NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Spintronic Devices for Neuromorphic Computing

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SpiNLab

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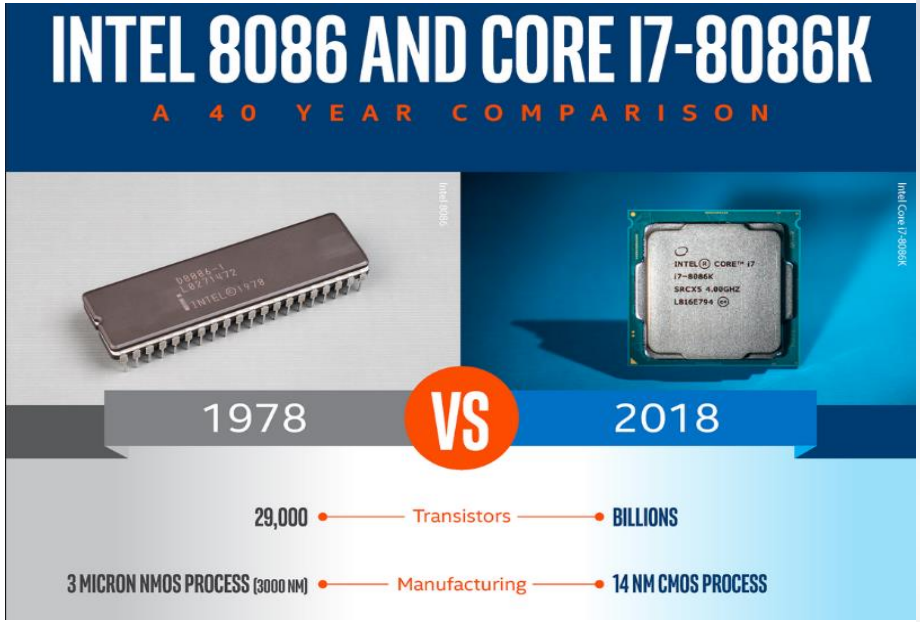
Outline

- Introduction
- Spin-based Neuromorphic Computing Devices
  - Synthetic Neurons and Synthetic synapses
- Domain wall pinning – Geometric approach
- Domain wall pinning – Magnetic texture approach
- Summary

Motivation

- Traditional scaling of semiconductor technologies – getting stagnated

- New architectures, apart from von Neumann architectures, are needed



Motivation

- Traditional scaling of semiconductor technologies – getting stagnated
- Artificial Intelligence is widely implemented

- New architectures, apart from von Neumann architectures, are needed
- Neuromorphic computing

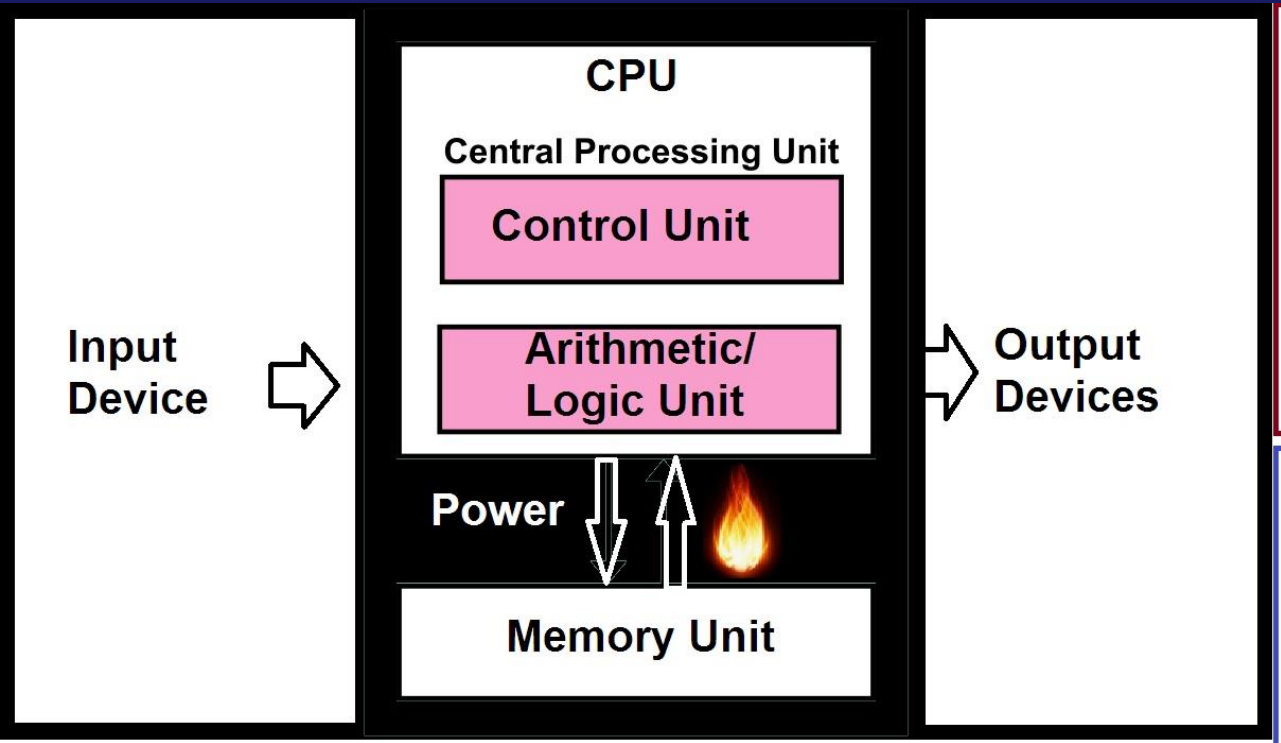
Artificial Intelligence

- Market in 2017 – valued at $16 B
- Market in 2025 - $190 B

(forecast)

Spin-based neuromorphic computing is rich in **science** and **application** potential.
Recent (2019) funding → €36 M (Germany) , A few M$ (Singapore)

Motivation



von Neumann Architecture

Existing Hardware

+

Algorithms

Artificial Intelligence

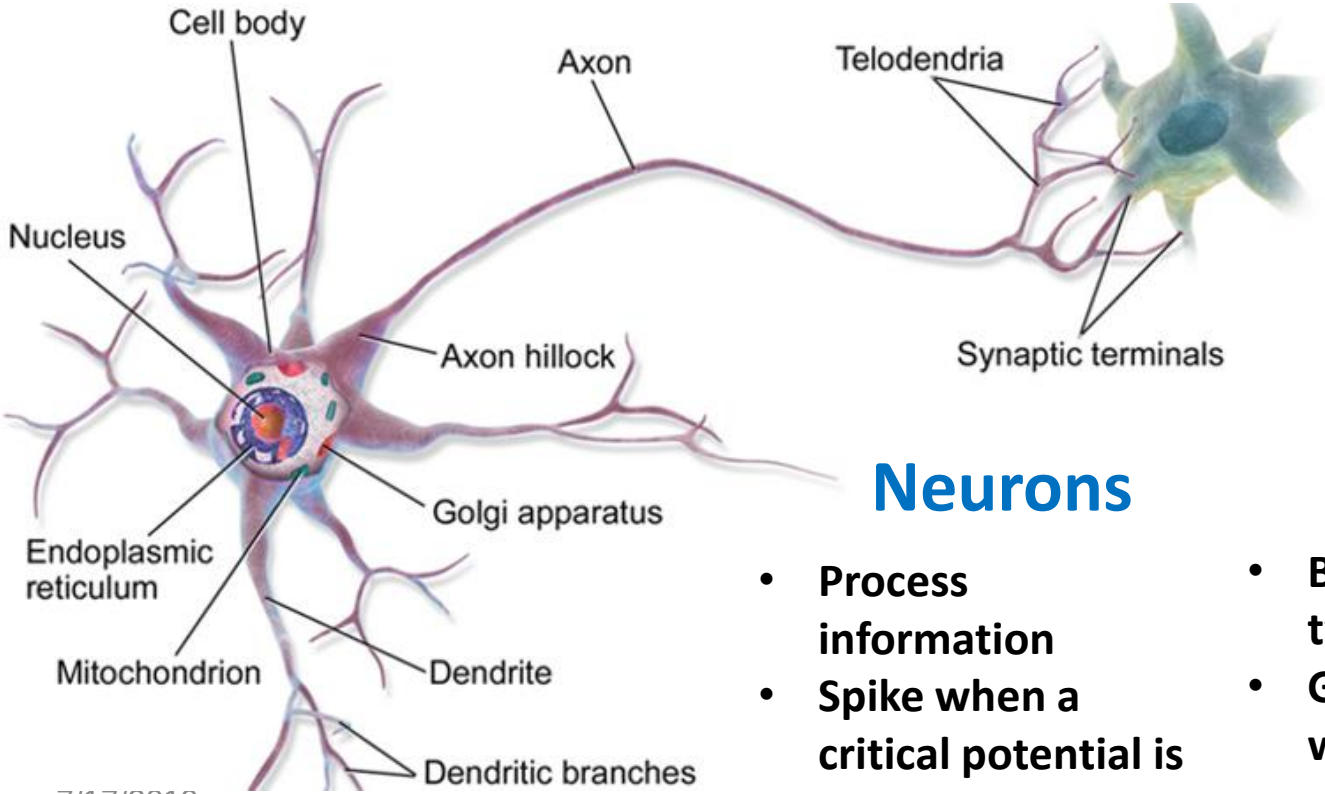
New Hardware Elements

+

New Algorithms

Neuromorphic Computing

Neuromorphic Computing



Neurons

- Process information
- Spike when a critical potential is reached

Synapses

- Bridge between two neurons
- Gradually stronger with learning

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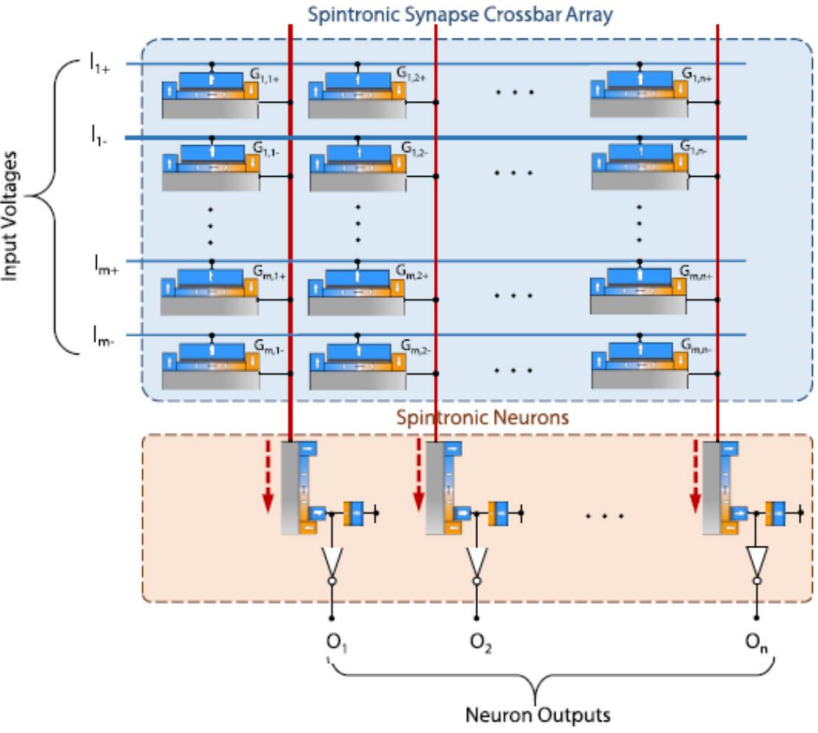
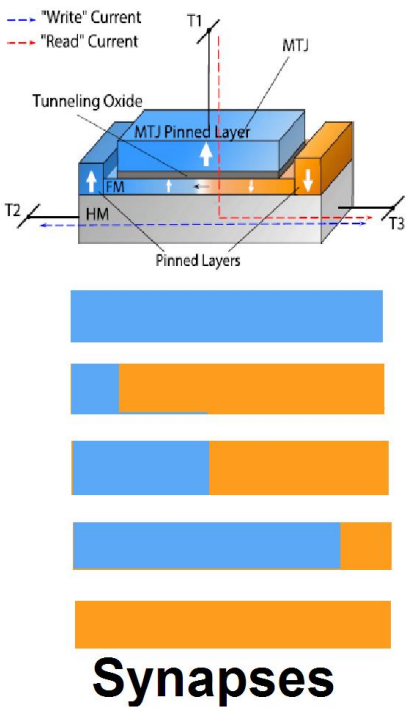
Requirements

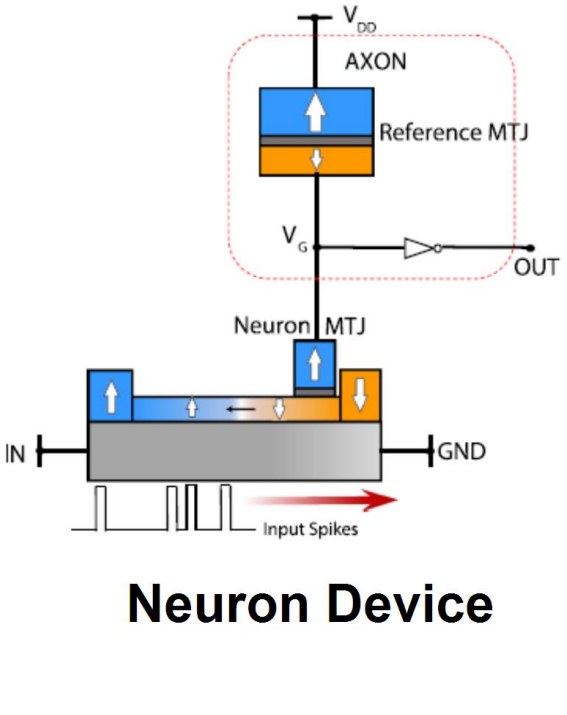
- Neurons
- Respond (analog manner) and produce an output (digital manner)
- Grollier et al., STOs

- Synapse
- Respond to the other devices (neurons) and change state gradually
- Multiple resistance states
- Fukami et al., AHE

Neuromorphic Computing



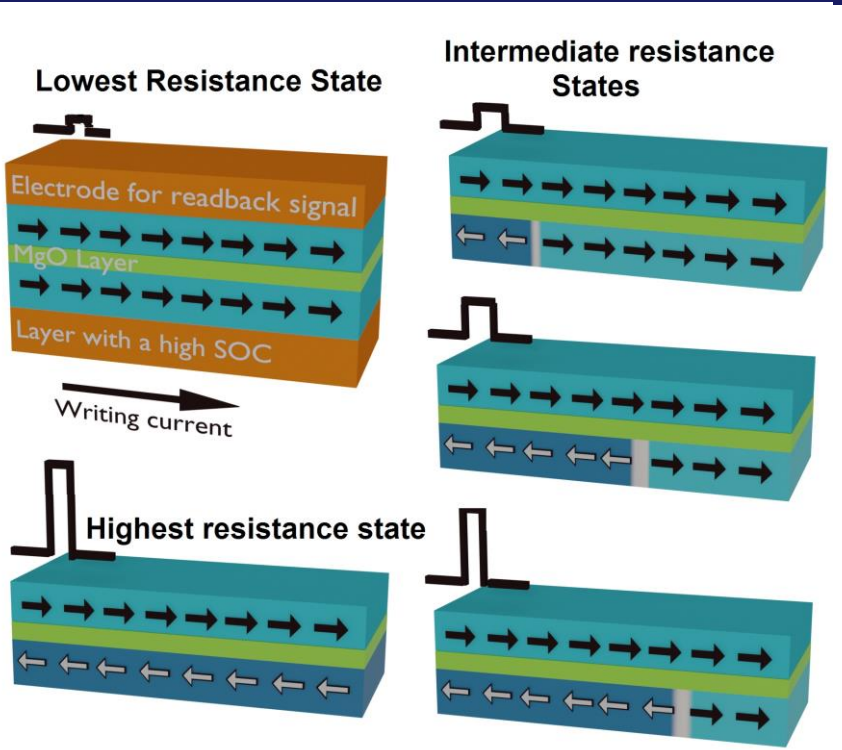




A. Sengupta and K. Roy APPLIED PHYSICS REVIEWS 4, 041105 (2017)

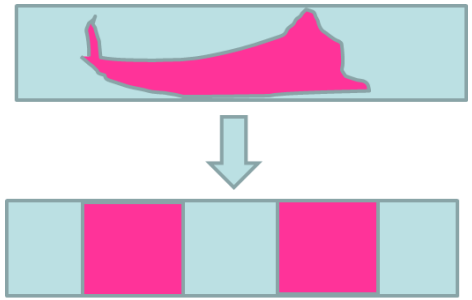
Synapses – Multiple Resistance states

- Magnetic Tunnel Junctions
  - MRAM – 0 and 1
- Domain Wall devices
  - Can show multiple resistance states
- Change domain wall position by current (STT or SOT)

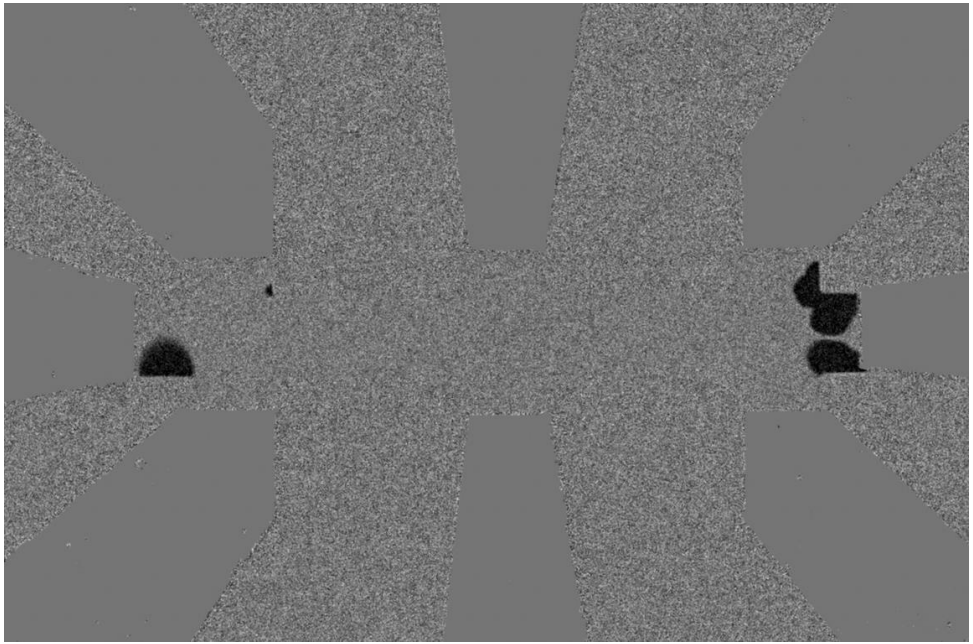


Pinning Domain wall motion

- In systems that involve domain, the domain wall motion can be uncontrollable to the precision required of modern devices

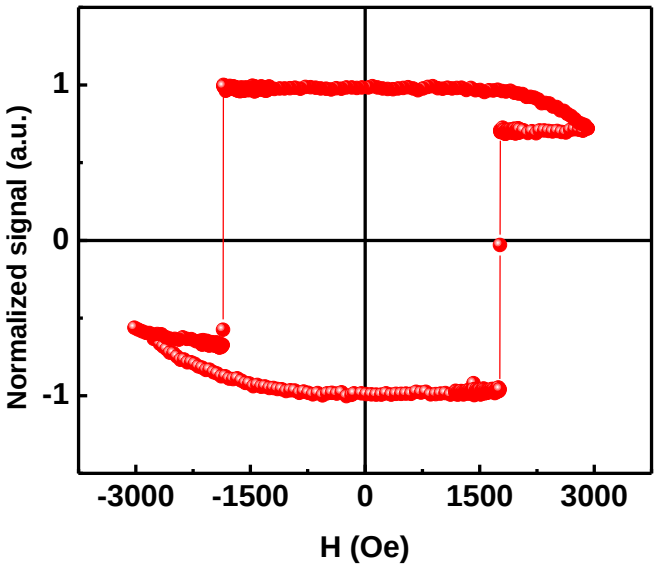


Ideal

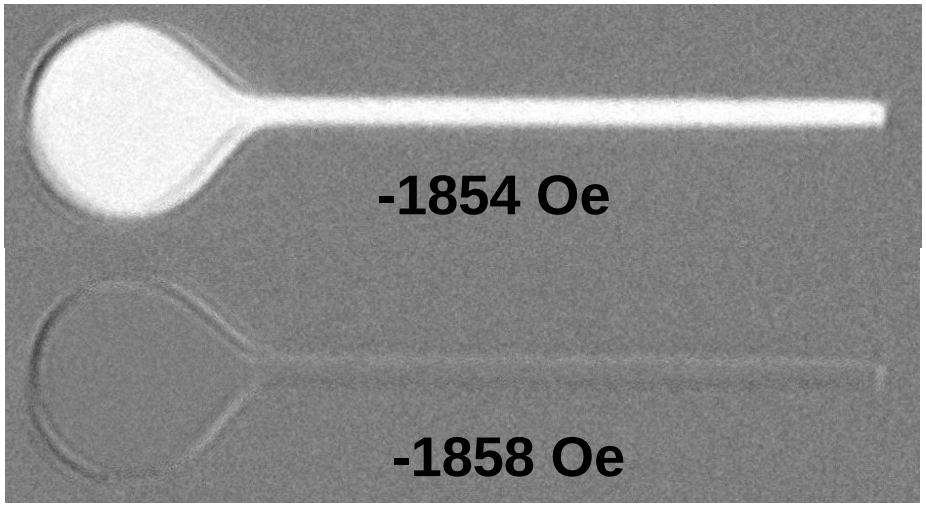


Ta/CoFeB/MgO device with a PMA

Domain patterns : No pinning sites



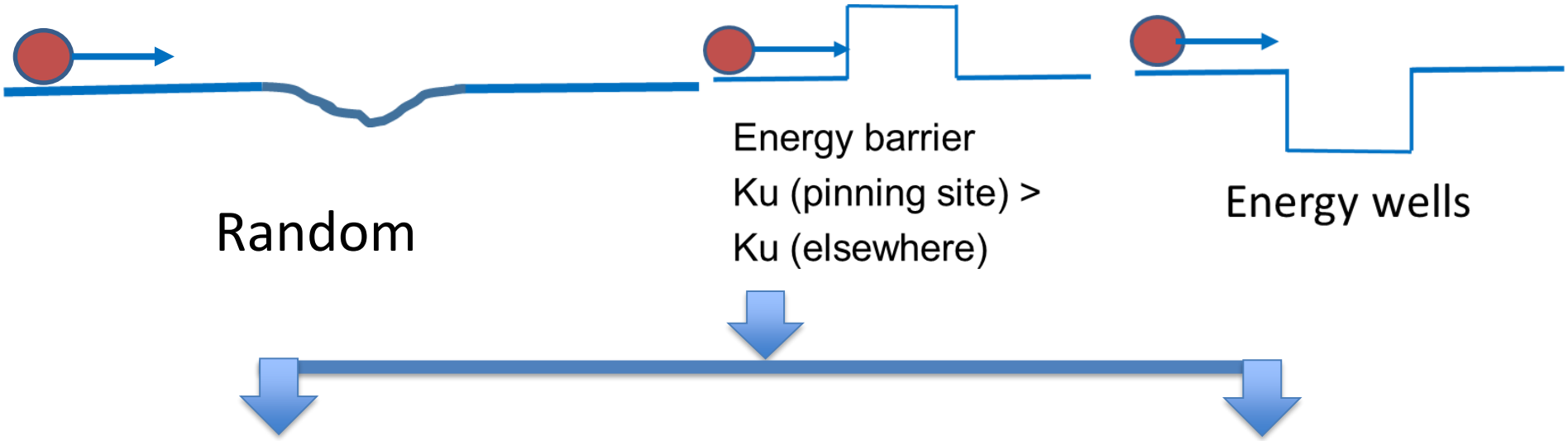
White: Magnetization up



Grey: Magnetization down

DOMAIN WALL PINNING IS ESSENTIAL

Energy Barriers and Energy Wells



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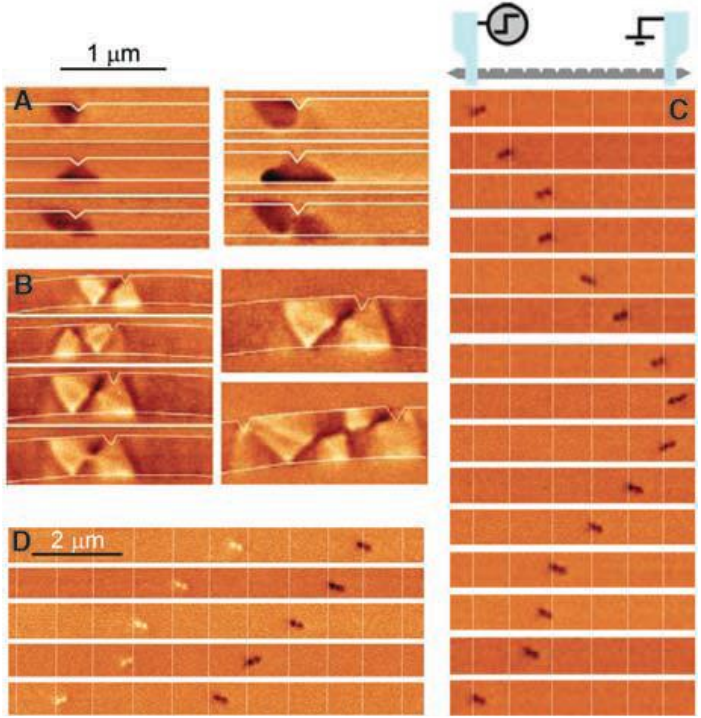
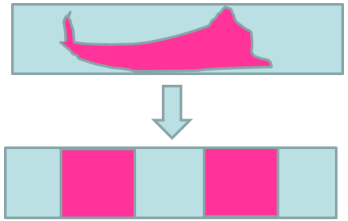
Pinning Domain wall motion – Geometrical approach

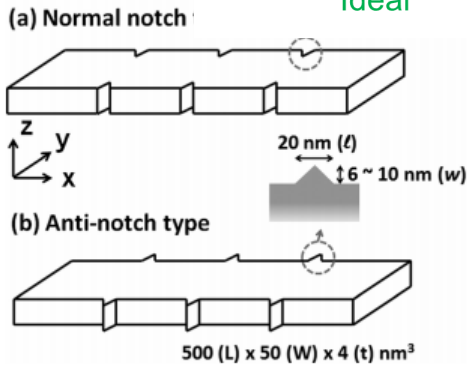


Stuart S. P. Parkin, Masamitsu Hayashi, Luc Thomas, Science 320, 190, (2008)

- Pinning the domain walls is proposed to be achieved by the use of “notches”
- DW design does not make use of the smallest feature size possible with lithography →
- density issue

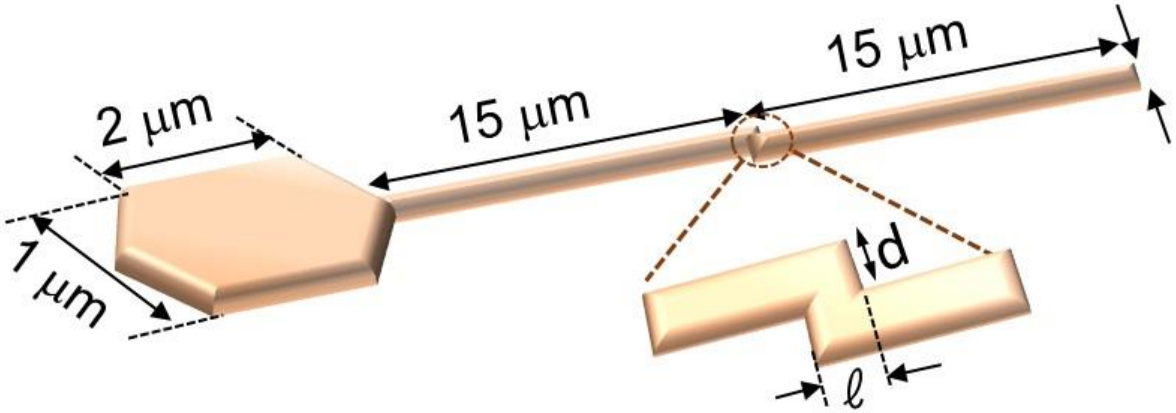


Ideal

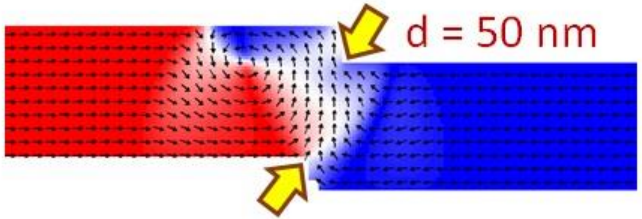


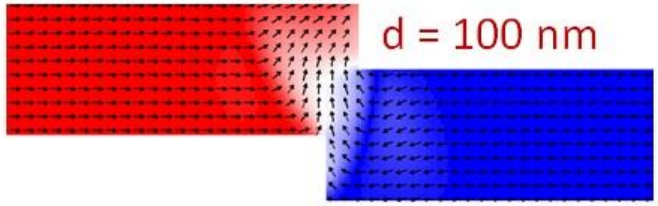
S. Noh, Y. Miyamoto, M. Okuda, N. Hayashi, Y. Kim, JAP, 111, 07D123 (2012)

Staggered Domain Wall Device

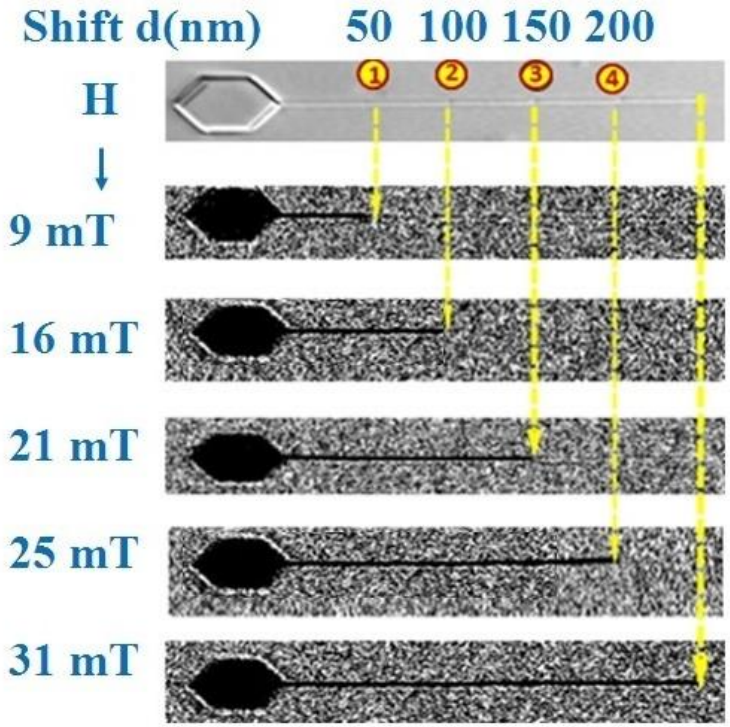


M. Al Habri, R. Sbiaa, …
S.N. Piramanayagam… et al.
PHYS. REV. APPLIED **11,**
024023 (2019)





Staggered Domain Wall Device



- Domain wall can be pinned
- NiFe films

Rule of Thumb:

- Narrower the nano-constriction, stronger is the pinning

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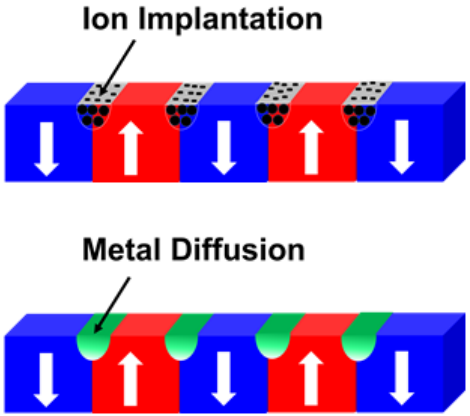
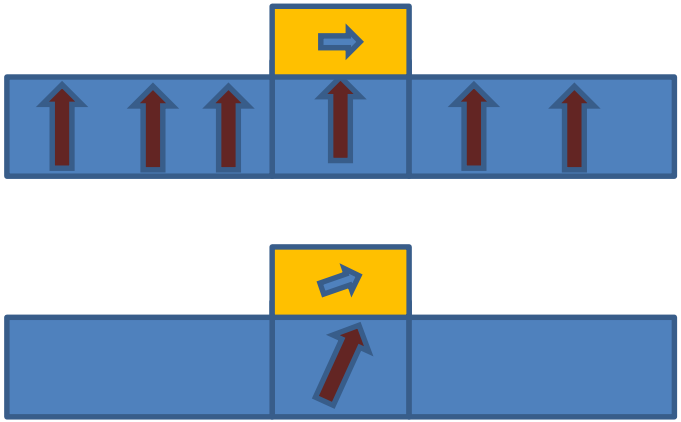
Domain wall pinning in non-topographical ways "Synthetic Magnetic textures"

- Diffusion of certain elements and causing magnetic textures



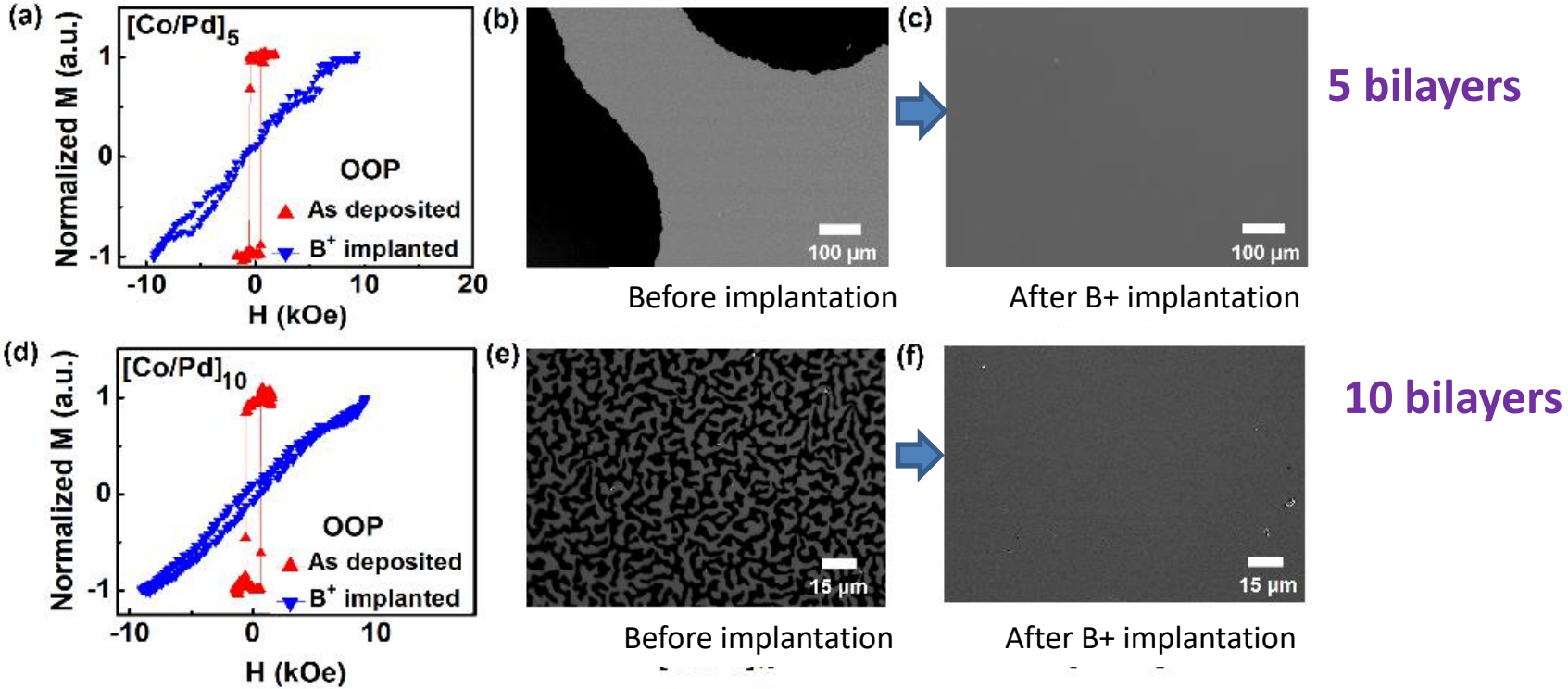
T.L. Jin et al., Sci. Reports 7, 16208 (2017)
DOI:10.1038/s41598-017-16335-z

- Magnetic materials of two different types stacked on each other



S.N. Piramanayagam, TMRC 2018
T.L. Jin et al., JMMM (2019)

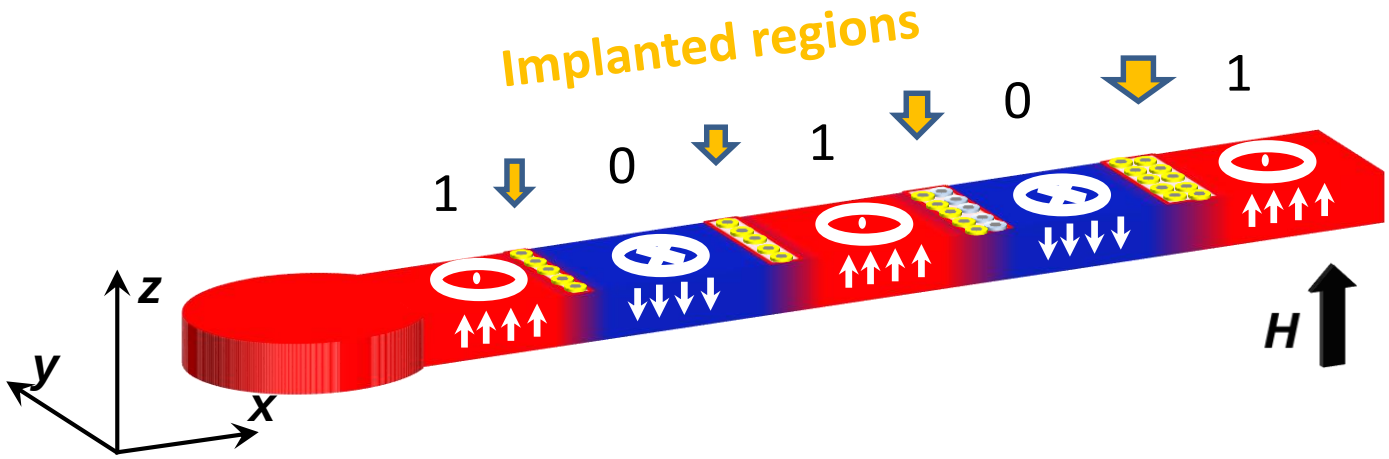
Ion-implantation in thin films



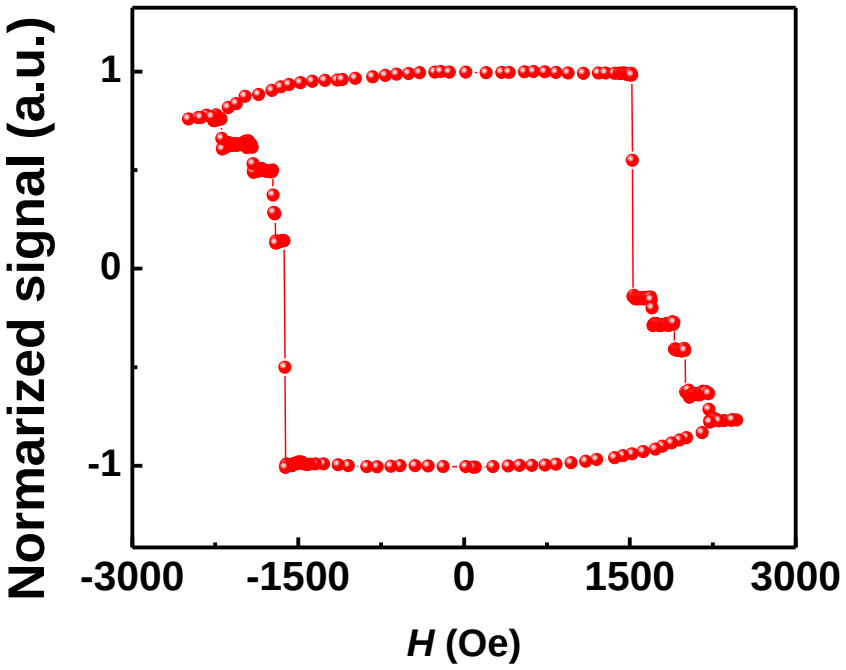
T.L. Jin, et al., Phys. Status Solidi RRL **2018**, 1800197

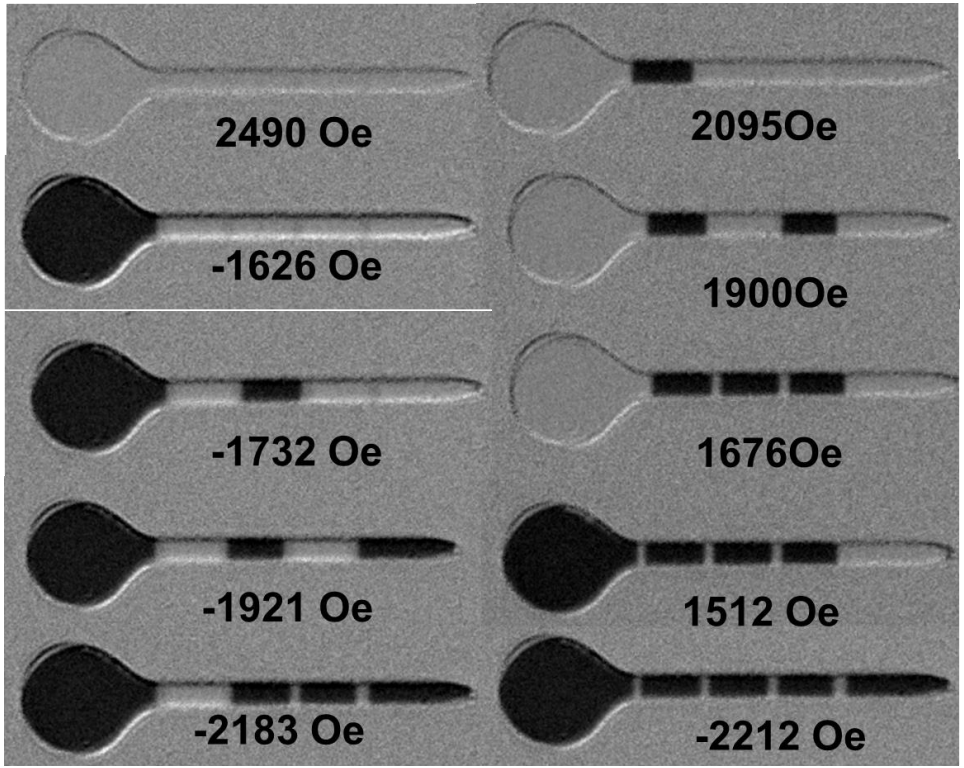
Domain Wall Pinning

- Domain wall pinning by ion-implantation

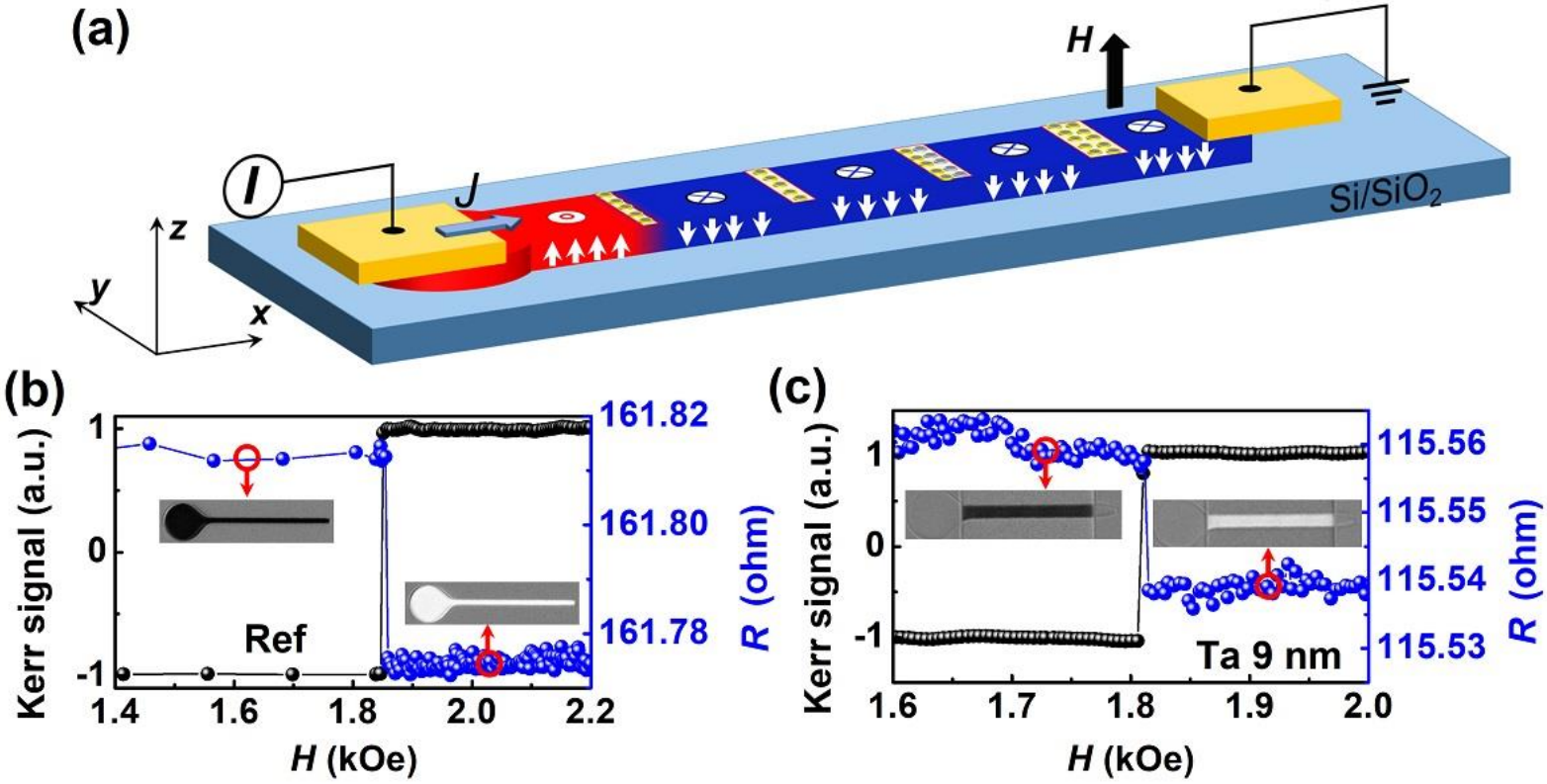


Domain Patterns: With pinning sites

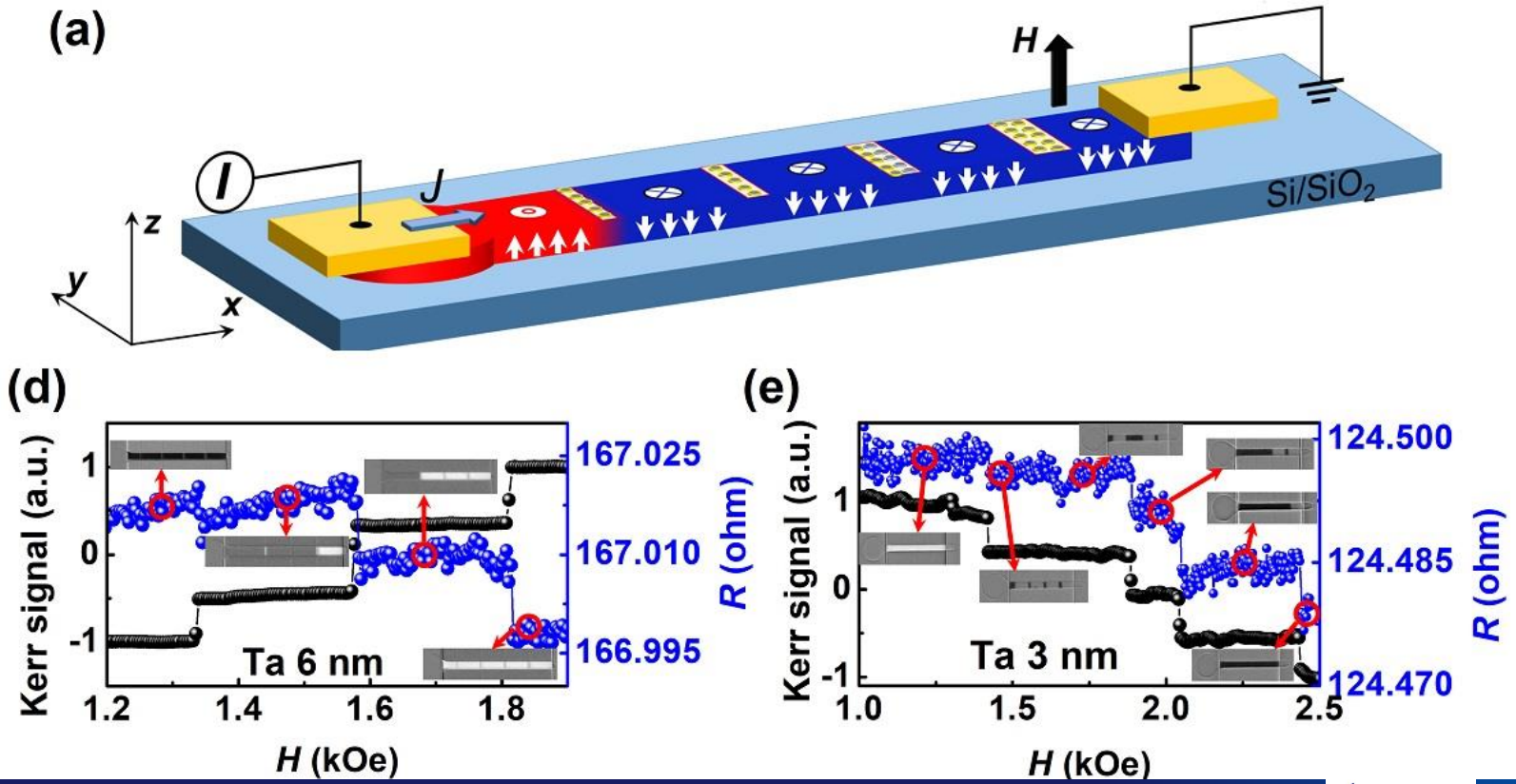




Domain wall without pinning sites

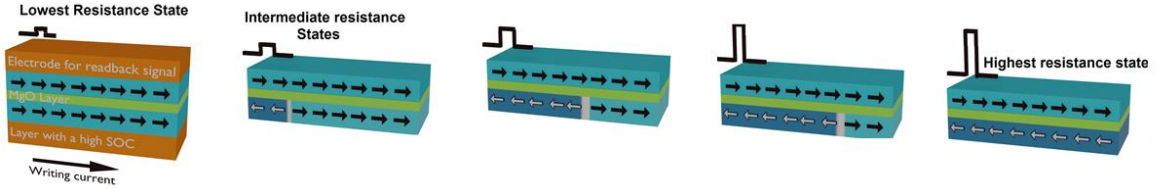


Synaptic behaviour of nanowires with pinning sites

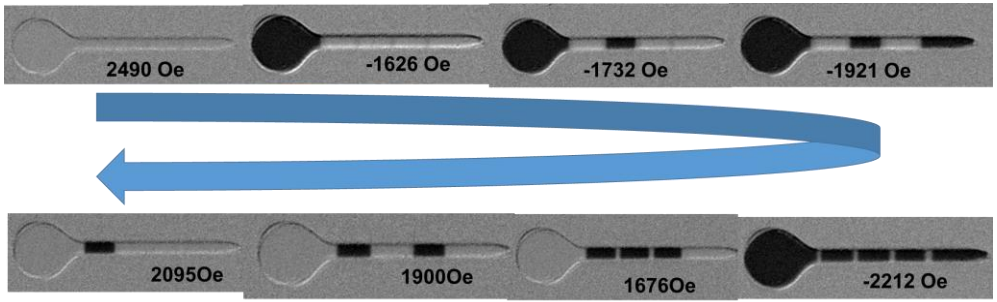


Summary

- Basic Concepts of Neuromorphic Computing were outlined



- Domain wall pinning was demonstrated Geometrical methods and magnetic texture modification (ion-implantation method and DMI modification)



- The potential of such domain wall devices for neuromorphic computing are highlighted.