

Biswajit Ray

Assistant Professor, Department of Electrical and Computer Engineering,
University of Alabama in Huntsville, Huntsville, AL 35899, USA.

Phone: (01) 256.824.5679; Email: biswajit.ray@uah.edu

Webpage: <https://www.uah.edu/eng/departments/ece/people/faculty-staff/biswajit-ray>

Education

Ph.D. Aug. 2008 – Sept. 2013	Purdue University, West Lafayette, IN, USA School of Electrical and Computer Engineering (Adviser: Prof. M.A. Alam)
M.S. Aug. 2006 – July 2008	Indian Institute of Science, Bangalore, India Center for Electronic Design and Technology (Adviser: Prof. S. Mahapatra)
B.Tech. Aug. 2002 – May 2006	National Institute of Technology, Trichy, India Department of Electrical and Electronics Engineering

Professional Appointment

Jan. 2017 - Present	Assistant Professor, Department of Electrical and Computer Engineering, The University of Alabama in Huntsville (UAH), Huntsville, AL, USA
Oct. 2013 – Jan. 2017	Senior Device Engineer, SanDisk Corporation, Milpitas, CA, USA
Aug. 2008 – Sept. 2013	Graduate Research Assistant, School of Electrical and Computer Engineering, Purdue University, West Lafayette, IN, USA

Summary of Research, Teaching and Leadership

- Raised research funding over \$2 million with currently active more than \$1 million.
- Published 36 journals (18 in last 5 years), and 30 articles (17 in last 5 years) in conference proceedings.
- Granted 16 U.S. issued patents and 10 more pending on solid-state storage devices/systems.
- Delivered 24 invited talks in conferences, universities, industries and national laboratories.
- Graduated two PhD students, two MS thesis students and currently advising five PhD students.
- Mentored more than 25 undergraduate students through senior design projects.
- Developed two new courses (EE 622: Hardware Reliability and EE 417: Photovoltaic Fundamentals) and taught a core undergraduate course EE 310: Solid State Fundamentals for 5 consecutive years at UAH.
- Four years of industry experience on 3D NAND technology development and flash storage solution.
- Doctoral work on modeling and characterization of solar cell reliability.
- Received Outstanding Faculty Research Award (2020), College of Engineering, UAH and Joseph Dowdle Outstanding ECE teaching Award (2019), UAH.
- Served as NSF panelist, and external proposal reviewer for NSF, NASA.
- U.S. Permanent Resident since 2018.

Selected Honors and Awards

- (2022) NSF CAREER Award
- (2020) Outstanding Faculty Research Award, College of Engineering, UAH
- (2020) Outstanding Junior Faculty Award, College of Engineering, UAH
- (2019) Elevated to IEEE Senior Member
- (2019) NSF EPSCoR Research Fellow (RII Track-4).
- (2019) Joseph Dowdle Outstanding ECE Faculty Award, UAH
- (2017) New Faculty Award, UAH
- (2014) Innovation Award, SanDisk Corporation, USA.
- (2013) Best student paper award finalist, IEEE Photovoltaic Specialist Conference, Tampa, FL, USA.
- (2012) Best poster award, IEEE Photovoltaic Specialist Conference, Austin, TX, USA.
- (2012) Best poster award, Symposium on Nanomaterial for Energy, Indo-US workshop, IN, USA.
- (2011) Best student paper award finalist, IEEE Photovoltaic Specialist Conference, Seattle, WA, USA.
- (2011) Graduate Student Mentor Award, Purdue University, West Lafayette, IN, USA.
- (2009) Technoinventor Award for master's thesis, Indian Semiconductor Association, India.
- (2006) Ministry of Human Resource Development Scholarship, Government of India
- (2006) Academic Excellence Award for undergraduate study, NIT Trichy, India.
- (2002) North Eastern Council Scholarship for undergraduate study, Government of India.
- (2002) First rank from North Eastern India, Indian National Mathematical Olympiad

Sponsored Research (Total amount > \$2 Million; currently active > \$1 Million)

1. National Science Foundation (Award # 2145311)
Title: *"CAREER: Leveraging physical properties of modern flash memory chips for resilient, secure, and energy-efficient edge storage systems"*
Period: 10/01/2022 - 09/30/2027
Amount: \$650,000
Investigators: Biswajit Ray (PI)
2. Alabama Commission for Higher Education, Graduate Research Scholars Program
Title: *"Energy-efficient storage system for space applications"*
Period: 08/01/2021-07/30/2022
Amount: \$25,000 (Student Fellowship)
Investigators: Biswajit Ray (PI)
3. Defense Advanced Research Projects Agency (DARPA contract # W911NF2120047)
Title: *"Development of ultrafast cameras for quantum heat assisted detection and ranging (Q-HADAR)"*
Period: 01/01/2021-09/30/2025
Amount: \$1,356,087 (My portion: \$363,349)
Investigators: PI: Zubin Jacob (Purdue Univ.), Co-Is: Biswajit Ray (UAH), Vishnu Boddeti (MSU)
4. Department of Energy, Office of Nuclear Energy (Nuclear Science User Facilities (NSUF) Rapid Turnaround Experiment (RTE) Award # 247446)
Title: *"Investigation of Total Dose Effects on Data Corruption Rates in 3-D Non-volatile Memory"*
Period: 5/14/2020-5/13/2021
Amount: \$50,000

Investigators: Biswajit Ray (PI)

5. National Science Foundation (Award # 2007403)
Title: " *CNS Core: Small: Ensuring Privacy by Runtime Analog Sanitization of Solid-State Storage Devices* "
Period: 10/01/2020 - 09/30/2023
Amount: \$496,925
Investigators: Biswajit Ray (PI), Aleksandar Milenkovic (Co-I)
6. National Science Foundation (Award # 1929099)
Title: " *RII Track-4: Real-Time Radiation Dosimetry Using Flash Memory* "
Period: 12/15/2019-11/30/2022
Amount: \$233,345
Investigators: Biswajit Ray (Single – PI)
7. National Science Foundation (Award # 1935676)
Title: " *SitS NSF-UKRI: Real-time and Continuous Monitoring of Phosphates in the Soil with Graphene-Based Printed Sensor Arrays* "
Period: 01/01/2020-12/31/2022
Amount: \$799,950 (My portion of fund: \$120,000)
Investigators: PI: Suprem Das (KSU), Co-Is: Biswajit Ray (UAH), Saugata Datta (UTSA)
8. The University of Alabama in Huntsville (Charger Innovation Fund)
Title: *Ensuring Privacy by Instant Secure Data Deletion in Solid-State Storage Devices*
Period: 05/01/2020 – 12/31/2020
Amount: \$10,000
Investigators: Biswajit Ray (Single – PI)
9. Department of Energy, Office of Nuclear Energy (Nuclear Science User Facilities (NSUF) Rapid Turnaround Experiment (RTE) Award # 244738)
Title: " *In-situ investigation of irradiation damage on non-volatile memory* "
Period: 5/14/2019-5/13/2020
Amount: \$50,000
Investigators: Biswajit Ray (Single – PI)
10. The University of Alabama in Huntsville (Charger Innovation Fund)
Title: *True Random Number Generator for Internet of Things Applications*
Period: 6/26/2018 – 1/31/2019
Amount: \$15,000
Investigators: Biswajit Ray (Single – PI)
11. The University of Alabama in Huntsville (Charger Innovation Fund)
Title: *Smart Phone Based Application for Continuous Radiation Monitoring*
Period: 6/26/2017 – 2/26/2018
Amount: \$15,000
Investigators: Biswajit Ray (Single – PI)
12. The University of Alabama in Huntsville (#234384- New Faculty Research Award)
Title: *Security Primitives Using Flash Memory*
Period: 11/20/17– 11/19/18
Amount: \$10,000
Investigators: Biswajit Ray (Single – PI)

Journal Publication

From UAH:

1. M. Buddhanoy, P. Kumari, U. Surendranathan, M. Wasiolek, K. Hattar, and **B. Ray**, “Total-Ionizing-Dose Effects on Long-term Data Retention Characteristics of Commercial 3-D NAND Memories,” IEEE Transactions on Nuclear Science (accepted).
2. P. Kumari, U. Surendranathan, M. Wasiolek, K. Hattar, N.P. Bhat and **B. Ray**, “Analytical Bit-Error Model of NAND Flash Memories for Dosimetry Application,” IEEE Transactions on Nuclear Science (accepted).
3. U. Surendranathan, M. Wasiolek, K. Hattar, D.M. Fleetwood, and **B. Ray**, “Total-Ionizing-Dose Effects on Read Noise of MLC 3-D NAND Memories,” IEEE Transactions on Nuclear Science (accepted).
4. M. Buddhanoy, S. Sakib, U. Surendranathan, M. Wasiolek, K. Hattar, A. Milenkovic, and **B. Ray**, “Total-Ionizing-Dose Resistant Novel Data Encoding Technique for NAND Flash Memory,” IEEE Transactions on Nuclear Science (under review).
5. Md Raquibuzzaman, A. Milenkovic, and **B. Ray**, “EXPRESS: Exploiting energy-accuracy trade-offs in 3D NAND flash memory for energy-efficient storage,” MDPI Electronics (accepted).
6. S. Sakib, A. Milenkovic, and **B. Ray**, “Flash-DNA: Identifying NAND Flash Memory Origins Using Intrinsic Array Properties,” IEEE Transactions on Electron Devices, vol. 68, no. 8, pp. 3794-3800, 2021.
7. S. Sakib, Md Raquibuzzaman, M. Wasiolek, K. Hattar, and **B. Ray**, “Total Ionizing Dose Effects on Physical Unclonable Function from NAND Flash Memory,” IEEE Transactions on Nuclear Science, 2021, vol. 68, no. 7, pp. 1445-1453, 2021.
8. U. Surendranathan, P. Kumari, M. Wasiolek, K. Hattar, T. Boykin and **B. Ray**, “Gamma Ray Induced Error Pattern Analysis for MLC 3-D NAND Flash Memories,” IEEE Transactions on Nuclear Science, vol. 68, no. 5, pp. 733-739, 2021.
9. P. Kumari, U. Surendranathan, M. Wasiolek, K. Hattar, N.P. Bhat and **B. Ray**, “Radiation Induced Error Mitigation by Read-Retry Technique for MLC 3-D NAND Flash Memory,” IEEE Transactions on Nuclear Science, vol. 68, no. 5, pp. 1032-1039, 2021.
10. P. Poudel, **B. Ray**, and A. Milinkovic, “Microcontroller Fingerprinting Using Partially Erased NOR Flash Memory Cells,” ACM Transactions on Embedded Computing Systems, vol. 20, no. 3, article no. 26, 2021.
11. P. Kumari, S. Huang, M. Wasiolek, K. Hattar, and **B. Ray**, “Layer Dependent Bit Error Variation in 3-D NAND Flash Under Ionizing Radiation,” IEEE Transactions on Nuclear Science, vol. 67, no. 9, pp. 2021-2027, 2020.
12. M. Hasan and **B. Ray**, “Reliability of NAND Flash Memory as a Weight Storage Device of Artificial Neural Network,” IEEE Transactions on Device and Materials Reliability, vol. 20, no. 3, pp. 596-603, 2020.
13. S. Sakib, A. Milenkovic, and **B. Ray**, “Flash Watermark: An Anti-Counterfeiting Technique for NAND Flash Memories,” IEEE Transaction on Electron Devices, vol. 67, no. 10, pp. 4172–4177, 2020.
14. S. Sakib, A. Milenkovic, M. T. Rahman, and **B. Ray**, “An Aging-Resistant NAND Flash Memory Physical Unclonable Function,” IEEE Transaction on Electron Devices, vol. 27, no. 3, pp. 937–943, Mar. 2020.
15. S. Huang, T. B. Boykin, R. S. Gorur and **B. Ray**, “Electrical Tree Formation in Polymer-Filler Composites,” IEEE Transactions on Dielectrics and Electrical Insulation, vol. 26, no. 6, pp. 1853-1858, Dec. 2019.
16. B. Talukder, **B. Ray**, D. Forte, and M. T. Rahman “PreLatPUF: Exploiting DRAM Latency Variations for Generating Robust Device Signatures,” IEEE Access, vol. 7, no. 1, pp. 81106-81120, 2019.
17. P. Poudel, **B. Ray**, and A. Milinkovic, “Microcontroller TRNGs Using Perturbed States of NOR Flash Memory Cells,” IEEE Transaction on Computer, vol. 68, no. 2, pp. 307–313, 2019.
18. S. Sakib, P. Kumari, B.M.S.B. Talukder, M.T. Rahman, **B. Ray**, “Non-Invasive Detection Method for Recycled Flash Memory Using Timing Characteristics,” MDPI Cryptography, vol. 2, no. 3, pp. 17, Aug. 2018.

(This work was highlighted in IEEE Spectrum, phys.org, The Resister, etc.)

19. M. Raquibuzzaman, **B. Ray**, T. B. Boykin, and R. S. Gorur, "Polymer-Metal Layered Structures for Improved Energy Storage Density," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 15, no. 6, pp. 2375-2379, 2018.
20. **B. Ray**, and A. Milenkovic, "True Random Number Generation Using Read Noise of Flash Memory Cells," IEEE Transaction on Electron Devices, vol. 65, no. 2, pp. 963-969, 2018.

Prior to UAH:

21. **B. Ray**, A.G. Baradwaj, M.R. Khan, B.W. Boudouris, and M.A. Alam, "Collection-limited theory interprets the extraordinary response of single semiconductor organic solar cells," Proceedings of the National Academy of Sciences, 112 (36), 11193-11198, 2015.
22. **B. Ray**, A.G. Baradwaj, B.W. Boudouris, and M.A. Alam, "Defect Characterization in Organic Semiconductors by Forward Bias Capacitance Analysis," The Journal of Physical Chemistry C 118 (31), 17461-17466, 2014.
23. J.H. Beck, **B. Ray**, R.R. Grote, R.M. Osgood, C.T. Black, M.A. Alam, I. Kymissis, "Nanostructured Electrodes Improve the Fill Factor of Organic Photovoltaics," IEEE Journal of Photovoltaics, 4(4), 1100 - 1106, 2014.
24. R.K. Chavali, J.R. Wilcox, **B. Ray**, J.L. Gray, and M. A. Alam, "Correlated Non-Ideal Effects of Dark and Light I-V Characteristics in a-Si/c-Si Heterojunction Solar Cells," IEEE Journal of Photovoltaics, 4(3), 763 - 771, 2014.
25. M.R. Khan, **B. Ray**, M.A. Alam, "Prospects of layer-split tandem cells for high-efficiency OPV," Solar Energy Materials and Solar Cells, vol. 120, 716-723, 2014.
26. M.A. Alam, **B. Ray**, M.R. Khan, and S. Dongaonkar, "The Essence and Efficiency Limits of Bulk-Heterostructure Organic Solar Cells: A Polymer-to-Panel Perspective," Journal of Materials Research, 28 (4), 2013. (*Invited Feature Article*)
27. **B. Ray**, M.R. Khan, C.T. Black, and M.A. Alam, "Nano-structured Electrode for Organic Solar Cells: Analysis and Design Fundamentals," IEEE Journal of Photovoltaics, 3(1), 318-329, 2013.
28. **B. Ray**, and M.A. Alam, "Achieving Fill Factor Above 80% in Organic Solar Cells by Charged Interface," IEEE Journal of Photovoltaics, 3(1), 310-317, 2013.
29. J.E. Allen, **B. Ray**, M.R. Khan, K.G. Yager, M.A. Alam, C.T. Black, "Self-assembly of single dielectric nanoparticle layers and integration in polymer-based solar cells," Applied Physics Letters, 101(6), 063105, 2012.
30. J. Li, **B. Ray**, M. Alam, and M. Ostling, "On the Threshold of Hierarchical Percolating Systems," Physical Review E, vol. 85, p. 021109, 2012.
31. **B. Ray**, M.S. Lundstrom, and M.A. Alam, "Can morphology tailoring improve the open circuit voltage of organic solar cells?" Applied Physics Letters, vol. 100, pp. 013307-3, 2012.
(*Recognized as one of the most notable APL articles published in 2012*)
32. **B. Ray**, and M.A. Alam, "Random vs regularized OPV: Limits of performance gain of organic bulk heterojunction solar cells by morphology engineering," Solar Energy Materials and Solar Cells, vol. 99, pp. 204-212, 2012.
33. **B. Ray**, P.R. Nair, and M.A. Alam, "Annealing Dependent Performance of Organic Bulk-Heterojunction Solar Cells: A Theoretical Perspective," Solar Energy Materials and Solar Cells, vol.95, pp. 3287-3294, 2011.
34. **B. Ray**, and M.A. Alam, "A compact physical model for morphology induced intrinsic degradation of organic bulk heterojunction solar cell," Applied Physics Letters, vol. 99, pp. 033303-3, 2011.
35. **B. Ray**, and S. Mahapatra, "Modeling of Channel Potential and Subthreshold Slope of Symmetric Double Gate Transistor," IEEE Transactions on Electron Devices, Vol. 56, No. 2, pp. 260-266, 2009.
36. **B. Ray**, and S. Mahapatra, "Modeling and analysis of body potential of cylindrical Gate-All-Around nanowire transistor," IEEE Transactions on Electron Devices, Vol. 55, No. 9, pp. 2409-2416, 2008.

Peer-Reviewed Conference Proceedings

From UAH:

1. Md Raquibuzzaman, A. Milenkovic, and **B. Ray**, “Instant Data Sanitization on Multi-Level-Cell NAND Flash Memory,” IEEE Design and Automation Conference 2021. (under review).
2. Md Raquibuzzaman, A. Milenkovic, and **B. Ray**, “Layer-to-Layer Endurance Variation of 3D NAND”, in Proc. of the 2021 IEEE International Reliability Physics Symposium, 2021 (accepted).
3. M. Buddhanoy, S. Sakib, and **B. Ray**, “Runtime Variability Monitor for Data Retention Characteristics of Commercial NAND Flash Memory,” in Proc. of the 2021 IEEE International Reliability Physics Symposium, 2021.
4. P. Poudel, **B. Ray**, and A. Milenkovic, “Flashmark: Watermarking of NOR Flash Memories for Counterfeit Detection,” in Proc. of the 57th IEEE Design and Automation Conference, San Francisco, CA, USA, 2020. (Acceptance rate 23%).
5. M. Hasan and **B. Ray**, “Data Recovery from “Scrubbed” NAND Flash Storage: Need for Analog Sanitization,” in Proc. of the 29th USENIX Security Symposium, Boston, MA, Aug. 2020. (Acceptance rate 16%)
6. S. Sakib, and **B. Ray**, “Temperature Compensation Technique for NAND Flash Memory Based Physical Unclonable Function,” 2020 Government Microcircuit Applications & Critical Technology Conference (Gomactech), San Diego, CA, Mar. 2020.
7. M. Hasan, M. Raquibuzzaman, I. Chatterjee and **B. Ray**, “Radiation Tolerance of 3-D NAND Flash Based Neuromorphic Computing System,” in Proc. of the 2020 IEEE International Reliability Physics Symposium, Dallas, TX, Mar 2020.
8. B. Bahar Talukder, V. Menon, **B. Ray**, T. Neal, M. Rahman “Towards the Avoidance of Counterfeit Memory: Identifying the DRAM Origin,” in Proc. of the IEEE International Symposium on Hardware Oriented Security and Trust, 2020, pp. 111-121. (Acceptance rate 20%)
9. S. Chattopadhyay, P. Kumari, **B. Ray**, R. S. Chakraborty, “Machine Learning Assisted Accurate Estimation of Usage Duration and Manufacturer for Recycled and Counterfeit Flash Memory Detection,” in Proc. of the 2019 IEEE 28th Asian Test Symposium, Kolkata, India, pp. 49-54.
10. M. Raquibuzzaman, S. Dongaonkar, and **B. Ray**, “Can Bad Solar Cells Make a PV Module More Efficient?” in Proc. of the 46th IEEE Photovoltaic Specialists Conference, Chicago, IL, 2019.
11. M. Hasan and **B. Ray**, “Tolerance of Deep Neural Network Against the Bit Error Rate of NAND Flash Memory,” in Proc. of the 2019 IEEE International Reliability Physics Symposium, Monterey, CA, 2019.
12. B. Talukder, **B. Ray**, T. Morris, and M. T. Rahman, “Exploiting DRAM Latency Variations for Generating True Random Numbers,” in Proc. of the 2019 IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, NV, Jan. 2019.
13. S. Sakib, M.T. Rahman, A. Milenković, **B. Ray**, “Flash Memory Based Physical Unclonable Function,” in Proc. of the 2019 IEEE SoutheastCon, Huntsville, AL, USA, 2019.
14. P. Kumari, and **B. Ray**, “Prospect of Flash Memory Chip for Dosimetry Application in Low Dose Environment,” in Proc. of the 2019 IEEE SoutheastCon, Huntsville, AL, USA, 2019.
15. P. Kumari and **B. Ray**, “Wireless Passive Radiation Dosimeter Using Flash Memory,” in Proc. of the 6th IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE), Huntsville, AL, USA, 2018, pp. 239–245.
16. S. Ritter, T. Pigg, C. Brown, **B. Ray**, “True Random Number Generator using Solar Output Characteristics,” in Proc. of the IEEE International Conference on Wireless for Space and Extreme Environments, Huntsville, AL, USA, Dec. 2018, pp. 224-226. (**All the student authors are from undergraduate senior design project**)
17. P. Kumari, L. Davies, N. P. Bhat, E. X. Zhang, M. W. McCurdy, D. M. Fleetwood and **B. Ray**, “State-of-the-Art Flash Chips for Dosimetry Application,” in Proc. of the IEEE Radiation Effects Data Workshop, Kona, HI, USA, 2018.
18. L. Davies, R. Thornton, P. Hudson, and **B. Ray**, “Automatic Detection and Characterization of Partial Shading in PV System,” in Proc. of 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC)

(A Joint Conference of 45th IEEE PVSC, 28th PVSEC, 34th EU PVSEC), Kona, HI, USA, 2018, pp. 1185–1187. (All the student authors are from undergraduate senior design project)

19. P. Kumari, B. S. Talukder, S. Sakib, **B. Ray**, and M. T. Rahman, “Independent Detection of Recycled Flash Memory: Challenges and Solutions,” in Proc. of the IEEE International Symposium on Hardware Oriented Security and Trust, Washington, DC, USA, 2018, pp. 89-95. (Acceptance rate 20.2%)

Prior to UAH:

20. **B. Ray**, and M.A. Alam, “Role of Charged Defects on Organic Solar Cell Performance: Prospect of Heterojunction-Free Device Design,” Proc. of the 39th IEEE Photovoltaic Specialists Conference (PVSC), Tampa, Florida, USA, 2013.

(Nominated for best student paper award in Area 6: Organic Photovoltaic)

21. R.K. Chavali, J.R. Wilcox, **B. Ray**, J.L. Gray, and M. A. Alam, “A Diagnostic Tool for Analyzing the Current-Voltage Characteristics in a-Si/c-Si Heterojunction Solar Cells,” Proc. of the 39th IEEE Photovoltaic Specialists Conference (PVSC), Tampa, Florida, USA, 2013.

22. **B. Ray**, and M.A. Alam, “Is A Heterojunction Essential for High-Efficiency Organic Solar Cells?” Device Research Conference, Norte Dame, IN, USA, 2013.

23. **B. Ray**, M.A. Alam, “Achieving Fill Factor Above 80% in Organic Solar Cells by Interface Engineering,” Proc. of the 38th IEEE Photovoltaic Specialists Conference (PVSC), Austin, TX, USA, 2012.

(Best poster award in Area 6: Organic Photovoltaic)

24. **B. Ray**, M.A. Alam, “Optimum Morphology and Performance Gains of Organic Solar Cells,” Proc. of the 37th IEEE Photovoltaic Specialists Conference (PVSC), Seattle, WA, USA, 2011.

(Nominated for best student paper award in Area 6: Organic Photovoltaic)

25. M.A. Alam, **B. Ray**, M.R. Khan, and S. Dongaonkar, “The Essence and Efficiency Limits of Bulk-Heterostructure Organic Solar Cells,” Proc. of MRS Fall Meeting, Boston, MA, USA, 2011.

26. M.A. Alam, **B. Ray**, M.R. Khan, “Untangling the Essence of Bulk Heterostructure Organic Solar Cells: Why Complex Need Not be Complicated,” IEEE Semiconductor Device Research Symposium, College Park, MD, USA, 2011.

27. **B. Ray**, P.R. Nair, And M.A. Alam, “Morphology Dependent Short Circuit Current in Bulk Heterojunction Solar Cell,” Proc. of the IEEE Photovoltaic Specialists Conference (PVSC), Honolulu, HI, USA, 2010.

28. **B. Ray**, M.R. Khan, and M.A. Alam, “Performance Improvement of Polymer Based Solar Cell by Ordered Nano-morphology,” Proc. of the University Government Industry Micro/nano Symposium (UGIM), IEEE, West Lafayette, IN, USA, 2010.

29. **B. Ray**, P.R. Nair, R.E. García and M.A. Alam, “Modeling and Optimization of Polymer based Bulk Heterojunction (BH) Solar cell,” Proc. of the IEEE International Electron Devices Meeting (IEDM), Baltimore, MD, USA, 2009.

30. **B. Ray** and S. Mahapatra, “A New Threshold Voltage Model for Omega Gate Cylindrical Nanowire Transistor,” Proc. of the IEEE International Conference on VLSI Design, Hyderabad, India, 2008.

31. **B. Ray**, K. Shubhakar, and S. Mahapatra, “Necessity for Quantum Mechanical Simulation for the Future Technology Nodes,” Proc. of the IEEE International Workshop on Physics of Semiconductor Devices (IWPSD), Mumbai, India, pp. 880 - 883, 2007.

32. A. Agarwal, **B. Ray**, M. Choudhury, A. Basu and S. Sarkar, “Automatic Extraction of Multiword Expressions in Bengali: An Approach for Miserly Resources Scenario,” Proc. of the International Conference on Natural Language Processing (ICON), Hyderabad, India, pp. 165 - 172, Dec. 2004

Patents

From UAH:

1. **B. Ray**, "Systems and methods for runtime analog sanitation of memory," US patent # 11177003 (2021).
2. **B. Ray**, "Systems and methods to convert memory to one-time programmable memory," U.S. Patent # 11101009 (2021)
3. **B. Ray** and Preeti Kumari, "Systems and methods for hardening flash memory to radiation," US patent # 11164642 (2021).
4. **B. Ray** and M. T. Rahman, "Systems and methods for detecting counterfeit memory," U.S. Patent # 11114179 (2021).
5. **B. Ray**, "Systems and methods for sensing radiation using flash memory," U.S. Patent # 10878922 (2020)
6. **B. Ray**, Levi Davies, "Flash memory based radiation sensing," U.S. Patent # 10509132 (2019)
7. **B. Ray**, A. Milenkovic, Md. Raquibuzzaman, "Methods for energy-efficient storage in NAND flash memory," UAH Docket No. UAH-P-21007.
8. **B. Ray**, "Methods to Counter the Layer-Dependent Radiation Response of 3D NAND Flash Memory," UAH Docket No. UAH-P-21004.
9. **B. Ray**, A. Milenkovic, P. Kumari, "Methods to Enhance Radiation Tolerance of NAND Flash Memory," UAH Docket No.: *UAH-P-21005*.
10. **B. Ray**, "Methods for Detection of Defects in Flash Memory," UAH Docket No. *UAH-P-20028*.
11. **B. Ray**, Dylan Wallace, Andrew Lopes, Teven Buchanon, "Methods and design for partial shading tolerant car-roof PV," UAH Docket No. UAH-P-19026.
12. **B. Ray**, "True Random Number Generator using Solar Cell," UAH Docket No. UAH-P-18019.
13. **B. Ray**, "Long distance Traffic Monitoring using Solar-Powered Road Marker," UAH Docket No. UAH-P-18018.
14. **B. Ray**, and A. Milenkovic, "A method for true random number generation using read noise of flash memory," UAH Docket No. UAH-P-17022.

Prior to UAH:

15. B. Ray, P. Rabkin, M. V. Dunga, G. J. Hemink, C. Chen, "Programming to minimize cross-temperature threshold voltage widening" U.S. Patent # 10978145 (2021)
16. M. V. Dunga, A. Khandelwal, C. Chen, and B. Ray, "System and method for string-based erase verify to create partial good blocks," U.S. Patent # 10535411 (2020).
17. M. V. Dunga, C. Chen, B. Ray, "Post write erase conditioning," U.S. Patent # 10269439 (2020)
18. H. Naik, B. Ray, M. V. Dunga, C. Chen, "Memory write verification using temperature compensation," U.S. Patent # 10304559 (2019).
19. B. Ray, M. V. Dunga, G. J. Hemink, and C. Chen, "Erase speed based wordline control," U.S. Patent # 10304551 (2019).
20. H. Naik, M. V. Dunga, C. Chen, B. Ray, "System and method for programming a memory device with multiple writes without an intervening erase," U.S. Patent # 9972396 (2018).
21. B. Ray, M. V. Dunga, and C. Chen, "Erase for partially programmed blocks in non-volatile memory," U.S. Patent # 10074440 (2018).
22. B. Ray, G. J. Hemink, M. V. Dunga, B. Rajamohanam, C. Chen, "Cell current based bit line voltage for Flash memory," U.S. Patent # 10008273 (2018).
23. Chris Yip, Philip Reusswig, Nian Niles Yang, Grishma Shah, Abuzer Azo Dogan, Biswajit Ray, Mohan Dunga, Joanna Lai, Changyuan Chen, "System solution for first read issue using time dependent read voltages," U.S. Patent # 9711231 (2017).
24. B. Ray, M. V. Dunga, C. Chen, "Apparatus and method for preconditioning currents to reduce errors in sensing for non-volatile memory," U.S. Patent # 9704588 (2017).

25. B. Ray, M.V. Dunga, C. Chen, “Word line dependent temperature compensation scheme during sensing to counteract cross-temperature effect,” U.S. Patent # 9543028 (2017).
26. B. Ray, A. Dogan, C. Chen, “Temperature dependent sensing scheme to counteract cross-temperature threshold voltage distribution widening,” U.S. Patent # 9530512 (2016).

Book Chapter

1. Alam, M. A., Pimparkar, N. and **Ray, B.** (2010) The Future of Microelectronics is ... Macroelectronics, in Future Trends in Microelectronics: From Nanophotonics to Sensors and Energy (eds S. Luryi, J. Xu and A. Zaslavsky), John Wiley & Sons, Inc., Hoboken, NJ, USA. doi: 10.1002/9780470649343.ch30.

Oral/poster Presentations

Invited talk:

1. “3D NAND Storage for Extreme Environments,” Sandia National Laboratory, Albuquerque, NM, August, 2021 (Host: Dr. Matthew Marinella)
2. “Application of 3D NAND Storage for Hardware-security, Extreme Environment and Edge-computing,” Micron Technology, July, 2021, (Host: Mr. Himanshu Naik).
3. “3D NAND based Storage Systems for Hardware-security, Reliability and Edge-computing,” Purdue University, West Lafayette, IN, June, 2021 (Host: Prof. Sumeet Gupta).
4. “NAND Flash Storage for Extreme Environments,” Sandia National Laboratory, Albuquerque, NM, April, 2021 (Host: Dr. Khalid Hattar).
5. “Non-volatile Memories for Extreme Environments,” NASA Goddard Space Flight Center, Jan. 2021 (Host: Dr. Jonathan Pellish)
6. “Application of Non-volatile Memories for Security and Sensing,” Annual Technology Showcase Event at the University of Alabama in Huntsville, Feb. 2020 (Host: Mr. Kannan Grant).
7. “Wireless, Passive and Real-time Radiation Dosimeter for Enhanced Situational Awareness,” Kansas State University, Manhattan KS, Oct. 2019 (Host: Prof. Suprem Das).
8. “Hack-proof Non-volatile Memory Systems,” Air Force Research Laboratory, Albuquerque, NM, 2019 (Host: Dr. Jesse Mee).
9. “Low cost radiation dosimeter using flash memory chip,” NASA Marshall Space Flight Center, Huntsville, AL, 2019 (Host: Dr. Mark King).
10. “Hack-proof Non-volatile Memory System,” IEEE EDS Student Chapter, Indian Institute of Technology, Roorkee, India, May 2019 (Host: Prof. Bishnu Das).
11. “Secure Non-volatile Memory System,” Indian Institute of Technology, Dhanbad, India, May 2019 (Host: Prof. Manodipon Sahoo)
12. “Hack-proof Non-volatile Memory System,” IEEE Student Chapter, Indian Institute of Technology, Kharagpur, India, May 2019 (Host: Prof. Rajat Subhra Chakraborty)
13. “Hack-proof Non-volatile Memory System,” Cypress Semiconductor, San Jose, CA, April 2019 (Host: Mr. Sandeep Krishnegowda).
14. “Hack-proof Non-volatile Memory System,” Western Digital Corporation, Milpitas, CA, April 2019 (Host: Dr. Gertjan Hemink).
15. “Detection of Recycled Flash Memory,” 2018 Southeast Symposium on Contemporary Engineering Topics (SSCET), Aug. 2018 (Host: Dr. Thomas Field).
16. “Perspective on Solar Energy Harvesting: What are the present Challenges?” National Institute of Technology, Agartala, India, October 2014 (Host: Prof. Swapan Bhaumik).
17. “Operation and Design of Organic Solar Cells,” Bhabha Atomic Research Centre (BARC), India, January 2013 (Host: Dr. Dipak Palit).

18. "Defect Characterization in Organic Semiconductors by Forward Bias Capacitance," Network for Photovoltaic Technology (NPT) Center, Purdue University, November 2012 (Host: Prof. Mark Lundstrom).
19. "Performance Limits of Nano-Structured Organic Solar Cells," Tata Institute of Fundamental Research (TIFR), Mumbai, India, January 2012 (Host: Prof. K. L. Narasimhan).
20. "Morphology-Aware Design of High Performance Nano-Structured Organic Solar Cells," Indian Institute of Science, Bangalore, India, December 2011 (Host: Prof. Santanu Mahapatra).
21. "Design and Performance Limits of Organic Solar Cells," e-Workshop in Network for Photovoltaic Technology (NPT) Center, Purdue University, November 2011 (Host: Prof. Mark Lundstrom).
22. "OPV Operation: Insight from Numerical Simulation," Energy Frontier Research Center, Columbia University, April 2011 (Host: Prof. James Yardley).
23. "Organic Solar Cell: Modeling Optimization and Reliability," Indian Institute of Technology, Guwahati, India, January 2011 (Host: Prof. Amaresh Dalal).
24. "Modeling and Optimization of Polymer based Bulk Heterojunction (BH) Solar cell," Network for Computational Nanotechnology (NCN), Purdue University, 2010 (Host: Dr. Xufeng Wang).

Contributed Oral Presentation (Presenter's name in bold) from UAH:

1. **P. Kumari**, M. Wasiolek, K. Hattar, N.P. Bhat and B. Ray, "Design considerations for flash memory based dosimeter," 2021 IEEE Nuclear and Space Radiation Effects Conference, July 2021.
2. M. Hasan, and **B. Ray**, "Data Recovery from "Scrubbed" NAND Flash Storage: Need for Analog Sanitization," 29th USENIX Security Symposium, Aug. 2020.
3. **P. Poudel**, B. Ray, and A. Milinkovic, "Flashmark: Watermarking of NOR Flash Memories for Counterfeit Detection," the 57th IEEE Design and Automation Conference, San Francisco, CA, USA, 2020.
4. **P. Kumari** and B. Ray, "Radiation Induced Error Mitigation by Read-Retry Technique for MLC 3-D NAND Flash Memory," 2020 IEEE Nuclear and Space Radiation Effects Conference, Nov 2020.
5. **S. Sakib**, A. Milinkovic and B. Ray, "Hardware Demonstration of Watermarking of NAND Flash Memory Chips," the IEEE International Symposium on Hardware Oriented Security and Trust, Dec. 2020.
6. **B. Bahar Talukder**, V. Menon, B. Ray, T. Neal, M. Rahman "Towards the Avoidance of Counterfeit Memory: Identifying the DRAM Origin," the IEEE International Symposium on Hardware Oriented Security and Trust, Dec. 2020.
7. S. Chattopadhyay, P. Kumari, B. Ray, **R. S. Chakraborty**, "Machine Learning Assisted Accurate Estimation of Usage Duration and Manufacturer for Recycled and Counterfeit Flash Memory Detection," in Proc. of the 2019 IEEE 28th Asian Test Symposium, Kolkata, India, Dec. 2019.
8. **S. Sakib**, M.T. Rahman, A. Milenković, B. Ray, "Flash Memory Based Physical Unclonable Function," the 2019 IEEE SoutheastCon, Huntsville, AL, USA, 2019.
9. **P. Kumari**, and B. Ray, "Prospect of Flash Memory Chip for Dosimetry Application in Low Dose Environment," the 2019 IEEE SoutheastCon, Huntsville, AL, USA, 2019.
10. **B. Talukder**, B. Ray, T. Morris, and M. T. Rahman, "Exploiting DRAM Latency Variations for Generating True Random Numbers," 2019 IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, NV, Jan. 2019.
11. P. Kumari, F. Irom, and **B. Ray**, "Word Line Dependent Bit Error in 3-D NAND Flash Under Ionizing Radiation," 2019 IEEE Nuclear and Space Radiation Effects Conference, San Antonio, Texas, July 2019.
12. **P. Kumari** and B. Ray, "Wireless Passive Radiation Dosimeter Using Flash Memory," the 6th IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE), Huntsville, AL, USA, 2018.
13. S. Ritter, T. Pigg, C. Brown, **B. Ray**, "True Random Number Generator using Solar Output Characteristics," in Proc. of the IEEE International Conference on Wireless for Space and Extreme Environments, Huntsville, AL, USA, Dec. 2018.

14. P. Kumari, B. S. Talukder, S. Sakib, **B. Ray**, and M. T. Rahman, “Independent Detection of Recycled Flash Memory: Challenges and Solutions,” the IEEE International Symposium on Hardware Oriented Security and Trust, Washington, DC, 2018.

Contributed Poster Presentation (Presenter’s name in bold) from UAH:

1. S. Sakib, **M. Buddhano**y, U. Surendranathan, M. Wasiolek, K. Hattar and B. Ray, “Total-Ionizing-Dose Resistant Novel Data Encoding Technique for NAND Memory,” 2021 IEEE Nuclear and Space Radiation Effects Conference, July 2021.
2. **U. Surendranathan**, M. Wasiolek, K. Hattar, D.M. Fleetwood and B. Ray, “Total-Ionizing-Dose Effects on Read Noise of MLC 3D NAND Memories,” 2021 IEEE Nuclear and Space Radiation Effects Conference, July 2021.
3. **M. Buddhano**y, U. Surendranathan, P. Kumari, M. Wasiolek, K. Hattar and B. Ray, “Total-Ionizing-Dose Effects on Long-term Data Retention Characteristics of Commercial 3D NAND Memories,” 2021 IEEE Nuclear and Space Radiation Effects Conference, July 2021.
4. **M. Buddhano**y, S. Sakib, and B. Ray, “Runtime Variability Monitor for Data Retention Characteristics of Commercial NAND Flash Memory,” the 2021 IEEE International Reliability Physics Symposium, 2021.
5. S. Sakib, and **B. Ray**, “Temperature Compensation Technique for NAND Flash Memory Based Physical Unclonable Function,” 2021 Government Microcircuit Applications & Critical Technology Conference (Gomactech).
6. **S. Sakib**, and B. Ray, “Total Ionization Dose Effects on NAND Flash Memory Based Physical Unclonable Function,” 2020 IEEE Nuclear and Space Radiation Effects Conference, Dec 2020.
7. **U. Surendranathan** and B. Ray, “Gamma Ray Induced Error Pattern Analysis for MLC 3-D NAND,” 2020 IEEE Nuclear and Space Radiation Effects Conference, Dec 2020.
8. M. Hasan, M. Raquibuzzaman, I. Chatterjee and **B. Ray**, “Radiation Tolerance of 3-D NAND Flash Based Neuromorphic Computing System” 2020 IEEE International Reliability Physics Symposium, Dallas, TX, Mar 2020.
9. M. Hasan and **B. Ray**, “Tolerance of Deep Neural Network Against the Bit Error Rate of NAND Flash Memory,” in Proc. of the 2019 IEEE International Reliability Physics Symposium, Monterey, CA, 2019.
10. M. Raquibuzzaman, S. Dongaonkar, and **B. Ray**, “Can Bad Solar Cells Make a PV Module More Efficient?” the 46th IEEE Photovoltaic Specialists Conference, Chicago, IL, 2019.
11. **P. Kumari**, S. Sakib, B. M. S. Talukder, Md T. Rahman, B. Ray “Detection of Recycled Flash Memory using Timing Characteristics,” Workshop for Women in Hardware and Systems Security (WISE), Washington, DC, 2018.
12. M. Raquibuzzaman, S. Huang, **B. Ray**, and R. S. Gorur, “Polymer-Metal Layered Structures for Improved Energy Storage,” NASA Printed Electronics Workshop, Huntsville, AL 2018.
13. L. Davies, R. Thornton, P. Hudson, and **B. Ray**, “Automatic Detection and Characterization of Partial Shading in PV System,” 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC) (A Joint Conference of 45th IEEE PVSC, 28th PVSEC, 34th EU PVSEC), Kona, HI, USA, 2018.
14. P. Kumari, L. Davies, N. P. Bhat, E. X. Zhang, M. W. McCurdy, D. M. Fleetwood and **B. Ray**, “State-of-the-Art Flash Chips for Dosimetry Application,” the IEEE Radiation Effects Data Workshop, Kona, HI, USA, 2018.

Teaching and Curriculum Development

Summary of courses taught:

- EE 310: Solid State Fundamentals (Undergraduate course)
 - Enrollment: 42 (F' 17), 52(F'18), 57 (F'19), 62 (F'20)
 - SIE Score (out of 5): 4.1 (F'17), 4.5 (F'18), 4.7 (F'19), 4.4 (F'20)
- EE 417/510: Photovoltaic Fundamentals (**New Undergraduate/ Graduate Course**)
 - Enrollment: 14(S'17), 28(S'18), 21(S'19), 12(S'20), 12 (S'21)
 - SIE Score (out of 5): 4.8 (S'17), 4.9 (S'18), 4.9 (S'19), 4.6 (S'20), 4.9 (S'21)
- EE 622: Hardware Reliability (**New Graduate Course**)
 - Enrollment: 12 (F'17), 4(F'18), 7 (F'19), 4 (F'20)
 - SIE Score (out of 5): 4.7 (F'17), 4.9 (F'18); 4.8 (F'19)

New curriculum development:

- **New undergraduate course development: EE 417/510: Photovoltaic Fundamentals**
Description: The course covers fundamental device physics for solar cell operation, reliability issues in panel and module design, partial shading problems on PV module, cost and efficiency analysis.
- **New graduate course development: EE 622: Hardware Reliability**
Description: The objective for this course is to provide students with an understanding of the essential physics of reliability of electronic devices as well as some of the practical technological considerations. The course will provide a fundamental framework for the students to explore how and when things fail as devices are turned on and off trillions of times during the years of operation. In addition, the course will introduce the students with the industry standards for the reliability qualification of electronic products as well as few system level countermeasures.

Senior design project offerings:

- Spring 2021: “Alabama Smart Farm,” Evan Coy, Austin Fox, Orif Negmatov, Joshua Rencher, Christina Stovall
- Fall 2020: “Wireless Impedance Analyzer for Remote Sensing,” Joshua Pinkard, Michael Reyes-Brunick, Andrew Finocchio, Douglas Marr
- Fall 2019: “Car Roof PV Design,” Dylan Wallace, Andrew Lopez, Teven Buchanon (**Contributed to a patent application, UAH patent disclosure # UAH-P-19026.**)
- Spring 2019: “PV Power Meter,” Juan Gonzalez, Sajjwal Chaulagain
- Spring 2019: “Arduino based PV I-V tracker” John Bearden, Elizabeth Bekken, Dana Overton
- Spring 2018: “Automatic Shade detection on PV module” Levi Davies, Ryan Thornton, Paul Hudson (**Contributed to a publication in Proc. of 2018 IEEE PVSC, Kona, HI, USA, 2018**)
- Spring 2018: “Solar Power Monitor,” Stephen Ritter, Connor Brown, Tyler Pigg (**Contributed to a publication in IEEE WiSEE 2018**)
- Fall 2017: “Radiation Hardening Through Error Analysis in Flash Memory,” Aaron Mashburn, Bryan Fernandez, and Minh Nguyen

Mentoring and Advising

Current Ph.D. Students:

1. Mr. Sijay Huang (Fall 2017-present)
Thesis Topic: Numerical simulation of 3D NAND cells
2. Mr. Md Raquibuzzaman (Fall 2019- present)
Thesis Topic: Energy efficient storage system design
3. Mr. Umeshwarnath Surendranathan (Spring 2020- present)
Thesis Topic: Radiation tolerant non-volatile storage system
4. Ms. Matchima Buddhanoy (Fall 2021- present)
Thesis Topic: Novel data encoding and sanitization concepts in solid state storage systems
5. Mr. Horace Wilson (Fall 2021- present)
Thesis Topic: Byte addressable non-volatile memory

Former Ph.D. Students:

1. Dr. Sadman Sakib, Ph.D. in Electrical Engineering, UAH, Spring 2021.
Thesis Title: “Hardware Security Primitives using NAND Flash Memory”
Position after graduation: Intel Corporation, Folsom, CA
2. Dr. Preeti Kumari, Ph.D. in Electrical Engineering, UAH, Spring 2021.
Thesis Title: “Total Ionizing Dose Effects on the State-of-the-art NAND Flash Memories with an Emphasis on Dosimeter Design”
Position after graduation: Micron Technology, Boise, ID

Former M.S. Students:

1. Md Mehedi Hasan, M.S. in Computer Engineering, UAH, Spring 2020
Thesis Title: “Security and Privacy Threat of Scrubbed NAND Flash Memory and Countermeasure”
Position after graduation: Pursuing PhD at Stony Brook University
2. Ms. Matchima Buddhanoy, M.S. in Electrical Engineering, UAH, Summer 2021
Thesis Title: “Data Retention Characteristics of Non-volatile Flash Memory”
Position after graduation: Pursuing PhD at UAH

Ph.D. Thesis Committee Participation:

1. Dr. Prawar Poudel, Ph.D. in Computer Engineering, UAH (Adviser: Dr. Milenkovic)
2. Dr. Caroline John, Ph.D. in Electrical Engineering, UAH (Adviser: Dr. Gorur)
3. Dr. Rithvik Reddy Gutha, Ph.D. in Physics, UAH (Adviser: Dr. Sadeghi)

M.S. Thesis Committee Participation:

1. Mr. Md Kawser Bepary, M.S. in Computer Engineering, UAH (Adviser: Dr. Rahman)
2. Mr. Prawar Poudel, M.S. in Computer Engineering, UAH (Adviser: Dr. Milenkovic)
3. Mr. Md Raquibuzzaman, M.S. in Electrical Engineering, UAH (Adviser: Dr. Gorur)
4. Mr. William Ake, M.S. in Electrical Engineering, UAH (Adviser: Dr. Pour)

Professional Services

1. NASA external reviewer, 2021
2. NSF Panelist and external reviewer for NSF, 2020, 2021
3. Senior Member, IEEE, since 2019
4. Technical Program Committee Member for the following conferences:
 - IEEE International Symposium on Hardware Oriented Security and Trust (HOST), 2021.
 - The 34th International Conference on VLSI Design, India, 2021
 - IEEE SoutheastCon, 2020.
 - IEEE SoutheastCon, Huntsville, AL, 2019.
 - IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE), Huntsville, AL, USA, Dec. 2018.
 - 26th Photovoltaic Science and Engineering Conference (PVSEC-26), 2016
5. Manuscript reviewer for the following Journals:
 - IEEE Transactions on Circuits and Systems
 - IEEE Transactions on Dependable and Secure Computing
 - IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems
 - IEEE Transactions on Electron Devices,
 - IEEE Electron Device Letters
 - Applied Physics Letters
 - Journal of Applied Physics
 - Scientific Reports (Nature)
6. Participated as a judge in 14th Annual STEM Day, Alabama A&M University, 2021.
7. Volunteered as a judge for the 66th North Alabama Regional Science and Engineering Fair (NARSEF), 2021, a scientific competition for students in grades five through twelve.
8. Presented a lecture for UAH FYE 101 (Freshman Year Experience) major presentations (2020, 2018).
9. Actively participated in the ECE student advising and mentoring program (EE 399) by offering one-to-one mentoring session to more than 15 UAH undergraduate students (2019, 2020, 2021).
10. Served as a volunteer and offered presentation in UAH Discovery Day, College of Engineering (2019, 2018, 2017).
11. Member of the ad hoc committee of the COE Strategic Plan 2028 towards achieving excellence in education.
12. Served as a committee member for 3 Ph.D. and 4 M.S. thesis students at UAH.