ABHISHEK KHANNA

Contact Information

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Research Interests

Analog and Neuromorphic Computing, Emerging Device Modelling & Characterization

Education

PhD in Electrical Engineering
University of Notre Dame, Indiana — *Aug 2017 - Present*

Master of Techonology in Microelectronics
Indian Institute of Technology Bombay, India — *Aug 2016*

Bachelor of Techonology in Electrical Engineering
Indian Institute of Technology Bombay, India — *Aug 2015*

Selected Publications

- S. Dutta*, **A. Khanna***, et. al 'An Ising Hamiltonian solver based on coupled stochastic phase-transition nano-oscillators'
  Nature Electronics, July 2021
- **A. Khanna***, S. Dutta* et. al 'Lifelong Learning with Monolithic 3D Ferroelectric Ternary Content-Addressable Memory'
  2021 International Electron Device Meeting (accepted)
- **A. Khanna**, E. Elmitwalli, et. al 'A Bias and Correlation Free True Random Number Generator Based on Quantized Oscillator Phase under Sub-Harmonic Injection Locking'
  2020 Symposium on VLSI Technology
- E. Corti, **A. Khanna**, et. al 'Time-Delay Encoded Image Recognition in a Network of Resistively Coupled VO2 on Si Oscillators'
  IEEE Electron Device Letters, Feb 2020
- **A. Khanna***, S. Dutta*, et. al 'Spoken vowel classification using synchronization of phase transition nano-oscillators'
  2019 Symposium on VLSI Technology
- G. Detorakis, S. Dutta, **A. Khanna**, et. al 'Inherent weight normalization in stochastic neural networks'
  2019 Advances in Neural Information Processing Systems
- S. Dutta, A. Parihar, **A. Khanna**, et. al 'Programmable coupled oscillators for synchronized locomotion'
  Nature Communications, July 2019
- N. Panwar, **A. Khanna**, P. Kumbhare, and U. Ganguly , 'Self-Heating during sub-μs Current Transients in $Pr_{0.7}Ca_{0.3}MnO_3$ (PCMO) based RRAM'
  IEEE Trans. Electron Devices, Jan 2017
- **A. Khanna**, S. Prasad, N. Panwar and U. Ganguly, 'A Reaction-Diffusion Model for Switching Transients in $Pr_{0.7}Ca_{0.3}MnO_3$ (PCMO) based RRAM'
  arXiv:11612.05293

Awards and Honors

- Won **Best Poster Award** at IEEE/CAS AI Compute Symposium 2019 held at IBM T.J. Watson Research Lab, New York
- Won **Best Poster Award** at E2CDA-NRI EXCEL Annual Review 2018 held at University of Notre Dame, Indiana

Scholastic Achievements

- Secured **All India Rank 209** in IIT-JEE 2010 exam with 99.96 %ile among 500k students.
- Among **top 30** students selected nationally to attend Orientation cum Selection Camp (OCSC) for International Olympiad on Astronomy and Astrophysics **(IOAA)**
- **National top 1%** in National Standard Examination in Physics

Research Experience

Graduate Research Assistant
Advisor: Dr. Suman Datta, University of Notre Dame *July 2017 - Present*

Ising Machine with Phase Transition Nano-Oscillators for Combinitorial Optimization
Funded by: Intel Corporation, SRC
Ising machines are physical systems mapping certain classes of combinatorial optimization problems to the ground state of an Ising model. We use second-harmonic injection locking (SHIL) to create artifical 'spins' from VO_2 phase transition nano-oscillators (PTNO) and find the solution of problems like weighted Max-cut, Maximum Indepedent Set and Boolean Satisfiability.

- Experimentally demonstrate 10 oscillator network with 'ferromagnetic' and 'antiferromagnetic' interaction using novel dual-gate Ferroelectric FET based bidirectional analog coupling
- Develop SPICE simulation frameowrk for large scale oscillator network simulation with calibrated parasitics and noise parameters, evaluating quality of synchronization
- Develop Phase Projection Vector (PPV) based macromodel for non-linear PTNO, solving phase dynamics differnetial equations for 1000 oscillator network
- Benchmark 5x improvement in energy efficiency solving dense Max-Cut problems over closest memristor-based accelerator and several order of magnitude over GPU, FPGA implemenations
- Demonstrate efficient boltzmann sampling from coupled PTNO network enabing energy minimization based learning models

Monolithic 3D FeFET Ternary Content-Addressable Memory for Few-Shot Learning
Funded by: DARPA, SRC
Lifelong learning at the edge requires on-the-fly learning from scarce data in one or few shots which can be enabled by memory augmented neural networks (MANNs). We utilize a ternary content addresable memory (TCAM) to provide a highly dense, energy-efficient and low latency embedded non-volatile memory for performing in situ massively parallel search across all stored vectors.

- First demonstration of few-shot learning using a fabricated monolithic 3D ternary content addressable memory using back-end-of-line (BEOL) ferroelectric FETs
- Demonstrated record low write voltage of 1.6V with 20ns write latency for BEOL FeFETs and high write endurance exceeding 10^{10} cycles
- Experimentally demonstrate a 3-way 3-shot learning with 20-bit feature vectors using Omniglot dataset and achieve an inference accuracy of 70% comparable to GPU accuracy of 72%

Exploiting High Temperature Phase Transition in Lanthanum Cobaltite for abrupt Selectors and RF switches
Collaboration with : NIST Boulder, Northrup Grumman
We develop an insulator-to-metal transition (IMT) selector and RF switch using Lanthanum Cobaltite (LCO) for the first time which shows electrically triggered IMT transition at low operating voltage and high non-linearity over a wide range of temperature (25C-150C)

- Fabricated scaled (75nm dia) LCO/LSCO vertical selector and demonstrated sub-1V switching with >150x non-linearity at 85C
- Showed fast switching <20ns in 40nm tall LCO selector and ultra-high endurance $>10^{12}$ cycles
- Fabricated RF switch using sputtered LCO-on-SiC and measured low insertion loss $< 2dB$ and high isolation >20dB upto even upto 125C at 20GHz
- Demonstrated throughput of 40Gbps signal in LCO RF switch with $< 10^{-9}$ Bit Error Rate

Spatio-Temporal Vowel Learning and Classification with Coupled Nano-oscillators
Funded by: NSF, SRC
We exploit the synchronization dynamics of a network of VO_2 PTNOs to classify complex temporal patterns for speech discrimination .

- Train a network of four capacitively coupled PTNOs to provide over 20 different synchronization configurations, implementing real-time learning rule
- Achieve a high recognition accuracy of 90.5% over 5 classes of spoken vowels and show an 1.4x reduction in energy consuption, 8x reduction in training parameters compared to a CMOS neuron implementation

Research Experience

Visiting Research Scholar - IBM Zurich

Advisor: Dr. Siegfried Karg, IBM Research - Zurich, Switzerland *Jun 2019 - Sep 2019*

Time-delay encoded Pattern Recognition with Resistively Coupled ONN

Demonstrated novel concept for associative memory system based on Oscillatory Neural Networks (ONN) with resistively coupled VO_2-on-Si nano-oscillators and time domain encoded information.

- Implemented a three nano-oscillator network with tunable resistive coupling and experimentally showed the natural evolution of binarized phase patterns
- Applied Hebbian Learning rule to calculate resistive coupling weights for storage of 2 distinct phase patterns within the same network, accessed through time-delay encoding
- Simulated 9 oscillator network in SPICE and verified ideal network recognition performance for 6 stored patterns upto 25% grey-scale deviation
- Performed VO_2 film grain size engineering with flash-annealing to improve insulator-to-metal switching reliability and oscillatory behaviour

Masters Thesis

Advisor: Dr. Udayan Ganguly, IIT Bombay *Jul 2015 - Jul 2016*

Modelling the Transient Switching Characteristics of PCMO-based RRAM

Create a physics based model for the resistive switching process in $Pr_{0.7}Ca_{0.3}MnO_3$ (PCMO) as an oxide ion drift-diffusion phenomenon, with temperature and electric field dependence given by the Mott-Gurney equation

- Built a differential equation solver to implicitly solve coupled PDEs for heat flow and ionic motion, across time-scale of 10^{-9}s to 1s
- Simulated SET and RESET processes as positive and negative feedback respectively, showing excellent agreement with experimental curves for fast switching rates (sub-μs)
- Extracted the activation energy of diffusion by comparing experimental slow switching rates, having a nearly constant $t^{1/10}$ dependence, with interface ion reaction based model

Variation of Peak Device Temperature with Structure & Area Scaling

Create a thermal model of the PCMO RRAM device including substrate and electrode layers to show the increase in peak temperature as complexity of device structure increases from an experimental characterization setup to a CMOS compatible BEOL structure.

- Solved the 3D equivalent Fourier heat eqaution in MATLAB, derived equaivalent thermal resistance of the device structure
- Show reduction in device area causes a dip in peak temperature as nature of heat flow effectively changes from 1D to 3D.
- Model predicted a 20% increase in voltage required to commence switching in 25x smaller area device (compensating for increased heat loss), validated by experiment

Research Internship

Advisor: Prof. Vidya Madhavan, Department of Physics, Boston College *Summer 2014*

Identifying Topologically Crystalline Insulating states in Lead-Tin Tellerides

Conducting reverse Fourier transforms on the surface images of PbTn(Te) to analyse the effect of mechanical strain on the elctronic surface distribution.

- Explored the transition of state of the telleride from trivial to topological insulator with changes in the stoichometric ratio of Lead and Tin.
- Designed a cold-cleaver appendage on the STM for in-situ material sample preparation to obtain fresh surfaces for imaging without risk of contamination

Technical Skills

Electrical Characterization: DC/Pulsed I-V Electrical Measurements, C-V Measurement, RF Measurement, Transient Ferroelectric Polarization Switching

Fabrication and Material Characterization: Electron Beam Lithography, Projection Lithography, Reactive Ion Etching, DC/RF Sputtering, Electron Beam Evaporation, Raman Spectroscopy, Ellipsometry (VASE), Scanning Electron Microscopy

Programming, Analysis and CAD Tools: C/C++, Python, MATLAB, SPICE, Spectre, Sentaurus TCAD, AutoCAD, EAGLE