

Intrinsic Leaking in a Domain-Wall Magnetic Tunnel Junction Neuron

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Presentation Overview

I. Background

II. LIF Neuron

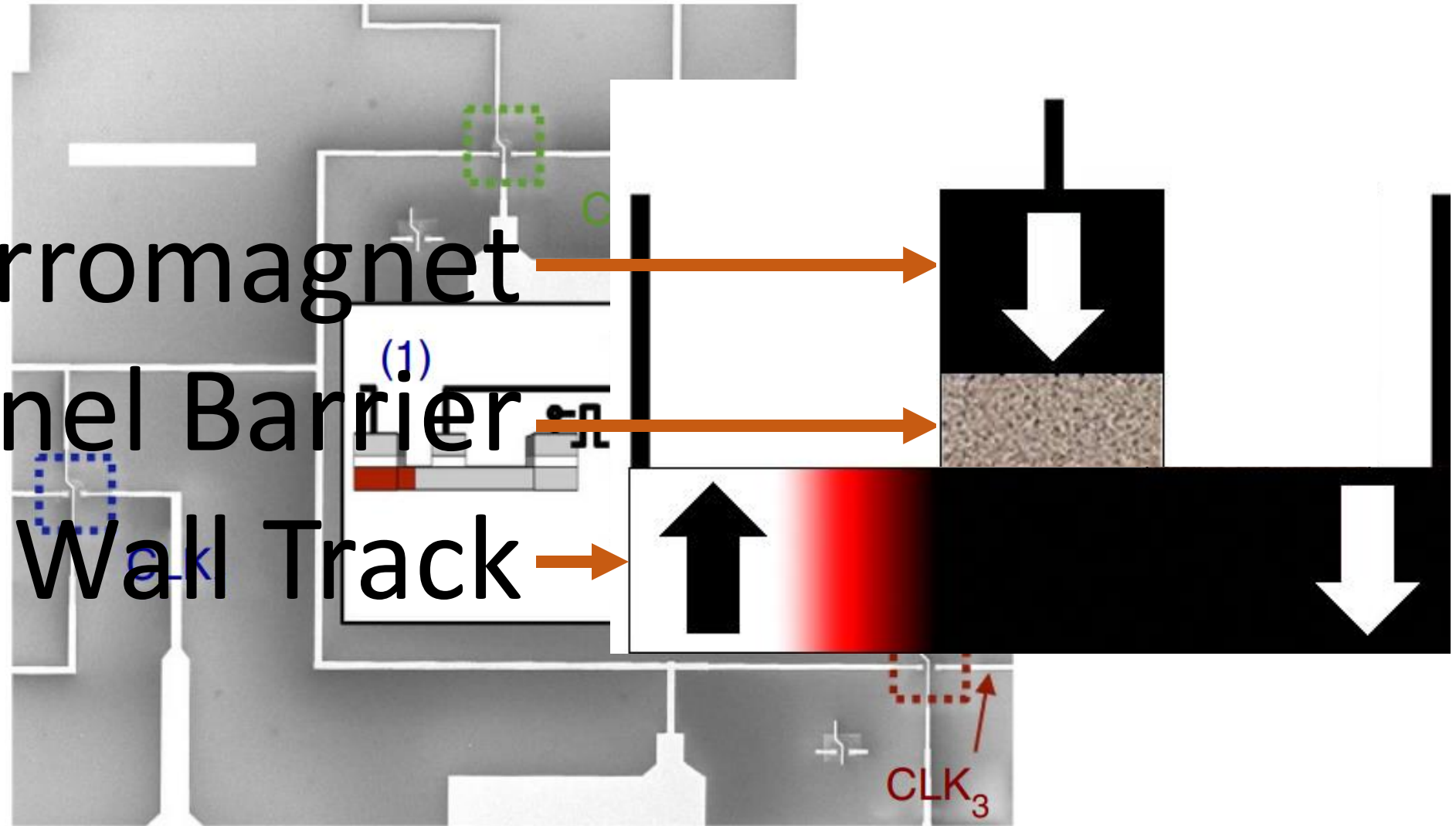
III. Linear Neuron

IV. Squashing Neuron

V. Conclusions

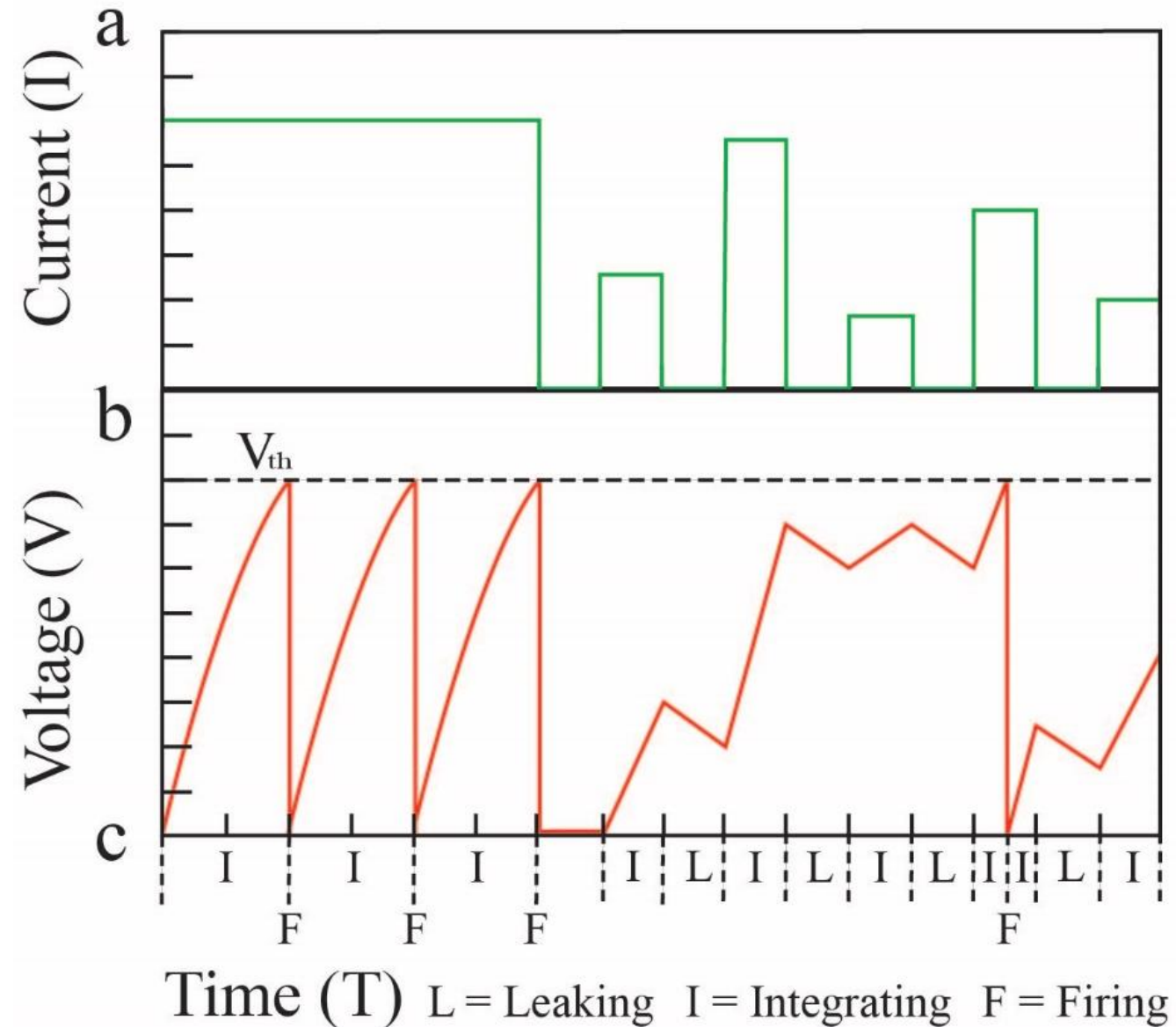
Background: DW-MTJ Logic

Fixed Ferromagnet
Tunnel Barrier
Domain Wall Track

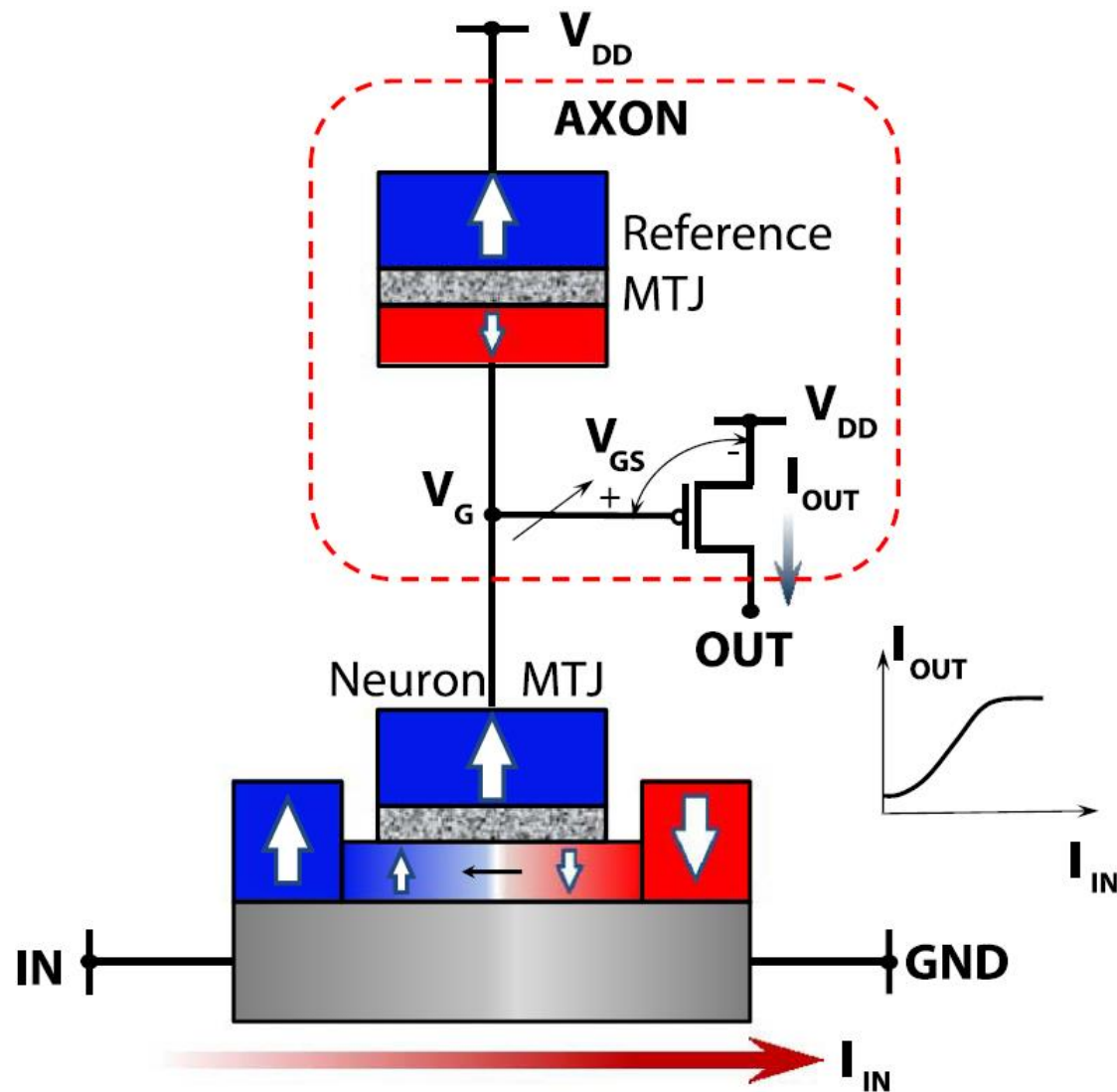


J. A. C. Incorvia, S. Siddiqui, S. Dutta, E. R. Evarts, J. Zhang, D. Bono, C. A. Ross, M. A. Baldo,
Nature Communications, 2016

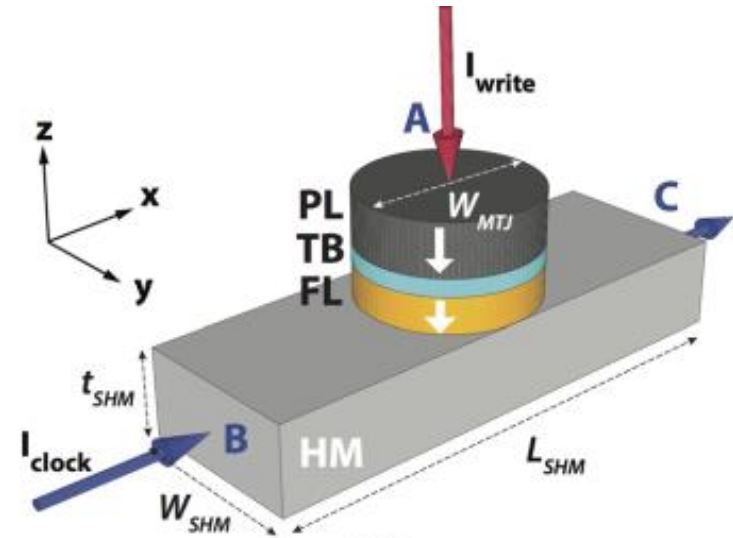
Background: Leaky-Integrate & Fire Neuron



Background: Previous Neuron Proposals



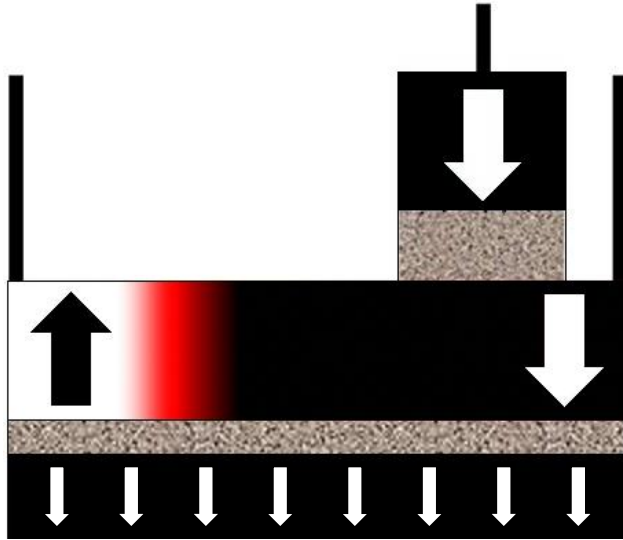
A. Sengupta, Y. Shim, K. Roy, *IEEE TBioCAS*, 2016



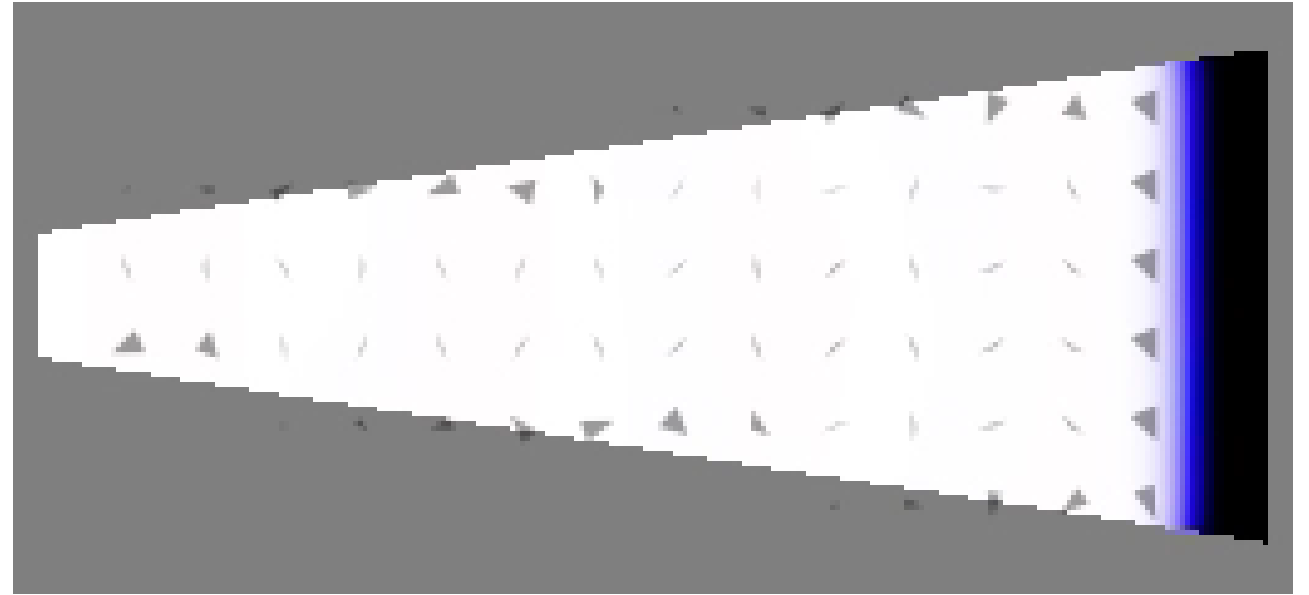
A. Sengupta, S. H. Choday, Y. Kim, and K. Roy, *Applied physics letters*, 2015

- Requires external circuitry for leaking and firing

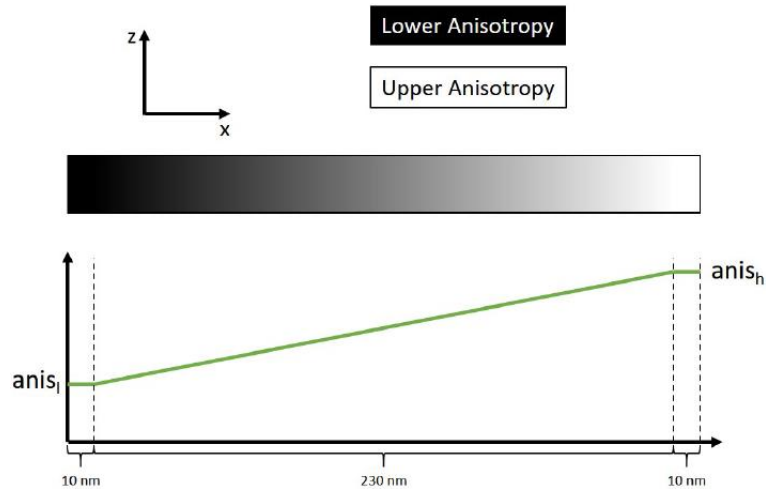
Background: Previous Neuron Proposals



N. Hassan, et al., *Journal of Applied Physics*, 2018



W. H. Brigner, et al., *IEEE Trans. Electron Devices* **66**:6, 2817-2821 (2019).



W. H. Brigner, et al., *IEEE JxCDC*, 2019

- Does not intrinsically implement activation functions

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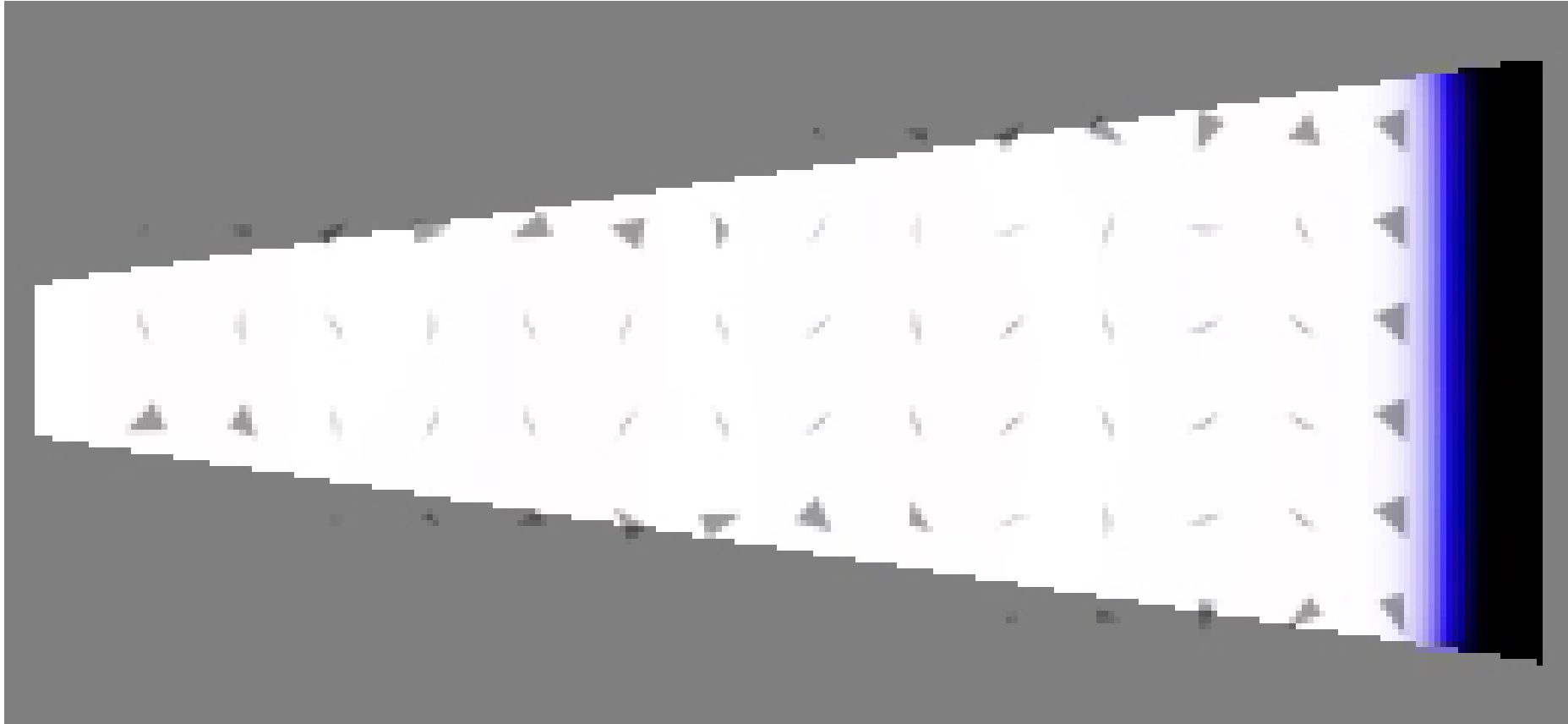
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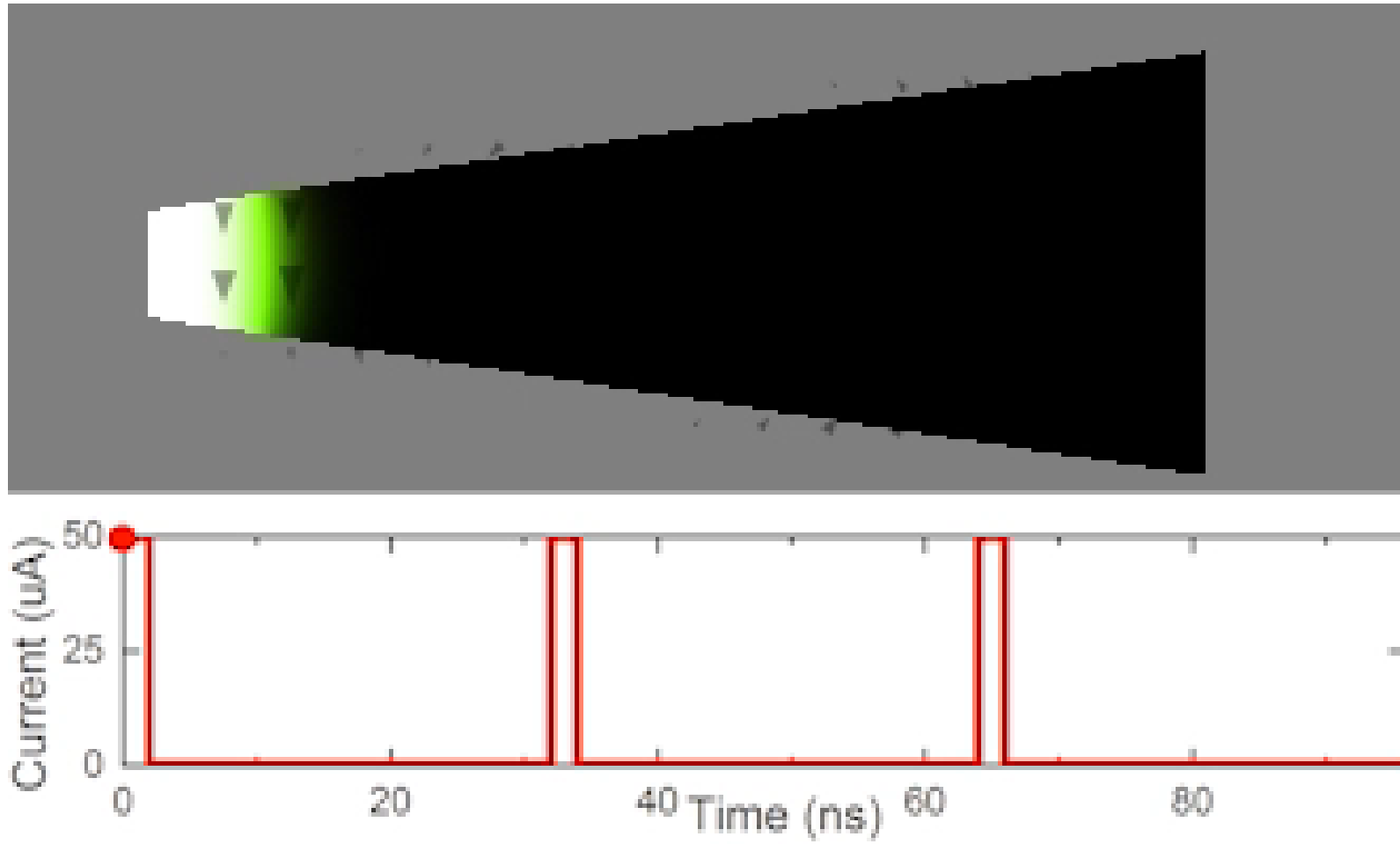
V. Conclusions

Shape Gradient: Leaking



W. H. Brigner, N. Hassan, L. Jiang-Wei, X. Hu, D. Saha, C. H. Bennett, M. J. Marinella, J. A. C. Incorvia, F. Garcia-Sanchez, J. S. Friedman, *IEEE Trans. Electron Devices* **66**:6, 2817-2821 (2019).

Shape Gradient: Leaking & Integrating



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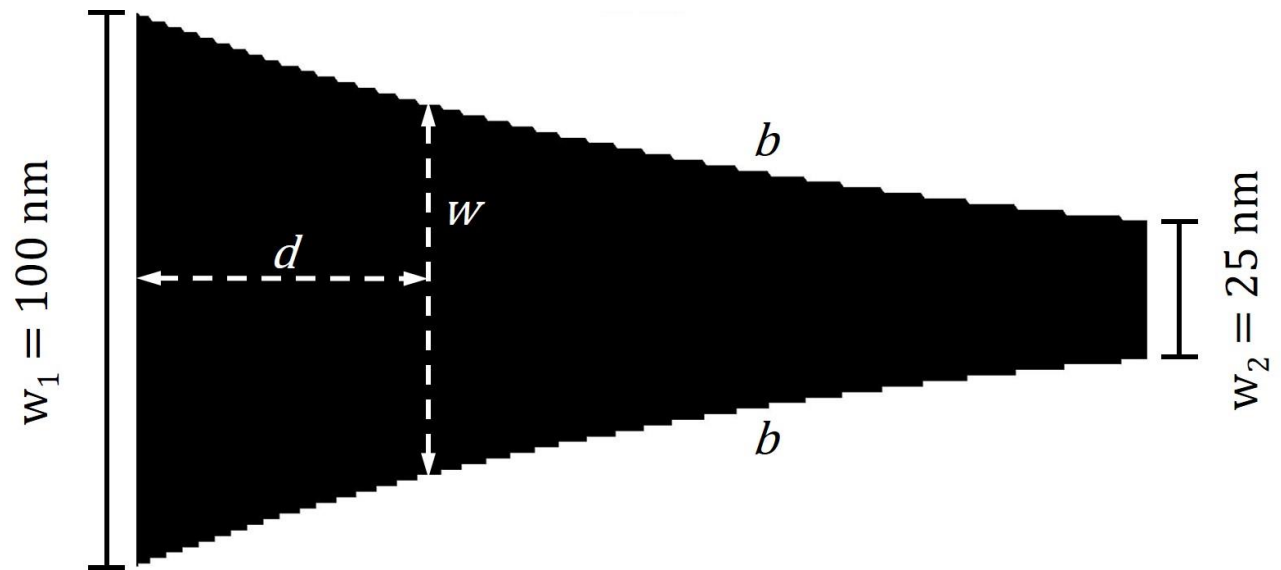
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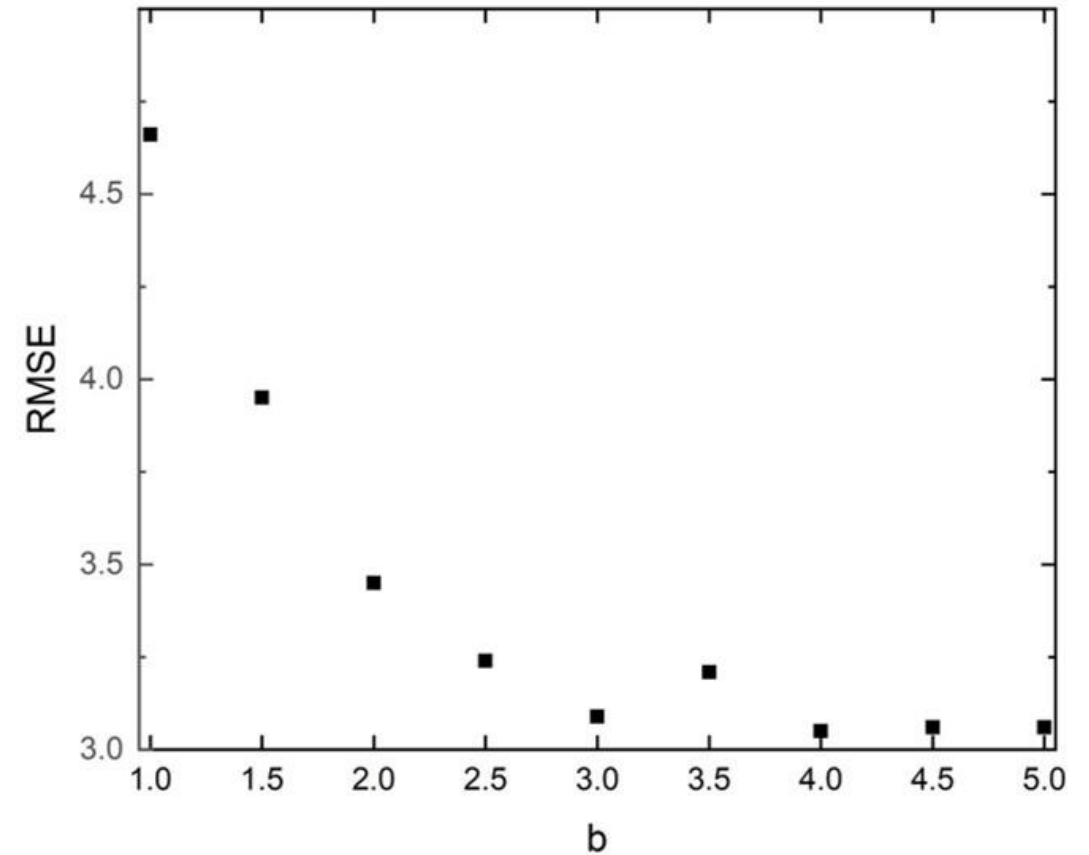
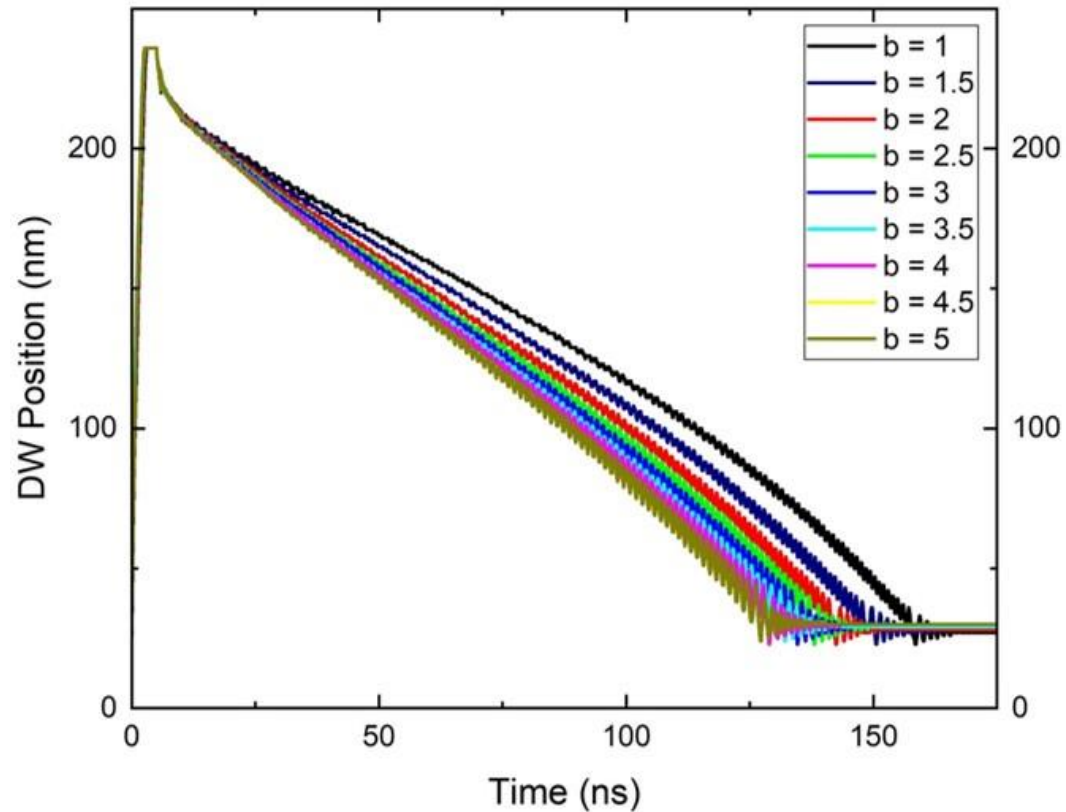
Linear Neuron Structure

- DW tends to accelerate as it nears the end of the track
 - Leaking force must be decreased towards the end of the track to counter this
- Accomplished via a slight exponential variation of the width, with the form $w \propto b^{-d}$
 - w : Width of track
 - b : Rate of exponential increase
 - d : Distance from wide end of track

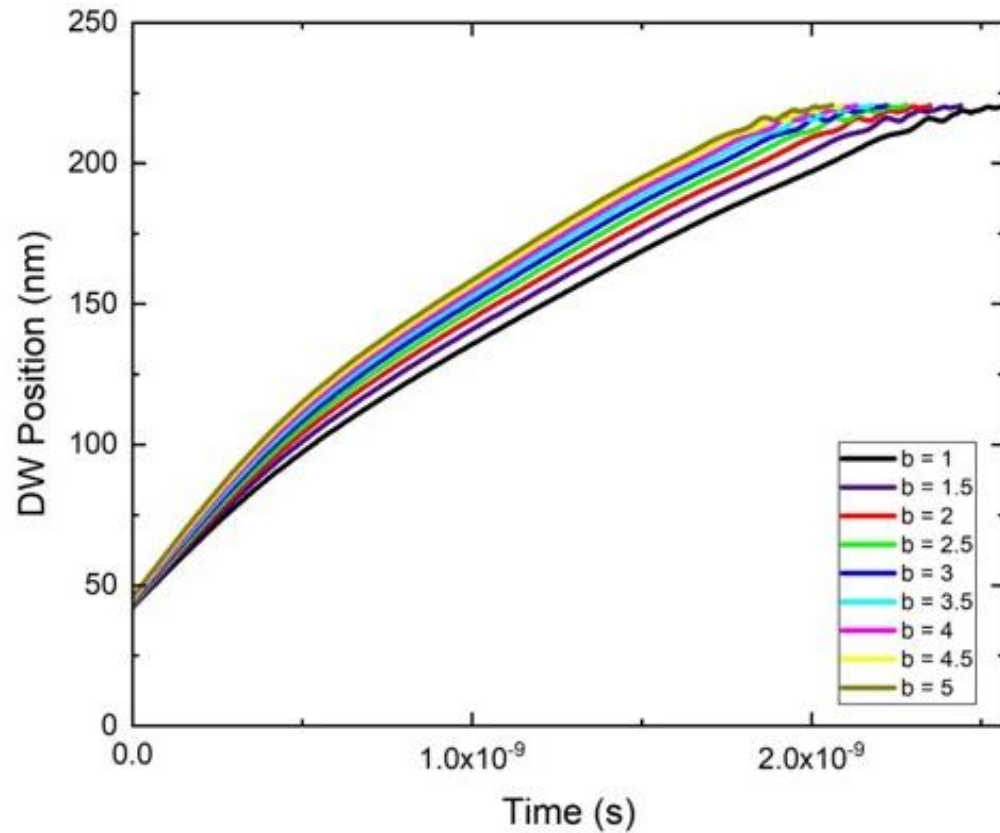


JAP Reference?

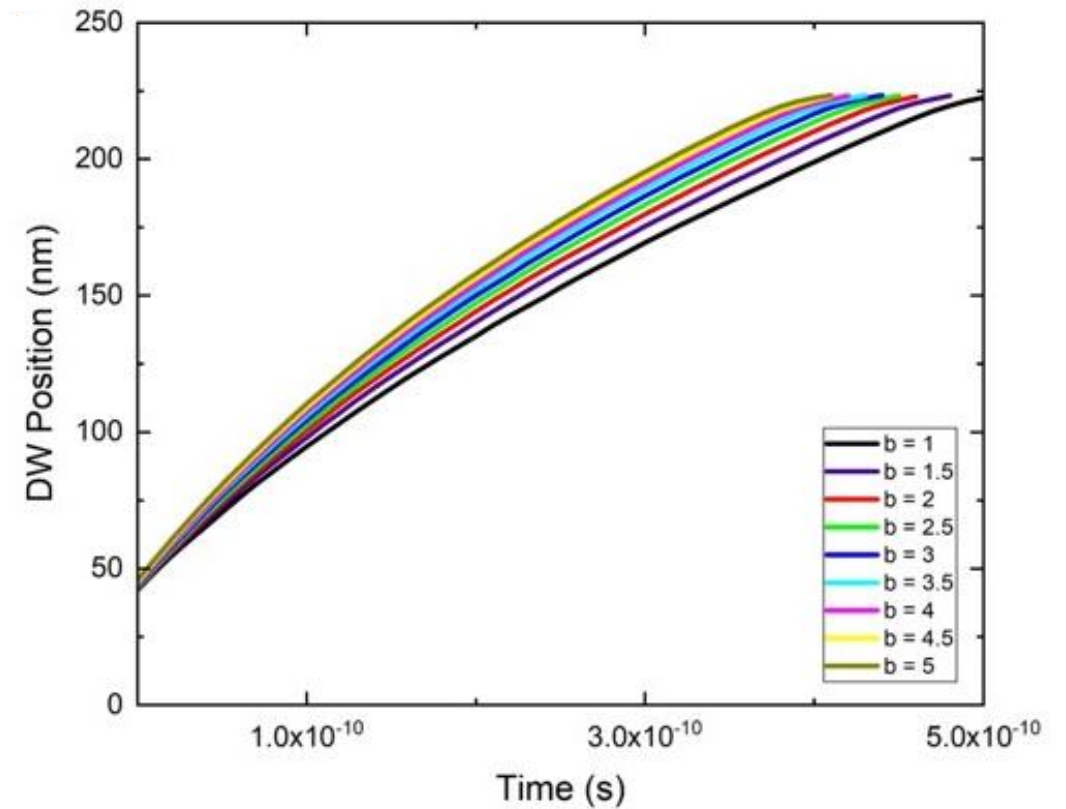
Linear Neuron Leaking Characteristics



Linear Neuron Integrating Characteristics



0.1 mA



0.5 mA

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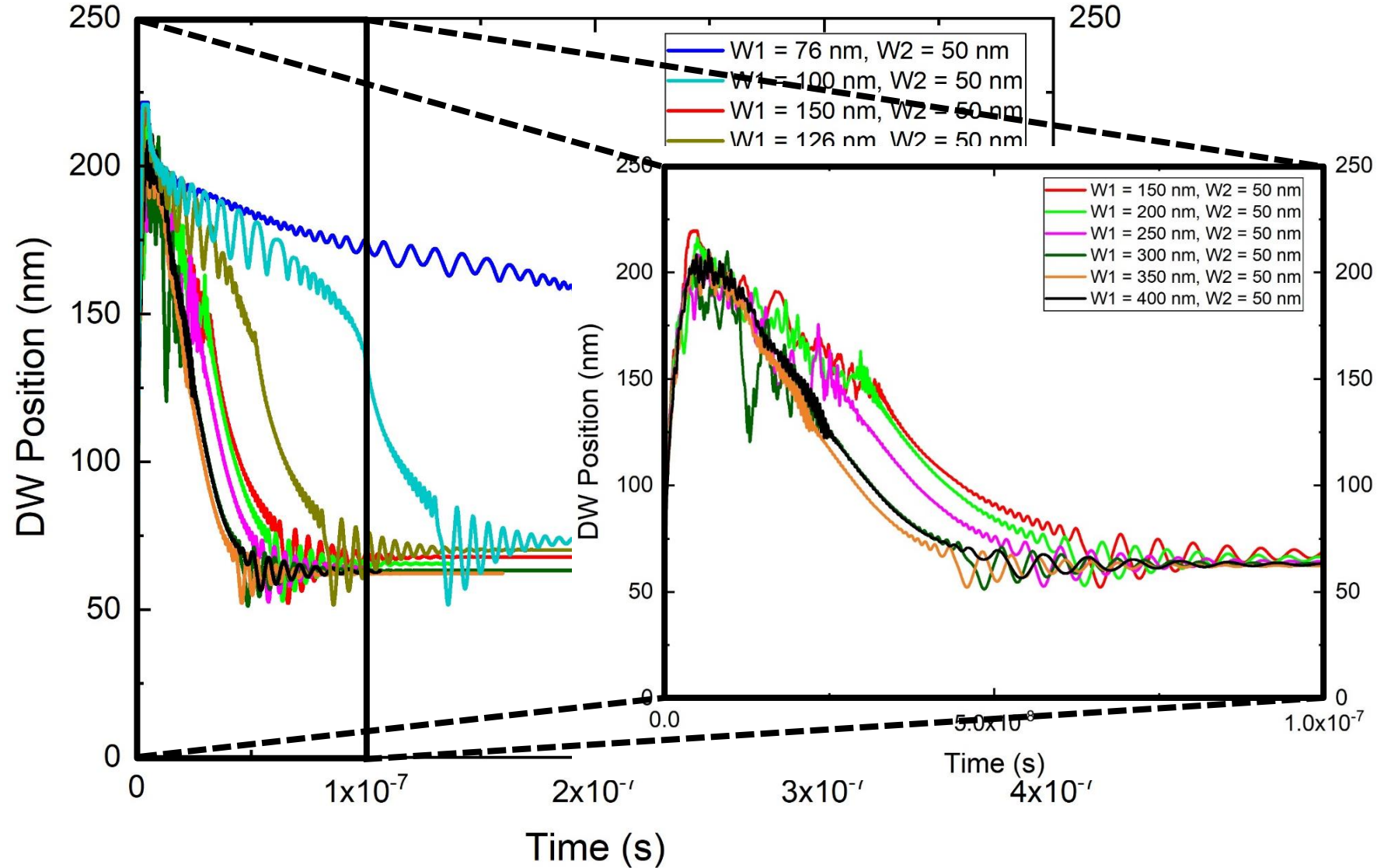
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Squashing Neuron Structure

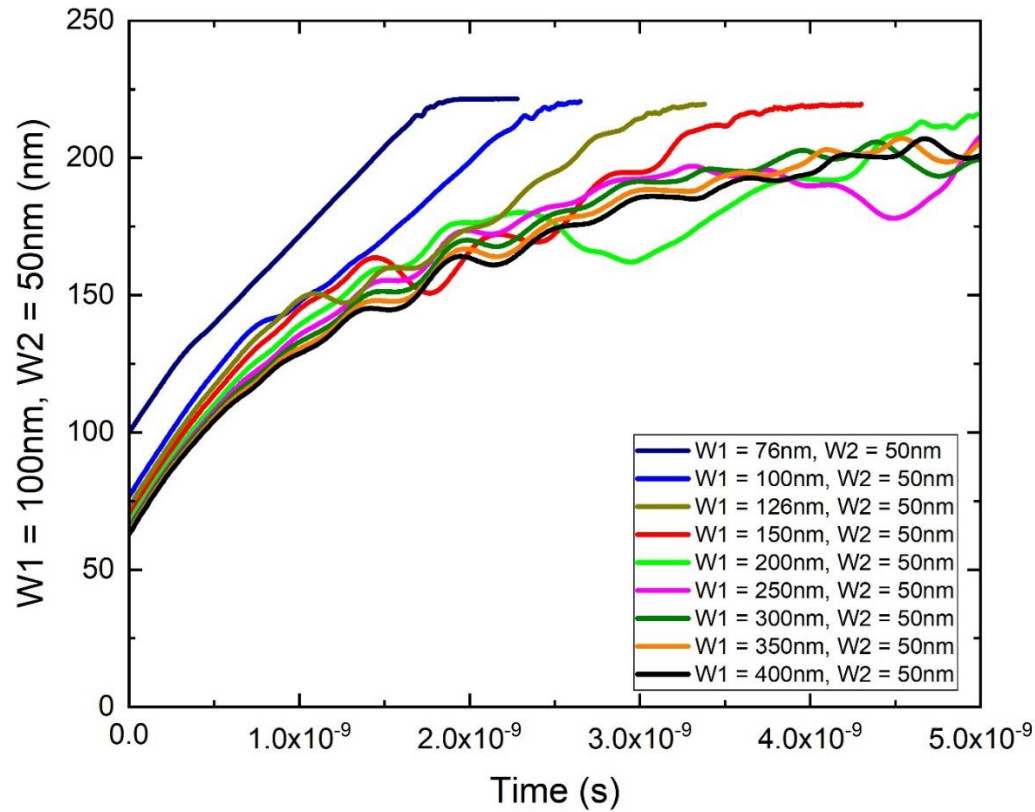
- DW tends to accelerate as it nears the end of the track
 - Leaking force must be decreased at both ends of the track
- Accomplished via a rapid decrease in the width of the DW track
 - w_1 : Width of wide end
 - w_2 : Width of narrow end



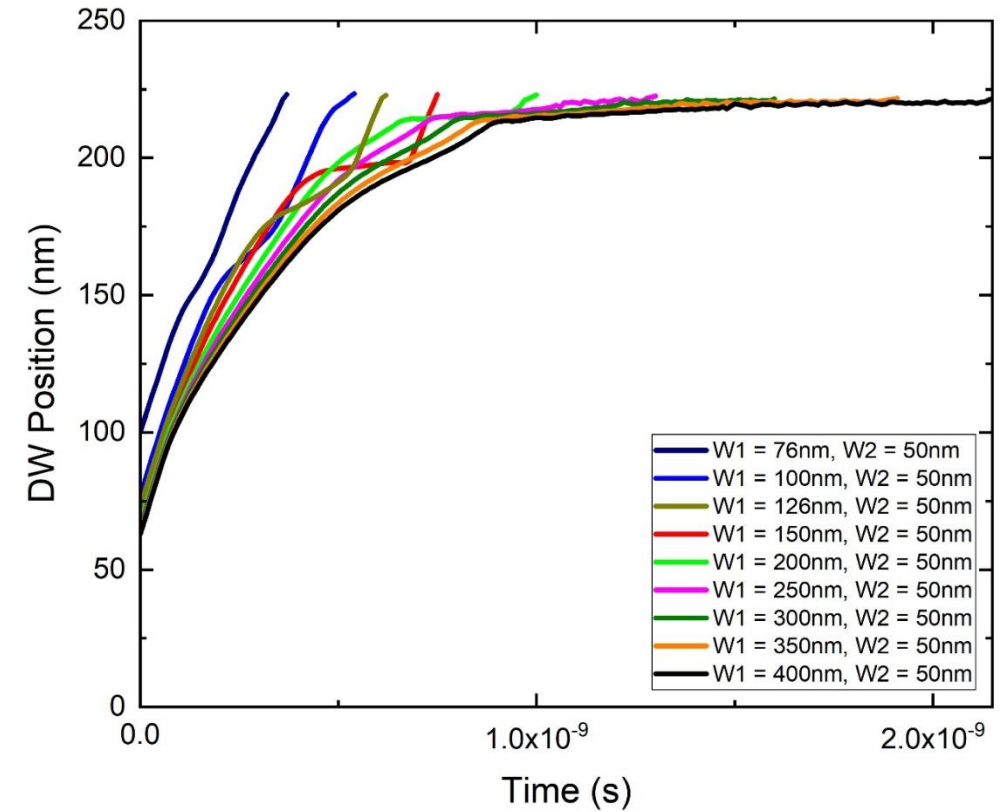
Squashing Neuron Leaking Characteristics



Squashing Neuron Integrating Characteristics



0.1 mA



0.5 mA

Conclusions

- Demonstrated LIF neurons with linear and squashing activation functions
 - Can theoretically implement any custom activation function by varying the DW track width in a particular manner
- Ability to implement various activation functions will provide for significantly improved learning characteristics compared to previous LIF neurons

Thank You



Xuan Hu



Naimul Hassan



Joseph Friedman



CCF Awards

1910800

1910997



Graduate Fellowship



Graduate Research Fellowship
Program (GRFP)

Award No. 1746053



McDermott Graduate Fellows

Award No. 202001



Jean Anne Incorvia



Otitoaleke Akinola



Sandia
National
Laboratories



Christopher Bennett



Matthew Marinella



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VNiVERSiDAD
DSALAMANCA



Felipe Garcia-Sanchez