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Intrinsic Synaptic Computing with Domain Wall Devices

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- Sandia National Laboratories
- O-REU at TAMU

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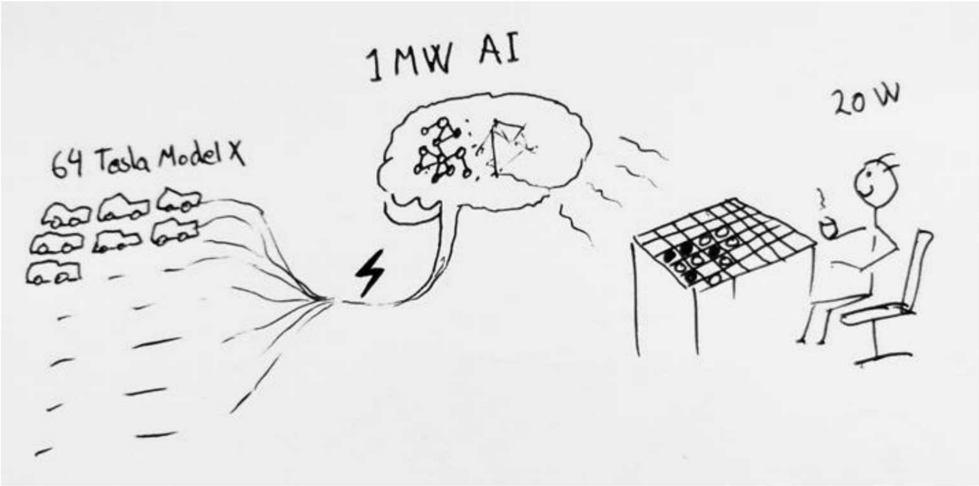
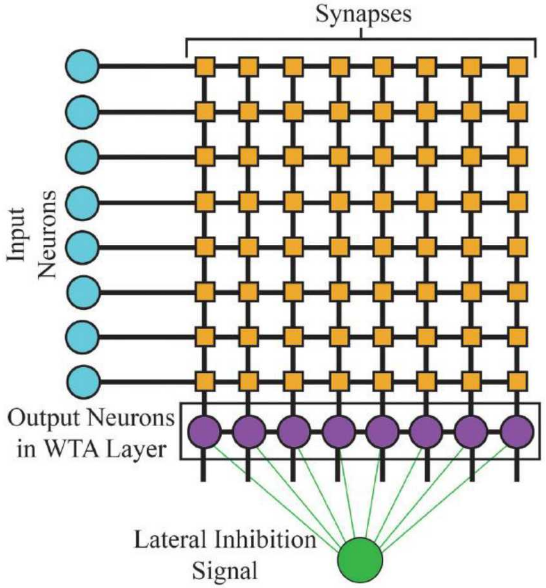
- INC Group at UT Austin

Neural Networks

- For big data applications, neural networks (NNs) are often used, but traditional computer architectures inefficient
- Synapses and neurons of a neural network can be implemented using spintronic devices
- Using intrinsic properties of magnetic materials, it is possible to implement controllable non-linear synapses
- Goal: model non-linear synaptic behavior at device and system level

https://www.imagimob.com/blog/are-there-fashion-trends-in-ai





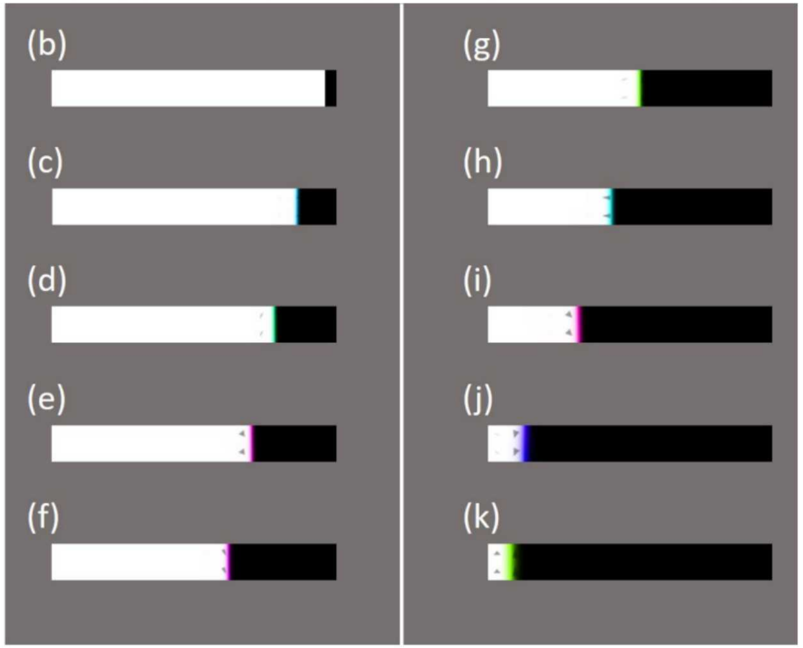
Hassan et al., *Magnetic domain wall neuron with lateral inhibition*

Micromagnetics and SPICE modeling

- Develop non-linear synapse model using micromagnetics simulation software MuMax3
- Verify behavior on a larger scale by using in conjunction with SPICE software
- Emphasis on ways to minimize leaking behavior in synapses

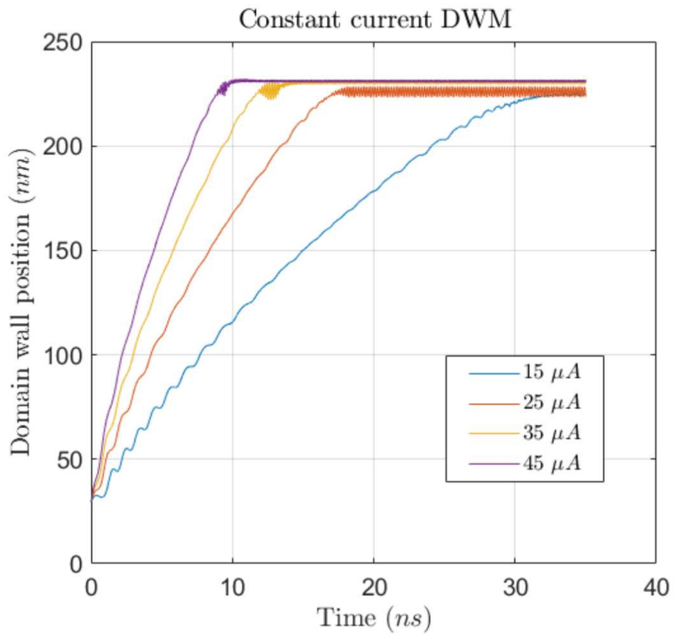
$$\vec{\tau}_{\mathrm{ZL}} = \frac{1}{1+\alpha^2}\left((1+\xi\alpha)\,\vec{\mathbf{m}}\times(\vec{\mathbf{m}}\times(\vec{\mathbf{u}}\cdot\nabla)\vec{\mathbf{m}}) + (\xi-\alpha)\,\vec{\mathbf{m}}\times(\vec{\mathbf{u}}\cdot\nabla)\vec{\mathbf{m}}\right)$$

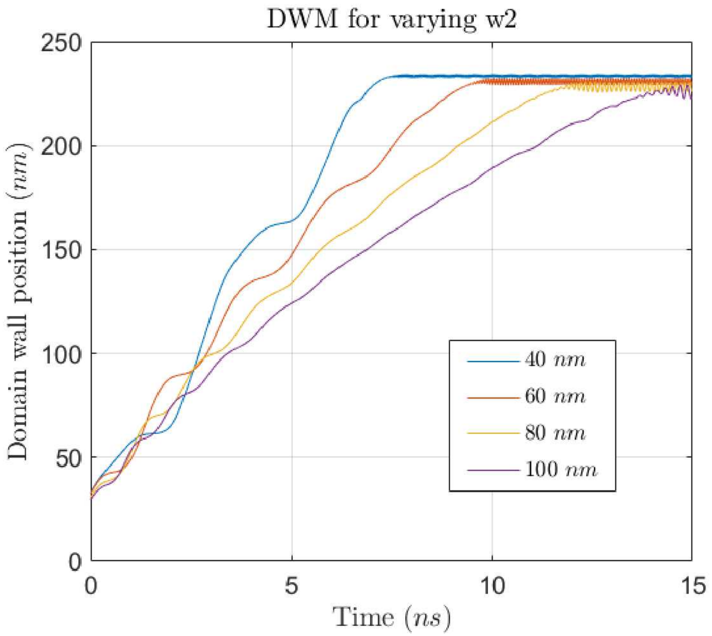
$$\vec{\mathbf{u}} = \frac{\mu_B\mu_0}{2e\gamma_0 B_{\mathrm{sat}}(1+\xi^2)}\vec{\mathbf{j}}$$

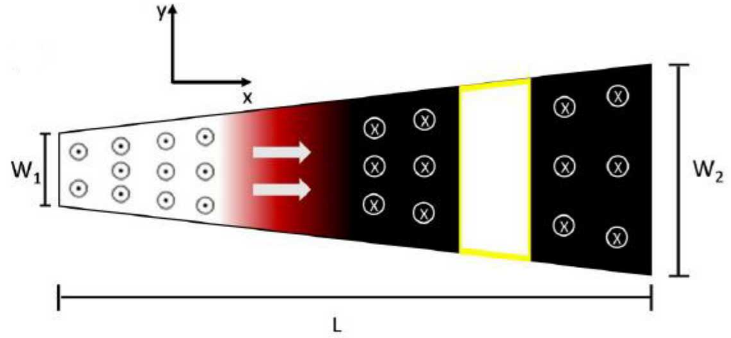


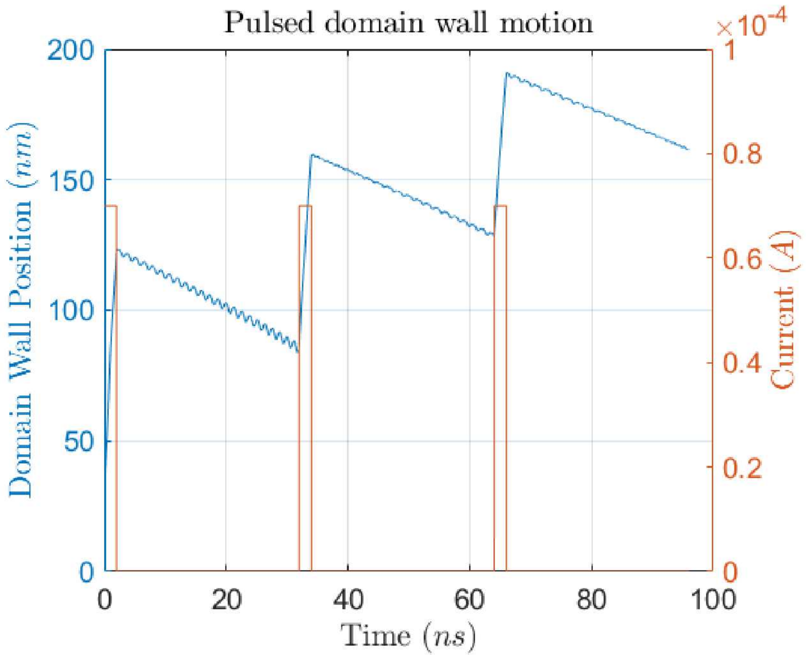
Brigner et al., *Graded-Anisotropy-Induced Magnetic Domain Wall Drift for an Artificial Spintronic Leaky Integrate-and-Fire Neuron*

Benchmark results for smooth synapse

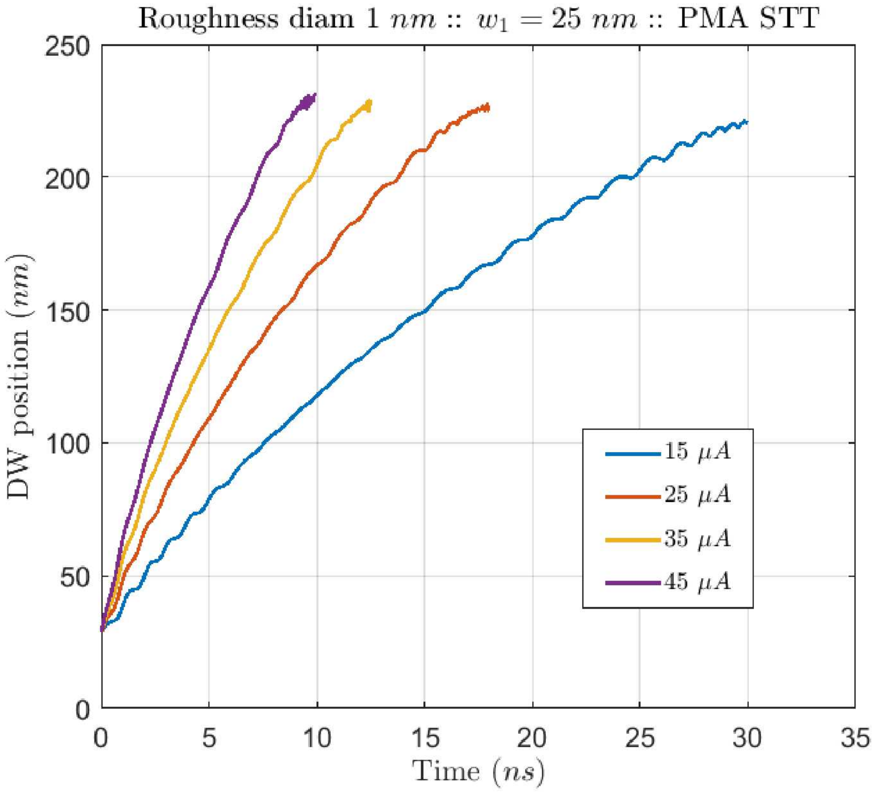


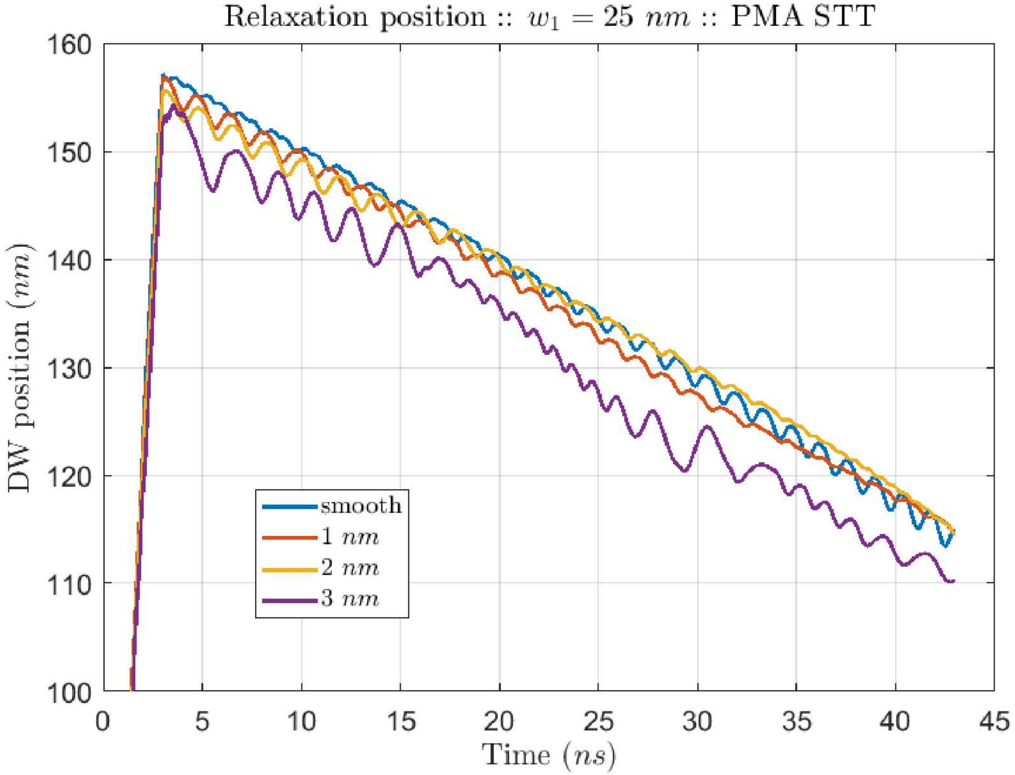




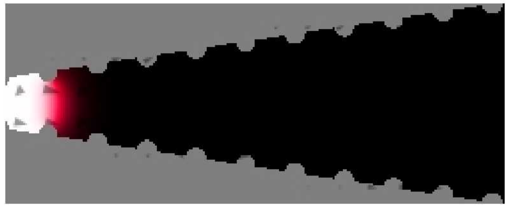


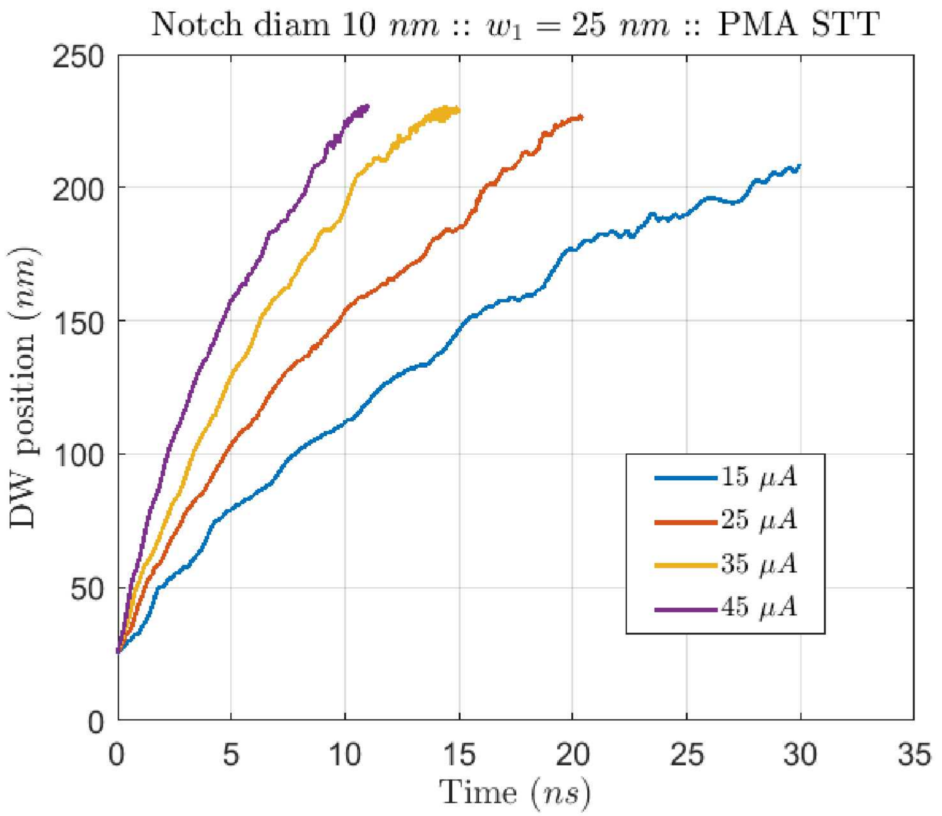
Results for synapse edge roughness

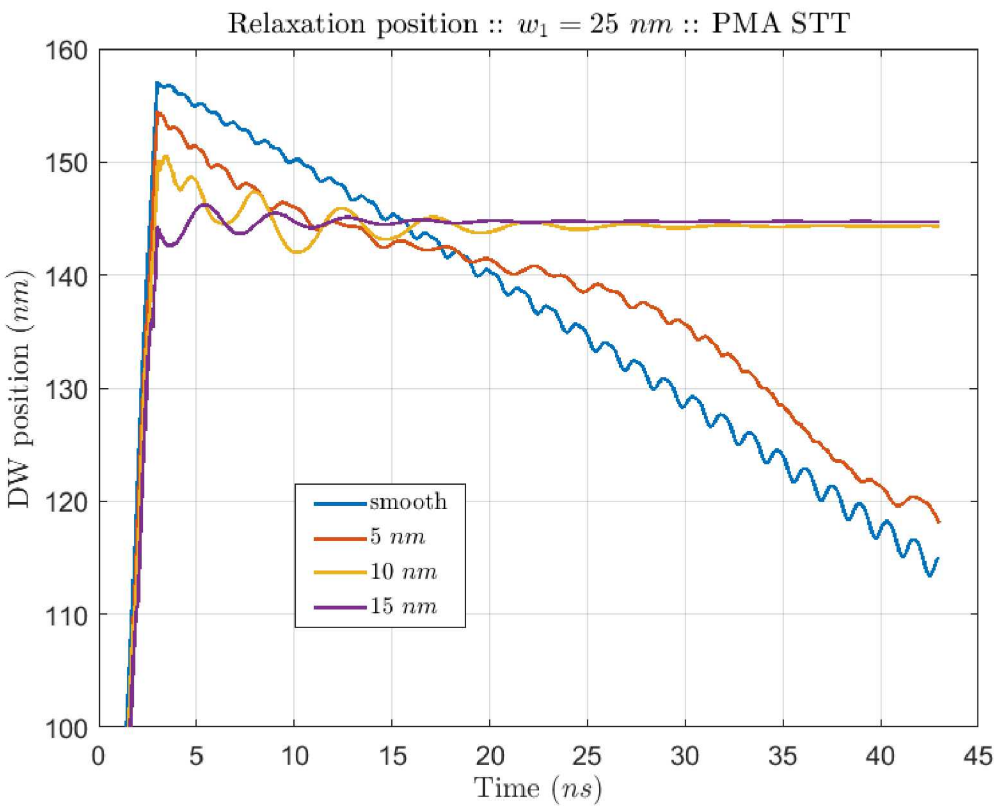




Results for synapse with notches







Conclusions and research direction

- Set up micromagnetics model of trapezoidal synapse using CoFeB material parameters with implementation of:
  - Spin transfer torque, spin Hall effect, Rashba effect
  - Notches and surface roughness
  - PMA vs IMA materials
- Notches and surface roughness both retain properties of nonlinear propagation, but only sufficient diameter notches prevent leaking
- Next step: Investigate notch diameter vs maximum synapse pinning location