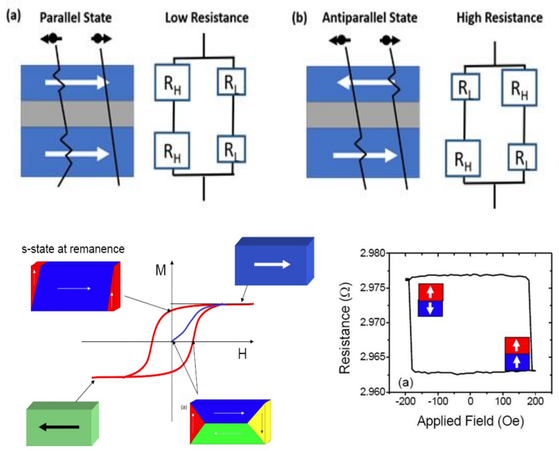
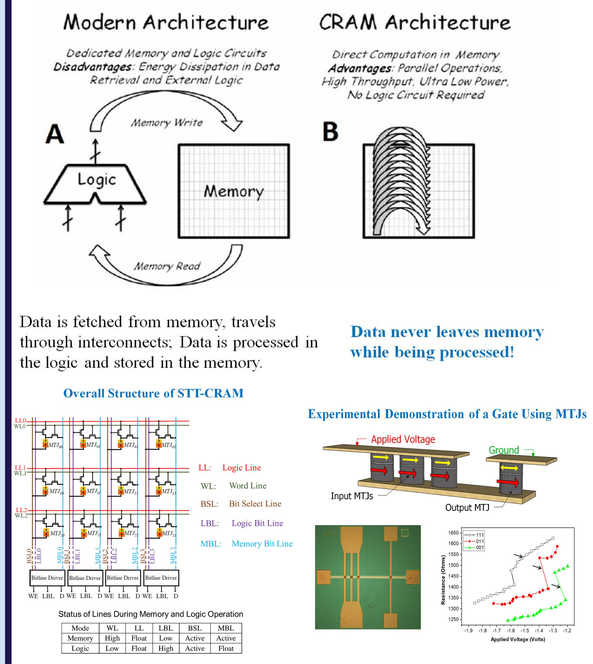
Spintronics Research

Magnetic Tunnel Junction (MTJ)

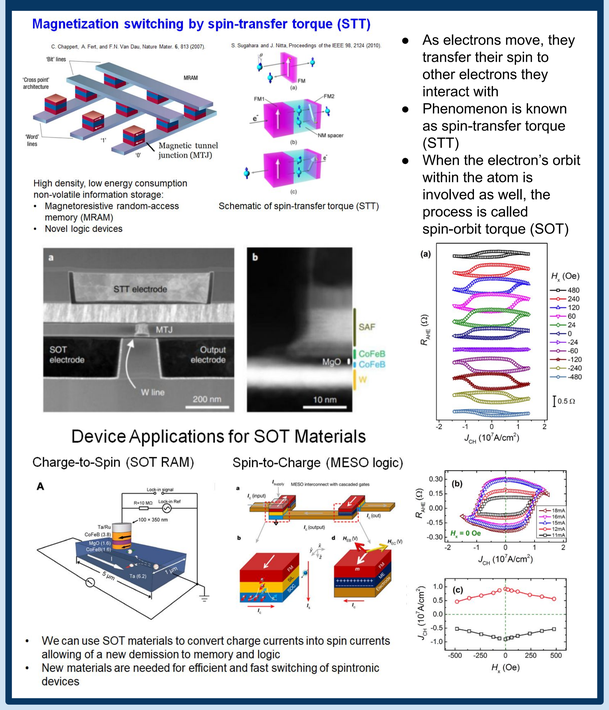


- Resistance value of the material stack changes depending on the magnetic orientation of the top and bottom layers relative to one another
- Orientation can be manipulated by applying an external magnetic field
- Forms the basis of all spintronic technology

CRAM



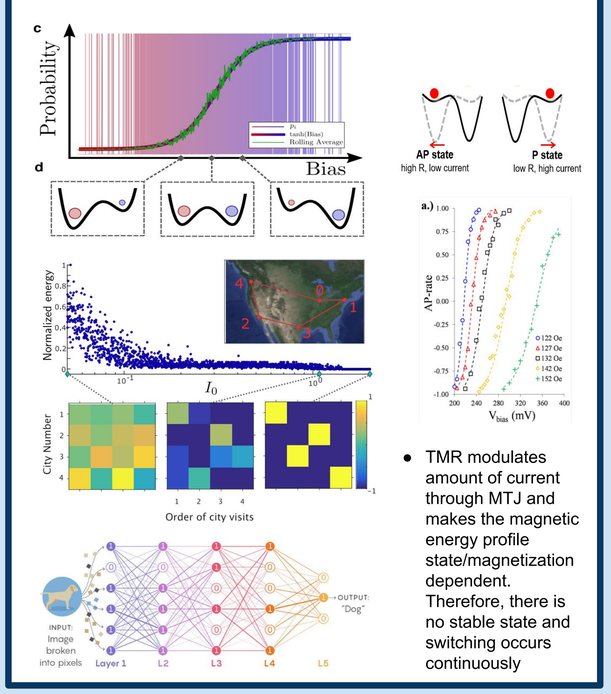
STT and SOT



- As electrons move, they transfer their spin to other electrons they interact with
- Phenomenon is known as spin-transfer torque (STT)
- When the electron's orbit within the atom is involved as well, the process is called spin-orbit torque (SOT)

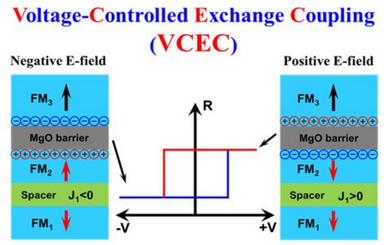
- We can use SOT materials to convert charge currents into spin currents allowing of a new demission to memory and logic
- New materials are needed for efficient and fast switching of spintronic devices

Probabilistic Computing

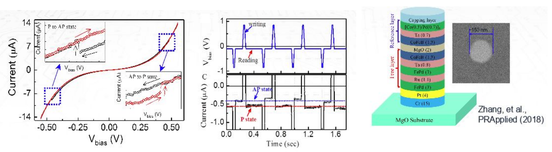


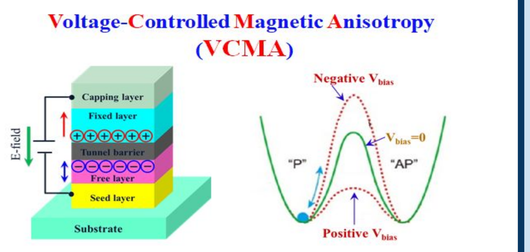
- TMR modulates amount of current through MTJ and makes the magnetic energy profile state/magnetization dependent. Therefore, there is no stable state and switching occurs continuously

Voltage-Controlled Effects

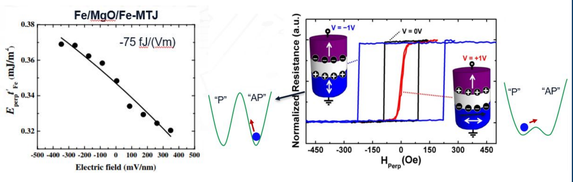


- E-field changes the reflectivity of majority and minority spin electrons at the MgO|FM_2 as well as FM_2|spacer interfaces, modifying the Interlayer Exchange Coupling (IEC)
- The IEC sign change of the SAF free layer can lead to the magnetization switching of p-MTJs, realizing a high or low resistance state



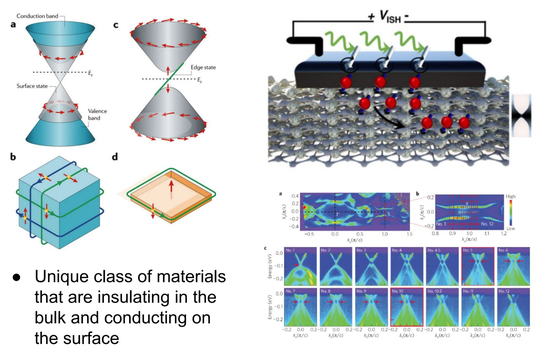


- E-field depletes or accumulates the electrons at the interface between the PMA layer and tunnel barrier, modifying the Magnetic Anisotropy (MA)
- The VCMA effect cannot switch a p-MTJ alone, however, lowering the magnetic anisotropy energy (MAE) allows for more efficient switching via STT or SOT

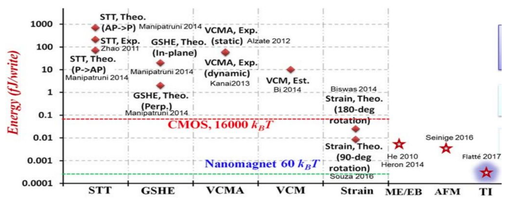


- An applied voltage can also assist in switching magnetization, or can switch it entirely on its own, without the need for an external magnetic field

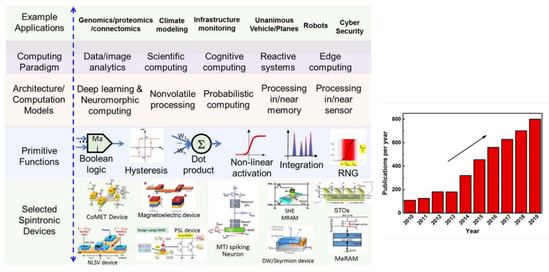
Topological Insulators (TI)



- Unique class of materials that are insulating in the bulk and conducting on the surface
- Can bring devices to the limit of energy efficiency



Future Applications



- New materials for memory and computing continue to emerge
- Much faster and more efficient than current technology
- Also opens up possibilities for new applications
- Interest in this area has increased greatly in the last decade

[1] J.-Y. Chen, M. Dc, D. Zhang, Z. Zhao, M. Li, and J.-P. Wang, "Field-free spin-orbit torque switching of composite perpendicular CoFeB/Gd/CoFeB layers utilized for three-terminal magnetic tunnel junctions," *Appl. Phys. Lett.*, vol. 111, no. 1, p. 012402, Jul. 2017

[2] H. Meng and J.-P. Wang, "Spin transfer in nanomagnetic devices with perpendicular anisotropy," *Appl. Phys. Lett.*, vol. 88, no. 17, p. 172506, Apr. 2006

[3] K. Yasuda, "Quantum Hall Physics in Magnetic Topological Insulators," in *Emergent Transport Properties of Magnetic Topological Insulator Heterostructures*, K. Yasuda, Ed. Singapore: Springer, 2020, pp. 29–45.

[4] K. Y. Camsari, B. M. Sutton, and S. Datta, "p-Bits for Probabilistic Spin Logic," *Applied Physics Reviews*, vol. 6, no. 1, p. 011305, Mar. 2019

[5] M. Jamali *et al.*, "Giant Spin Pumping and Inverse Spin Hall Effect in the Presence of Surface and Bulk Spin−Orbit Coupling of Topological Insulator Bi_2Se_3," *Nano Lett.*, vol. 15, no. 10, pp. 7126–7132, Oct. 2015

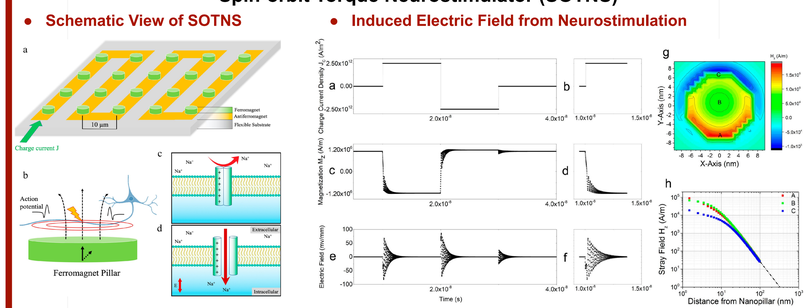
[6] J.-P. Wang *et al.*, "A Pathway to Enable Exponential Scaling for the Beyond-CMOS Era: Invited," in *Proceedings of the 54th Annual Design Automation Conference 2017*, Austin TX USA, Jun. 2017, pp. 1–6

Bio Research

Implantable Micromagnetic Neurostimulation

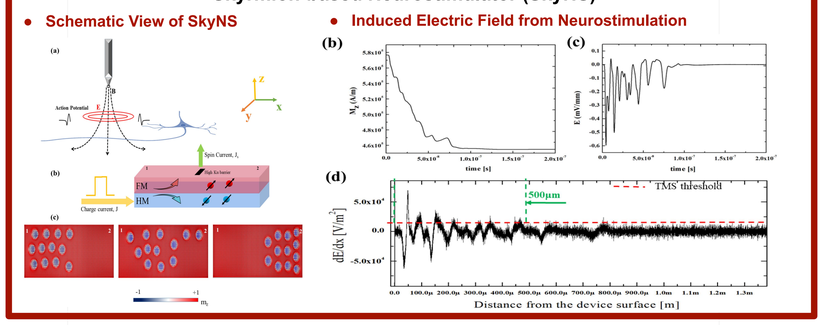
Spin-orbit Torque Neurostimulator (SOTNS)

- Schematic View of SOTNS
- Induced Electric Field from Neurostimulation

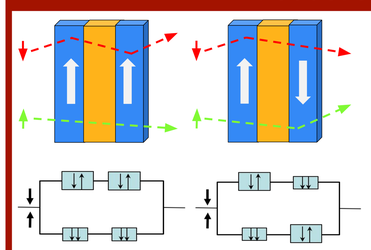


Skyrmion-based Neurostimulator (SkyNS)

- Schematic View of SkyNS
- Induced Electric Field from Neurostimulation

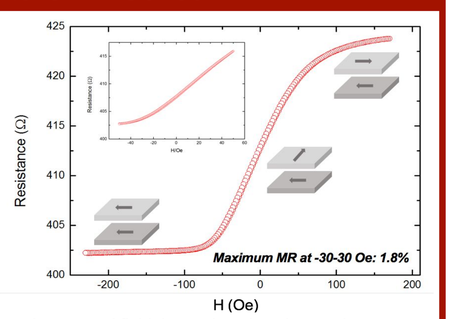


Introduction to GMR Sensor

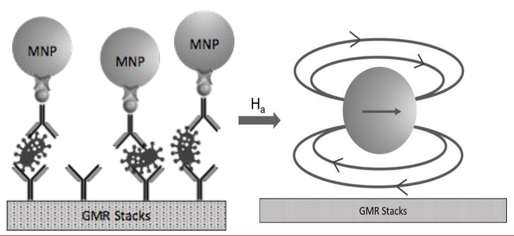


$$MR = \frac{R_{AP} - R_P}{R_P} = \frac{(R^{\uparrow} - R^{\downarrow})^2}{4R^{\uparrow}R^{\downarrow}}$$

- GMR effect exists in alternating ferromagnetic and nonmagnetic metal layers. The resistance is different for parallel and antiparallel states due to spin-dependent scattering.

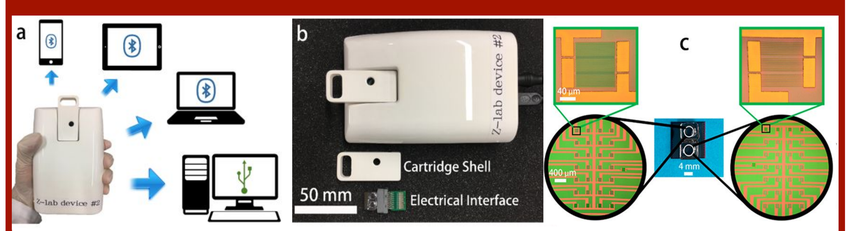


- An external field is employed to change the magnetization direction of the free layer.
- The resistance of the sensor will increase with the angle between the magnetization direction of free layer and pinned layer.

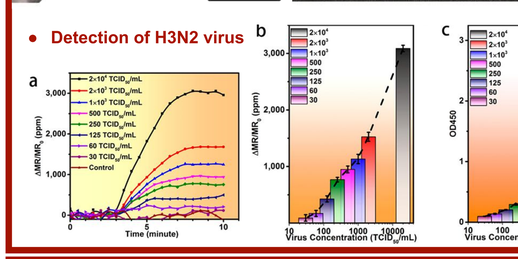


- A sandwich structure including capture antibody, antigen and detection antibody is functionalized on sensor surface.
- The sensor signal is proportional to the concentration of target antigens.

Handheld GMR Biosensor Platform



- Detection of H3N2 virus



- Can test two different concentrations on one chip
- Compatible with many devices, such as cellphones, tablets, laptops, and desktop computers
- Higher sensitivity than ELISA

[1] Wu, K., Klein, T., Krishna, V. D., Su, D., Perez, A. M., & Wang, J. P. (2017). Portable GMR handheld platform for the detection of influenza A virus. *ACS sensors*, 2(11), 1594-1601.

[2] Saha, R., Wu, K., Su, D., & Wang, J. P. (2019). Tunable magnetic skyrmions in spintronic nanostructures for cellular-level magnetic neurostimulation. *Journal of Physics D: Applied Physics*, 52(46), 465002.

[3] Wu, K., Su, D., Saha, R., & Wang, J. P. (2019). Spin–orbit torque and spin hall effect-based cellular level therapeutic spintronic neuromodulator: a simulation study. *The Journal of Physical Chemistry C*, 123(40), 24963-24972.

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