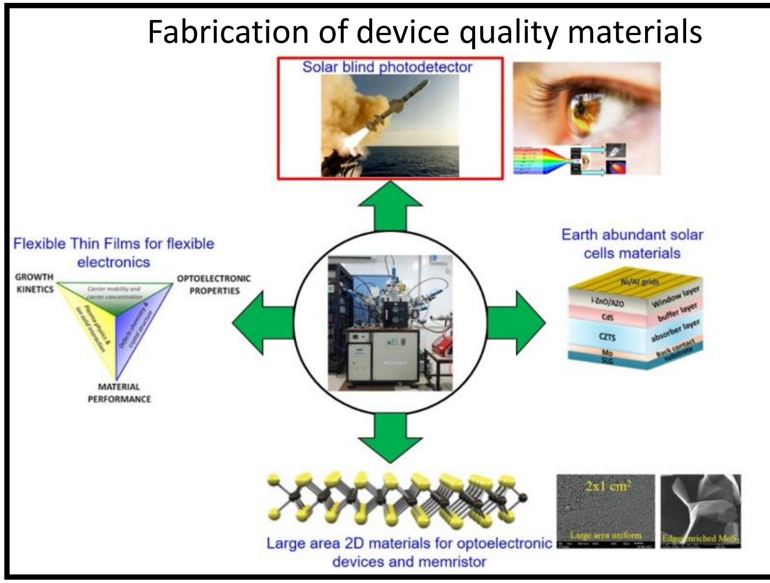


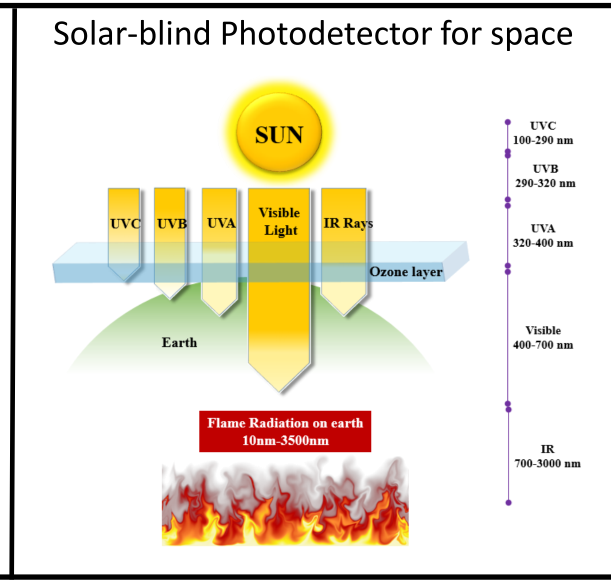


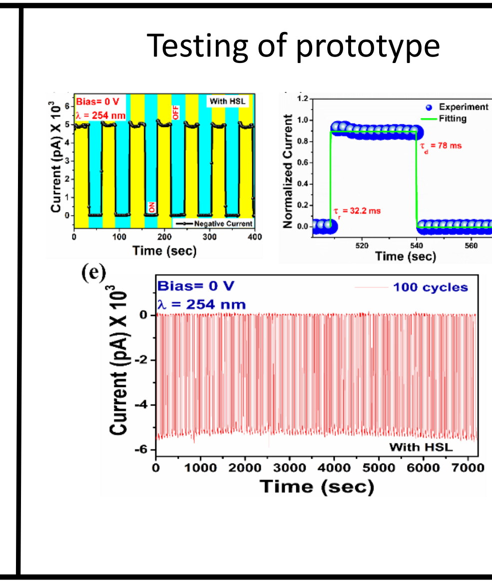
Nat. Nanotechnol. **15**, 47–52 (2020)

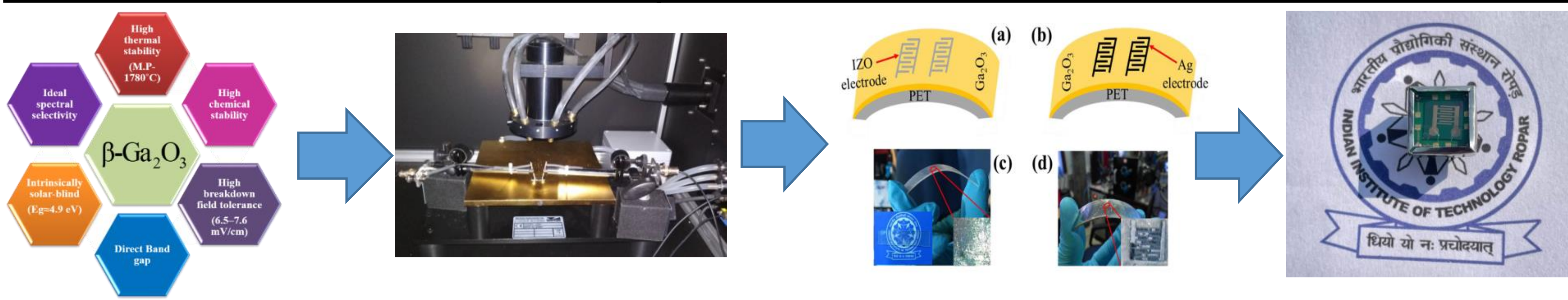
Ongoing project from MEITY-NSF joint consortium

Research activity: Semiconductors for space





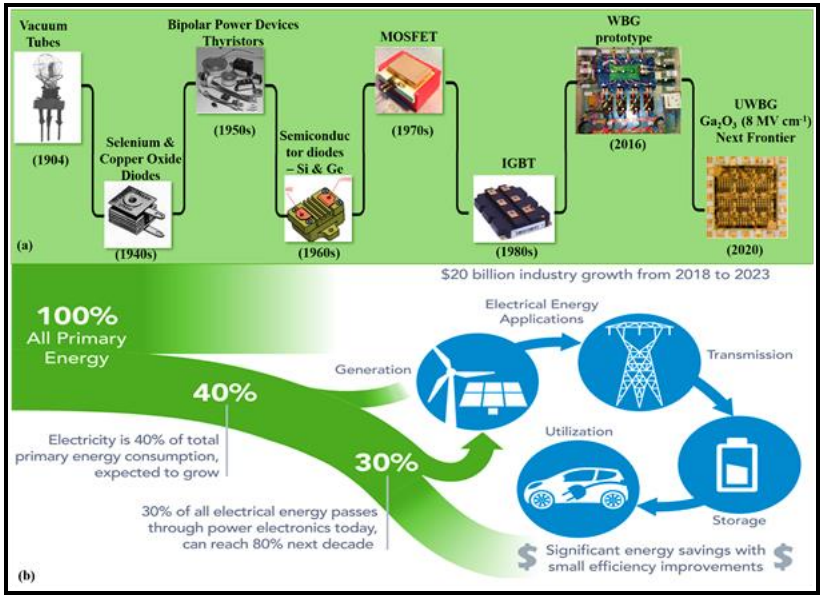




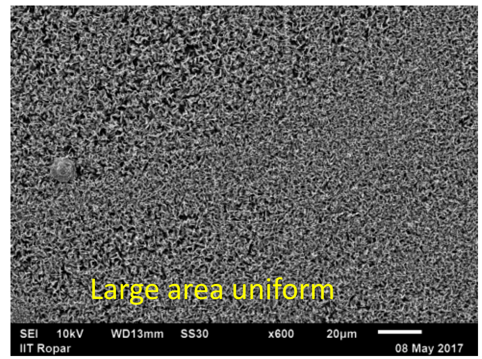
Small **2024**, 2309277 | ACS Photonics **2018**, 5, 2391 | Adv. Opt. Mater. **2020**, 8, 2000212 | Appl. Phys. Lett. **2024**, 124, 151601

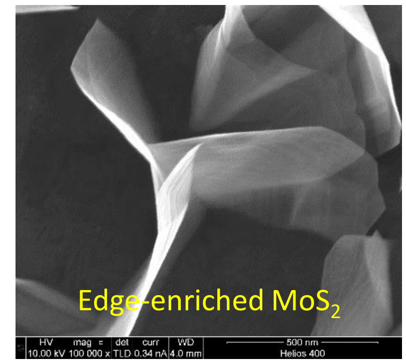
Research goals: Semiconductors for future

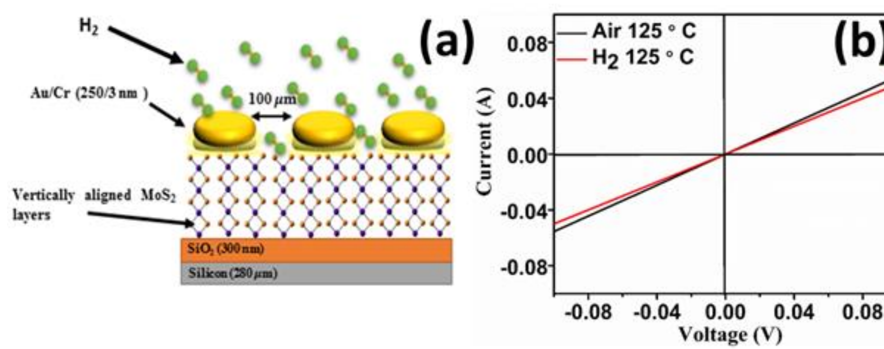
Nearly 30% of all electrical energy is transferred through power electronics and expected to reach up to 80% in upcoming decades



2D materials on wafer scale growth and device fabrication



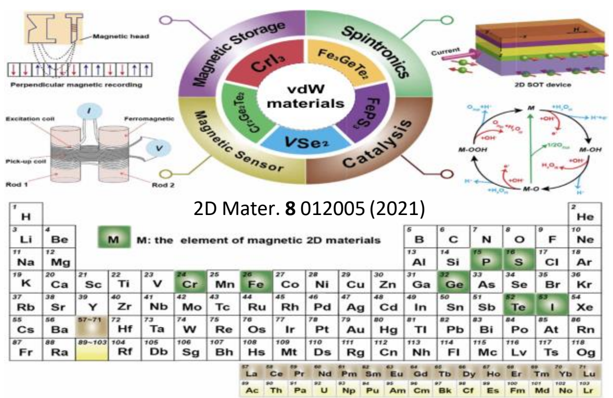




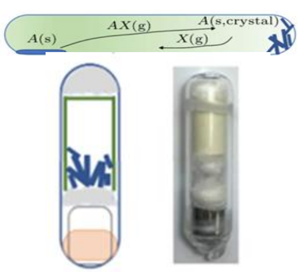
Surfaces and Interfaces **2024**, 46, 103937 | ACS Sens. **2018**, 3, 5, 998 | Appl. Phys. Lett. **2017**, 111, 093102

vdW semiconducting materials, heterostructures, and nanoscale devices for energy-efficient micro-electronic applications

Crystal and Epitaxial Thin Film Growth, and Computation

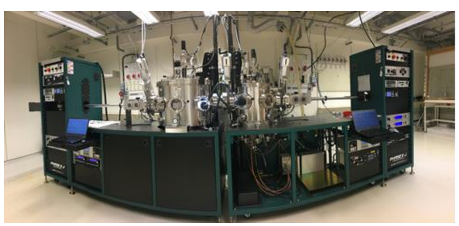


Library of vdW semiconducting materials



Bulk crystal growth

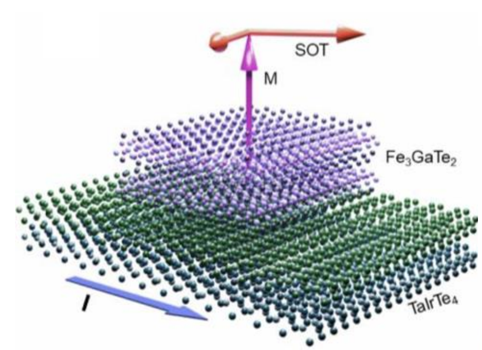
Phys. Rev. B **109**, 134507

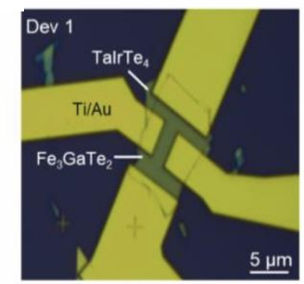


Thin film growth

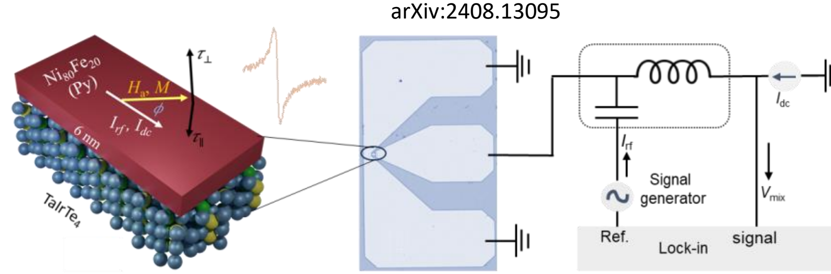
Phys. Rev. B **96**, 094404 (2017); Appl. Phys. Lett. **112**, 052403 (2018)

Heterostructure design: experiment and computation





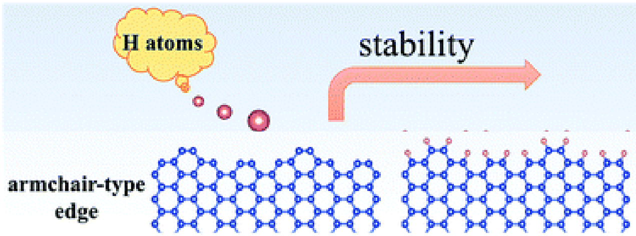
arXiv:2408.13095



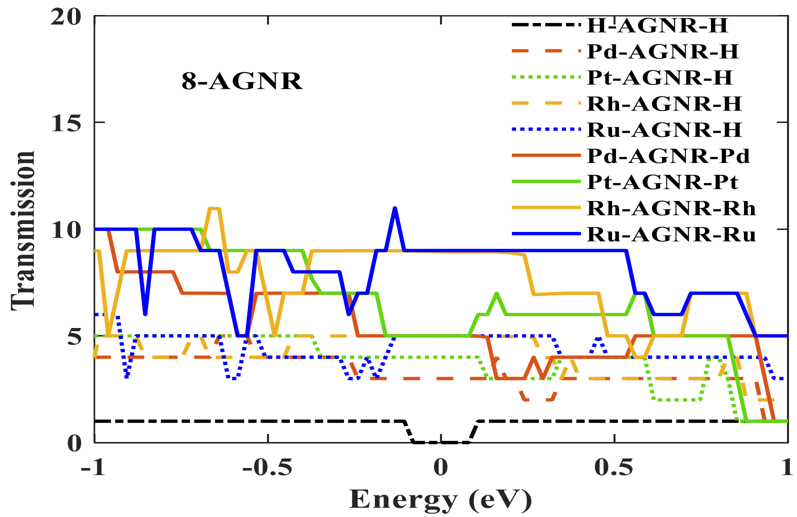
Nat Commun. **15**, 4649 (2024); arXiv:2311.08145v2

Spin-torque ferromagnetic resonance measurement in $TaIrTe_4/Ni_{80}Fe_{20}$

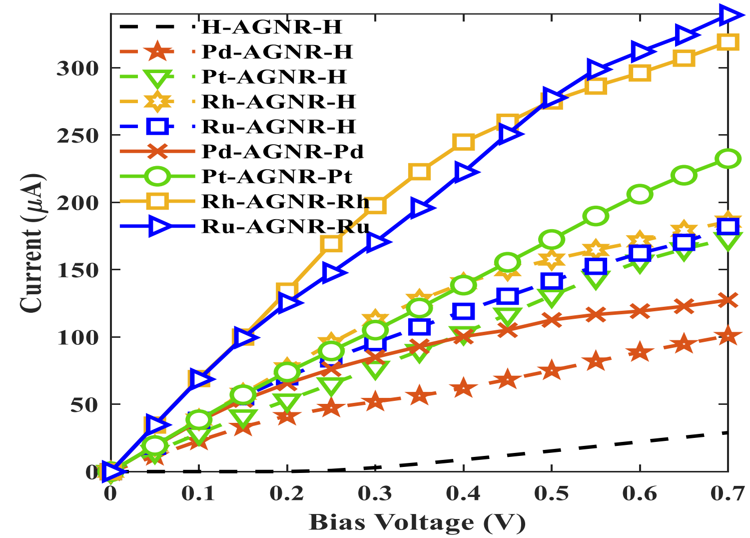
First-Principles Analysis of TMD and Edge-Passivated AGNRs for Nano-Interconnects



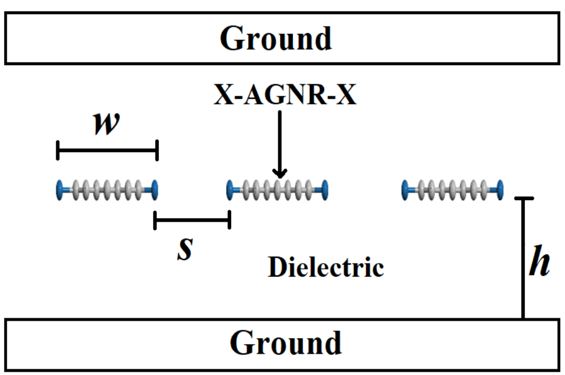
Edge-passivation by **transition metal** atoms in single layer (armchair graphene nanoribbons)AGNRs, that offer significantly lower resistance, can be seen as a promising technique for interconnect a



Transmission spectrum for 8-AGNR configurations at zero bias.



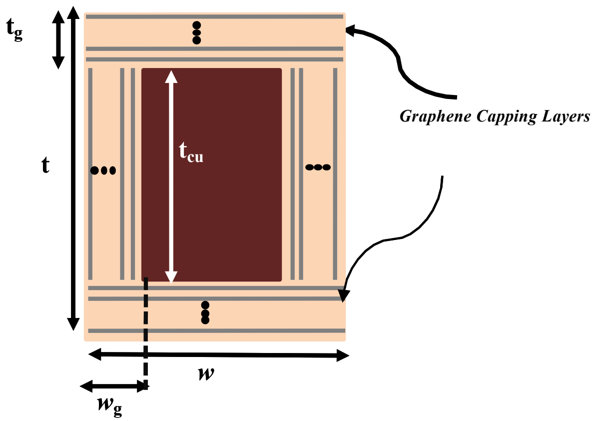
I-V characteristics of 8-AGNR configurations.



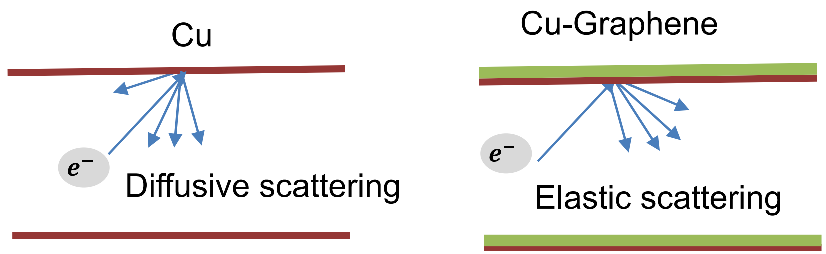
Cross-section of X-AGNR-X interconnects embedded in a dielectric

[REF] V. K. Nishad, A. K. Nishad, B. K. Kaushik and Rohit Sharma, "First-Principle Analysis of Transition Metal Edge-Passivated Armchair Graphene Nanoribbons for Nanoscale Interconnects," in *IEEE Transactions on Nanotechnology*, vol. 20, pp. 92-98, 2021.

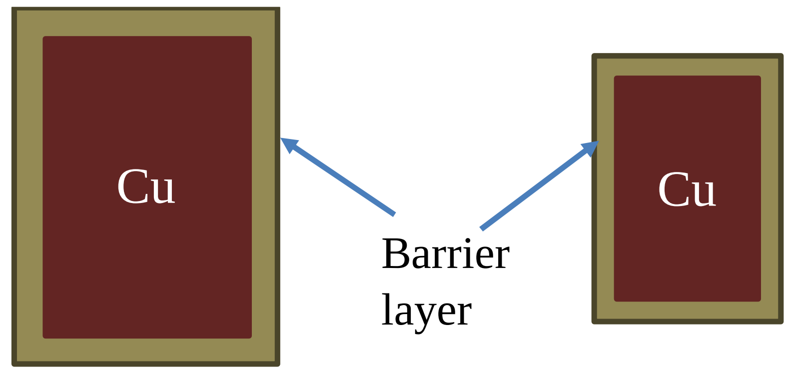
Copper Graphene Hybrid Interconnects



Graphene and Cu in some sort of hybrid heterogeneous structure can bring potential benefits of reducing Cu electromigration and diffusion.



Surface scattering



Technology scaling with barrier layer

Effective resistivity of Cu hybrid interconnect

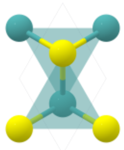
$$\frac{1}{R_{eq}} = \frac{1}{R_{Cu}} + \frac{1}{R_B}$$

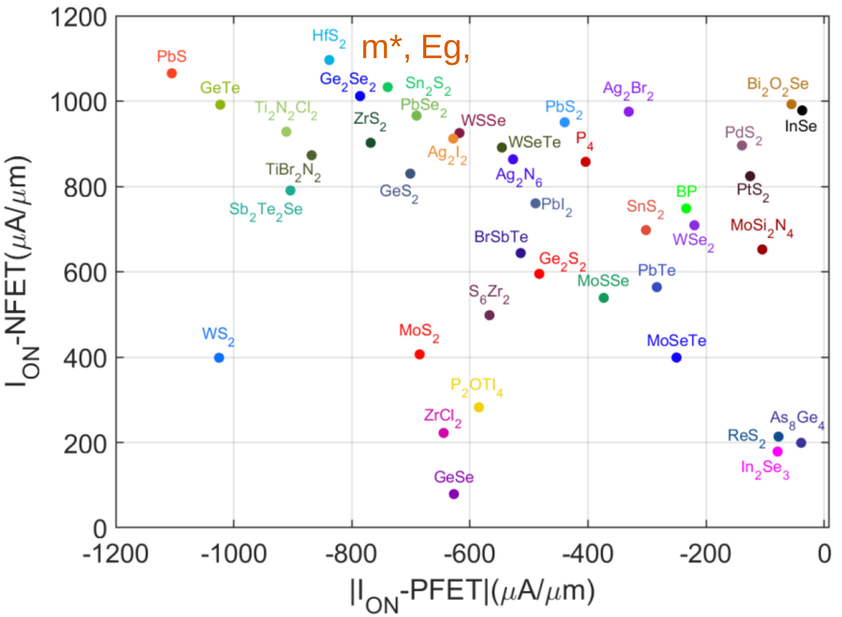
[REF] R Kumar and R Sharma, "A Temperature and Dielectric Roughness-Aware Matrix Rational Approximation Model for the Reliability Assessment of Copper– Graphene Hybrid On-Chip Interconnects," in *IEEE Trans. on Components, Packaging and Manufacturing Technology*, 2020.

Resistivity for different barrier layers at 22, 13, and 7 nm

Thickness	2 nm	1.2 nm	0.6 nm
Ta Barrier Layer (ρ_{Ta})	278.6×10^{-8}	433.2×10^{-8}	852.4×10^{-8}
W Barrier Layer (ρ_W)	65.1×10^{-8}	100×10^{-8}	194.2×10^{-8}
MLGNR Barrier Layer (ρ_{MLG})	**8×10^{-8}**	**10.22×10^{-8}**	**14×10^{-8}**

Atom-to-Circuit Simulation for 2DM Beyond MoS_2





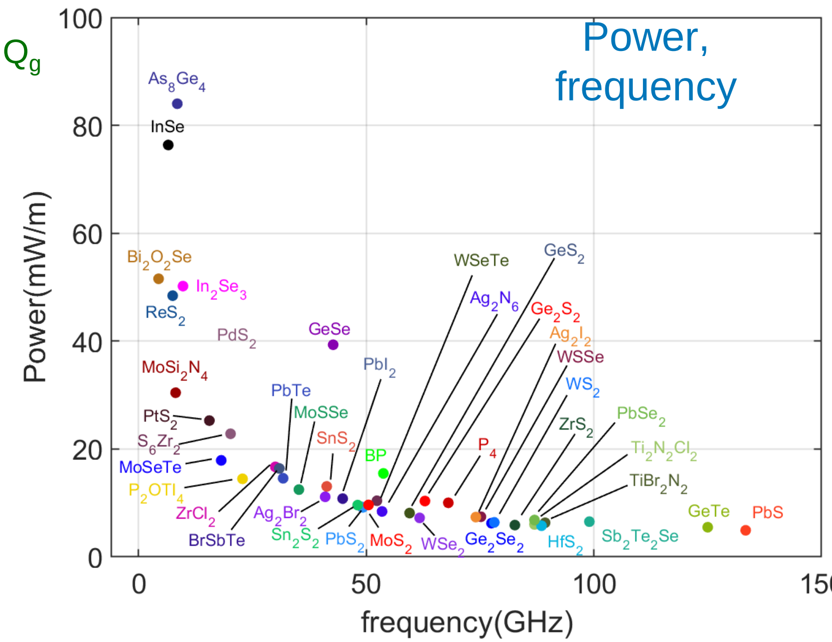


Fig.1: I_{ON} of n-FET Vs I_{ON} of p-FET in double gate geometry.

Fig. 2: Power vs frequency of 2DM-based 6T SRAM Cell at V_{DD}=0.5 V.

Two-dimensional (2D) materials, including PbS, GeTe, $Ti_2N_2Cl_2$, HfS_2, and WS_2, have demonstrated excellent switching performance, surpassing that of their silicon counterparts.

Ref: [1] A. Rawat and B. Rawat, IEEE TED, 71, 6, 2024
[2] A. Rawat, et al. IEEE TED, 68,7,2021

Horizontal Vs Vertical MoS_2 for Next-Generation Memristor

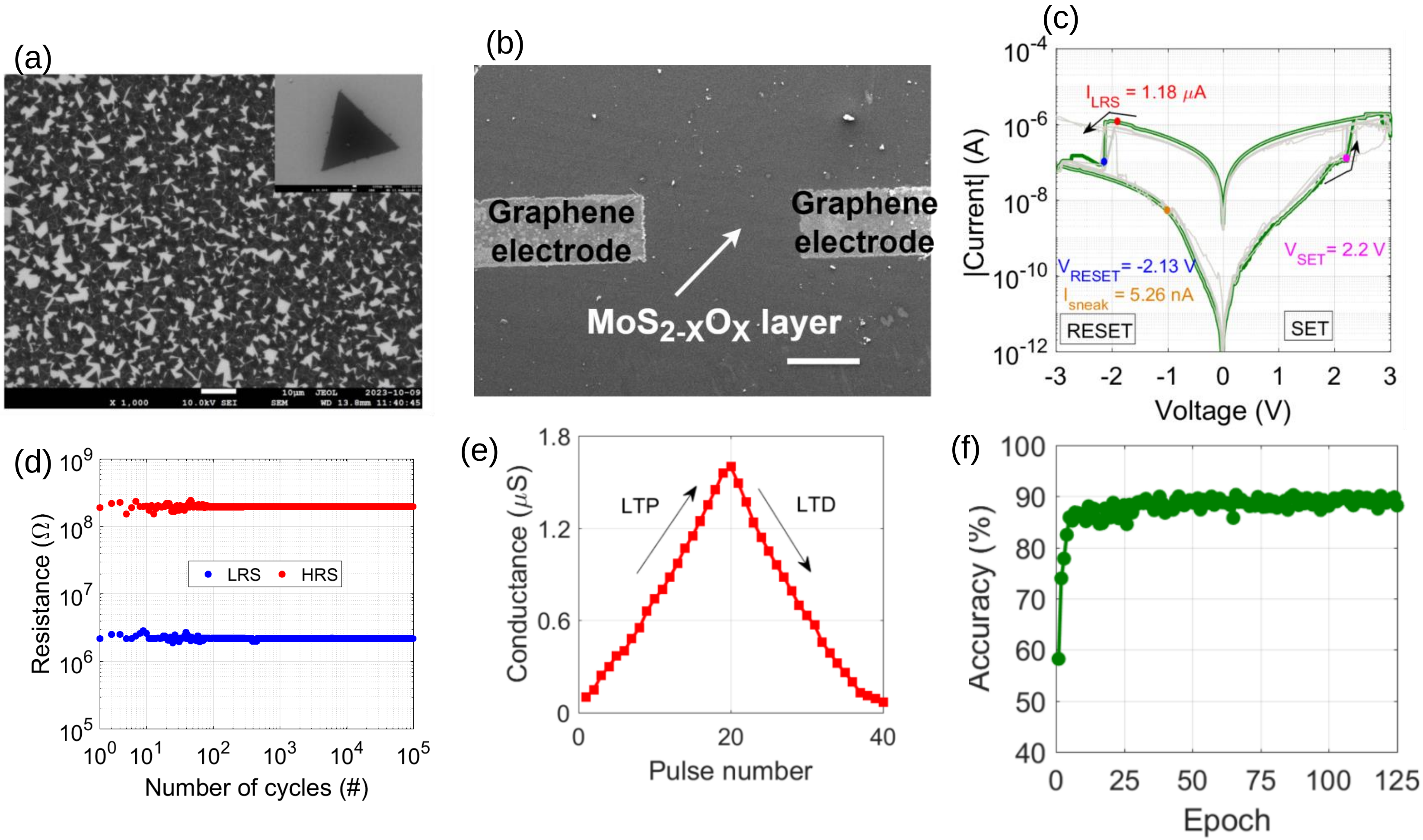


Figure 3: FESEM image of (a) CVD grown MoS_2 nanoflakes, (b) fabricated 2-D MoS_2 Memristor (c) I-V characteristics for 20 cycles, (d) endurance test, (e) long-term potentiation (LTP) and depression (LTD) characteristics, and (f) accuracy with MoS_2 synapse in neural network.

Ref: B. Rawat et al., IEEE JED, 2024 (Accepted).

Vertical Aligned MoS_2 for RT Gas Sensors

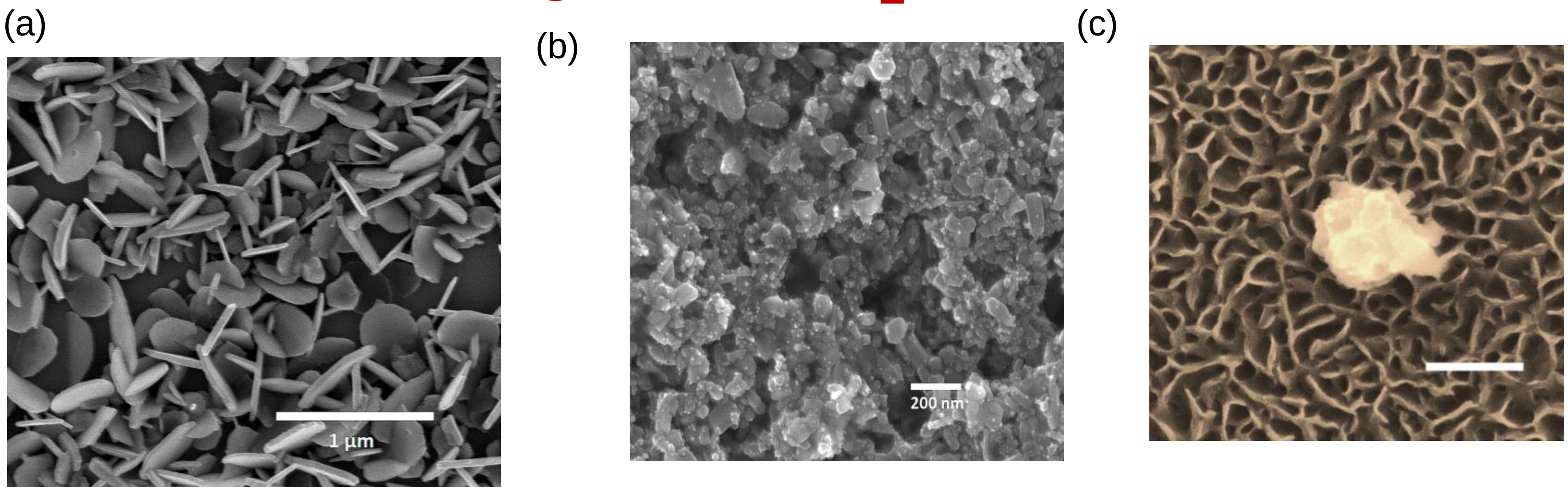


Figure 2: FESEM image of (a) CVD grown VA-MoS_2 nanoflakes, and (b) average size ~20 nm ZnO- NPs and (c) ~200 nm Fe_2O_3 supttered decoration over VA-MoS_2.

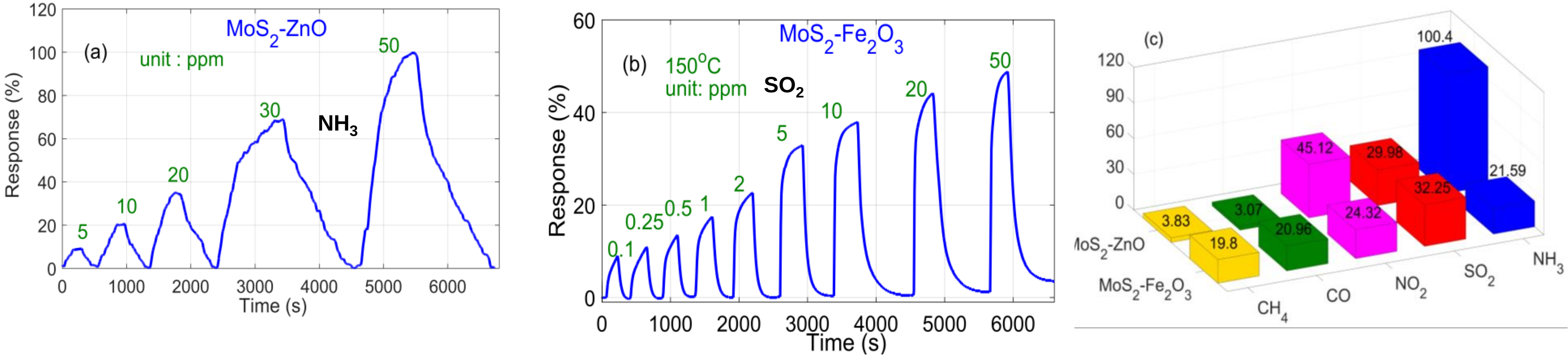


Figure 2: (a) VA-MoS_2-ZnO sensor in presence of 5-50 ppm of NH_3, (b) MoS_2-Fe_2O_3 sensor in presence of the 0.1-50 ppm of SO_2., and (C) selectivity of MoS_2-ZnO and MoS_2-Fe_2O_3 sensors.

Ref: B. Rawat et al., ACS Applied Electronics Materials , 2024, 6,4.

Thank you