

Rahul P Panat

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RESEARCH INTERESTS:

- Advanced Manufacturing
 - Micro and Nanoscale Additive Manufacturing
 - Printed Electronics
 - Flexible Electronics
- Sensors
- Mechanical behavior of Materials
- Li-ion Batteries

EDUCATION:

PhD	Theoretical and Applied Mechanics, University of Illinois, Urbana, IL	99-04
MS	Mechanical Engineering, University of Massachusetts at Amherst, MA	97-99
BS	Mechanical Engineering, Pune University, India	93-97

WORK EXPERIENCE:

- Aug 2017 – Present: Associate Professor, Department of Mechanical Engineering, Carnegie Mellon University, Pittsburgh PA
- Aug 2014 – July 2017: Associate Professor, School of Mechanical and Materials Engineering, Washington State University (WSU), Pullman WA
- July 2004-July 2014: Senior Engineer/Engineering Manager, Assembly Technology and Test Development (R&D division for Microelectronic Packaging), Intel Corporation, Chandler AZ
- Oct 2012- June 2014: Adjunct Research Faculty, School of Engineering of Matter, Transport, and Energy, Arizona State University, Tempe, AZ

TEACHING EXPERIENCE:

- Developed and taught courses through Intel University while at Intel
- Courses taught at universities
 - ‘Advanced Mechanical Design’, ongoing, fall 2017 (CMU)
 - ‘Advanced Fracture Mechanics’ in spring 2017 (WSU)
 - ‘Design for Machine Components’ in fall 2016 (WSU)
 - ‘Materials Laboratory’ in fall 2016 and spring 2017 (WSU)
 - ‘Design for Manufacturing’ in spring 2016 (WSU)
 - ‘Machine Design’ in fall 2015 (WSU)
 - ‘Manufacturing Processes’ in fall 2014 and spring 2015 (WSU)

R&D ACCOMPLISHMENTS:

- **2004:** As a PhD student at Illinois, co-developed and validated a model to predict surface evolution of thick coatings at low stress and high temperatures via volume and surface diffusion (with KJ Hsia/DG Cahill) ([paper](#))
- **2006:** Lead process engineer for a team that developed industry’s first fully green (halogen free as well as lead free) integrated circuit chip. This was a flash memory chip and the technology was later adopted in logic chips (also at Intel) and by other companies worldwide.

- **2013:** Integrated Embedded Array Capacitors (EACs) into ultra-high performance Intel chips. This work significantly impacted high performance chip market by enabling Intel chips to operate efficiently at high frequencies not possible until that time ([paper](#)).
- **2015:** First demonstration of stretching of a metal film to 100% linear strain without failure. ([News](#), [patent](#), and papers ([APL](#), [JAP](#))).
- **2016:** Developed a new fabrication technique for hierarchical 3-D porous materials with structural control over 5 orders of magnitudes in length scales for applications such as energy storage, surface modification, bio-scaffolds/implants, actuation, etc.

PUBLICATIONS:

1. M. Sadeq Saleh, C. Hu, R. Panat, “Three Dimensional micro-architected materials and devices using nanoparticle assembly by pointwise spatial printing” **Science Advances**, 3, e1601986 (2017). [Link](#)
2. J. Geng, M. T. Rahman, R. Panat, and L. Li, “Self-assembled Axisymmetric Microscale Periodic Wrinkles on Elastomer Fibers”, **ASME Journal of Micro and Nano-manufacturing**, Vol. 5, Issue 2, pp. 021006 (2017). [Link](#)
3. M. T. Rahman, J. Gomez, K. Mireles, P. Wo, J. Marcial, M. Kessler, J. McCloy, C. Ramana, and R. Panat, “High temperature physical and chemical stability and oxidation reaction kinetics of Ni-Cr nanoparticles”, **Journal of Physical Chemistry – C**, Vol.121 (7), pp. 4018–4028 (2017). [Link](#)
4. J. Li, M. Leu, R. Panat and J. Park, “A hybrid 3-D structured electrode for Lithium-ion batteries via 3D printing”, **Materials and Design**, Vol. 119, pp. 417-424 (2017). [Link](#)
5. R. Sun, H. Yang, M. Rock, R. Danaei, R. Panat, M. Kessler, and L. Li, “Manufacturing PDMS Micro Lens Array using Spin Coating under a Multiphase System”, **Journal of Micromechanics and Microengineering**, Vol. 27(5), pp.1 (2017). [Link](#)
6. Y. Arafat, I. Dutta, R. Panat, “On the deformation mechanisms and electrical behavior of highly stretchable metallic interconnects on elastomer substrates”, **Journal of Applied Physics**, Vol. 120, Issue 11, pp. 115103-1 to 11 (2016). [Link](#)
7. M. T. Rahman, J. McCloy, C. V. Ramana, and R. Panat, “Structure, electrical characteristics and high-temperature stability of Aerosol Jet printed silver nanoparticle films”, **Journal of Applied Physics**, Vol. 120, Issue 7, pp. 075305-1 to 11 (2016). [Link](#)
8. B. Paul, R. Panat, C. Mastrangelo, D. Kim, and D. Johnson “Manufacturing of Smart Goods: Current state, future potential and research recommendations” **ASME Journal of Nano and Micro-Manufacturing**, Vol. 4, Issue 4, pp. 044001-1 to 044001-12 (2016). [PDF](#)
9. M. T. Rahman, A. Rahimi, S. Gupta, and R. Panat, “Microscale additive manufacturing and simulations of interdigitated capacitive touch sensors”, **Sensors and Actuators A: Physical**, Vol. 248, 94-103 (2016). [Link](#)
10. H. Yang, M. T. Rahman, D. Du, R. Panat, and Y. Lin, “Electrochemical sensors for biological applications using 3-D printed adjustable microelectrode arrays“, **Sensors and Actuators B: Chemical**, Vol. 230, 600-606 (2016) [Link](#)
11. Y. Arafat, I. Dutta, R. Panat, “Super-stretchable metallic interconnects on polymer with a linear strain of up to 100%” **Applied Physics Letters**, 107 081906 (2015) [Link](#)
12. M. T. Rahman, L. Renaud, M. Renn, D. Heo, R. Panat, “Aerosol based direct-write micro-additive fabrication method for sub-mm 3-D metal-dielectric structures”, **Journal of Micromechanics and Microengineering**, Vol. 25 (10), pp. 107002 (2015) [Link](#)
13. R. Panat, “A model for crack initiation in the Li-ion battery electrodes”, **Thin Solid Films**, Vol. 596, pp. 174-178 (2015) [Link](#)
14. Y. Arafat, I. Dutta, R. Panat, “Highly stretchable interconnects for flexible electronics applications” **ASME 2015 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems**, Paper No. IPACK2015-48187, pp. V003T03A002 (2015) [Link](#)
15. M. T. Rahman, L. Renaud, M. Renn, D. Heo, R. Panat, “3-D Antenna Structures Using Novel Direct-Write Additive Manufacturing Method”, **ASME 2015 International Technical Conference and**

- Exhibition on Packaging and Integration of Electronic and Photonic Microsystems**, Paper No. IPACK2015-48130, pp. V002T02A029 (2015) [Link](#)
16. Z. Song, T. Ma, R Tang, Q. Cheng, X. Wang, D. Krishnaraju, R. Panat, C. K. Chan, H. Yu, and H. Jiang, “Origami Lithium ion batteries”, **Nature Communications**, 5:33140 10.1038/ncomms4140, (2014). [Link](#)
 17. R. Panat, S. Dattaguru, H. Balkan, Y. Min, H. Seh, X. Zhao, “Mechanical reliability of embedding of components in ultra-high performance microprocessors”, **IEEE Transactions on Device and Materials Reliability**, Vol 4 (5), 857 (2014). [Link](#)
 18. R. Panat, E. Parks, and J. Wang, “On the effects of triboelectrostatic charging between polymer surfaces in manufacturing and test of integrated circuit packages”, **IEEE Transactions on Components, Packaging and Manufacturing** Vol. 4 (5), 943 (2014) [Link](#)
 19. R. Panat, V. Dimitrova, S. Selvamundiany, K. Ishiko, and D. Sun, “The application of Lean Six Sigma to the configuration control in Intel’s manufacturing R&D environment”, **International Journal of Lean Six Sigma**, Vol. 5 (4), 444-459 (2014). Selected by the journal as a ‘Highly Commended Paper of 2014’. [Link](#)
 20. R. Panat, “On the data and analysis of research output of India and China: India has significantly fallen behind China”, **Scientometrics** (Springer), Vol. 100 (2), 471-481 (2014). [Link](#)
 21. Y. Min, R. Olmedo, M. Hill, K. Radhakrishnan, K. Aygun, M. Kabiri-badr, R. Panat, S. Dattaguru, and H. Balkan, “Embedded capacitors in the next generation processors”, **63rd ECTC Conference, IEEE**, 1225-1229 (2013). [Link](#)
 22. N. Raravikar, R. Panat, and S. Jadhav, “A tombstone initiation model for small form factor surface mount passives” **IEEE Transactions on Components, Packaging and Manufacturing**, Vol. 2 (9), 1486-1491 (2012). [Link](#)
 23. Li Yan, R. Panat, R. Mulligan, P. Srinath, and A. Raman, “The application of 2D X-ray hot stage in flip chip package failure analysis”, **IEEE Transactions on Device and Materials Reliability**, Vol. 11 (1), 141-147 (2011). [Link](#)
 24. **R. Panat**, et al “Solving the solder bridging issue in large die processors”, **Intel Assembly and Test Technology Journal**, Vol. 13, 249-260 (2010) (Intel’s internal confidential journal)
 25. H. Balkan, others, **R. Panat**, “Passive technology requirements for future flip-chip packages”, **Intel Assembly and Test Technology Journal**, Vol. 11, 405-413 (2008) (Intel’s internal confidential journal)
 26. R. Panat, K.J. Hsia and D.G. Cahill, “Evolution of surface waviness in thin films via volume and surface diffusion”, **Journal of Applied Physics**, 97, 013521 (2005). [Link](#)
 27. R. Panat, K.J. Hsia and J. Oldham, “Observation of rumpling instability in thermal barrier systems under isothermal conditions in vacuum”, **Philosophical Magazine**, 85 (1), 45-64 (2005). [Link](#)
 28. R. Panat and K.J. Hsia, “Experimental investigation of the bond coat rumpling instability under cyclic and isothermal temperature histories in thermal barrier systems,” **Proceedings of the Royal Society of London, Series A**, Vol. 460, 1957-1979 (2004). [Link](#)
 29. R. Panat, S. Zhang and K.J. Hsia, “Bond coat surface rumpling in thermal barrier coatings” **Acta Materialia**, Vol. 51, 239-249 (2003). [Link](#)
 30. S. Zhang, R. Panat and K.J. Hsia, “Influence of surface morphology on the adhesion strength of aluminum/epoxy interfaces”, **Journal of Adhesion Science and Technology**, Vol. 17 (12), 1685-1711 (2003). [Link](#)
 31. R. Panat, K. Jakus, J.E. Ritter and P. Shah, “Erosion and strength degradation of an elastic modulus graded alumina-glass composite,” **Ceramic Engineering and Science Proceedings**, Vol. 21 (3), 635 (2000). [Link](#)
 32. J.E. Ritter, K. Jakus, R. Panat, “Impact damage and strength degradation of fused silica,” **MRS Symposium Proceedings**, 531, pp. 53 (1998). [Link](#)

PATENTS (Total of 7: 3 issued or in the process of being issued and 4 filed):

- R. Panat and B. Jaiswal, “Nanowires coated on traces in electronic devices”, US Patent Number 9627320, issued April 2017. [Link](#)

- I. Dutta and R. Panat, "Highly stretchable interconnect devices and systems", US Patent Number 9770759, issued Sept 2017. [Link](#)
- R. Panat and L. Lei, "Low-cost fiber optic sensor for large strain", U. S. Patent Application # 15/098,891, filed April 2016. [Link](#)
- R. Panat, "Additive manufacturing of porous scaffold structures", U. S. Patent Application # 14/957,849, filed Dec 2015. [Link](#)
- R. Panat and D. Heo, "Three-dimensional passive components", U.S. Patent Application # 14/964,451, filed Dec 2015. [Link](#)
- R. Panat and D. Heo, "Three-dimensional sub-mm wavelength sub-THz frequency antennas on flexible and in-situ cured dielectric using printed metal structures", U.S. Patent Application # 14/964,635, filed Dec 2015. [Link](#)
- Raravikar and R. Panat, "Nanolithographic method of manufacturing an embedded passive device for a microelectronic application, and microelectronic device containing the same", US Patent Number 8068328, issued May 2014. [Link](#)

RESEARCH PROJECTS:

- 2017-2020: "A Breakthrough Additive Manufacturing Method for High-Strength Lightweight 3D Micro-Architected Materials" **NSF/CMMI. PI: Rahul Panat**, CMU; co-PI: Prof. Hussein Zbib, WSU. (Total funding : \$309,943; my share: \$209,000).
- Jan-Dec 2017: "Highly stretchable metallic interconnects for flexible electronics", WSU Commercialization Gap Fund. **PI: Rahul Panat**, WSU; co-PI: Indranath Dutta, WSU. Grant for commercialization of the patent application (\$40,000).
- 2016-2019: "GOALI/Collaborative Research: Additive Manufacturing of Mechanically Strong and Electrochemically Robust Porous Electrodes for Ultra-High Energy Density Batteries" **NSF/CMMI. PI: Rahul Panat**, WSU; co-PI: Prof. Jonghyun Park, MUST, Rolla; GOALI Partner: Dr. Michael Renn, CTO, Optomec Inc., Minneapolis MN. (Total funding: \$300,000; my share: \$150,000)
- 2015-2018: "Low-Cost, Efficient and Durable High Temperature Wireless Sensors by Direct Write Additive Manufacturing for Application in Fossil Energy Systems", **DOE/NETL. PI: Rahul Panat**, WSU, and co-PI: Prof. C. V. Ramana, University of Texas, El Paso. (Total funding: \$399,932).
- 2016: Alaska Airlines travel grant for sustainability research
- 2015: "A low-cost super-stretchable polymer optical fiber strain sensor and Fiber-Bragg-Grating (FBG)" **Washington Research Foundation (WRF). PI: Rahul Panat**. (\$23,000).
- 2015: "Workshop: Advanced Manufacturing for Smart Goods; Vancouver, Washington, May 2015", **NSF/CMMI. PI: Brian Paul, co-PI: Rahul Panat**, David Johnson, Christina Mastrangelo, Dae-Wook Kim. (\$33,401)
- 2015: "Three dimensional sub-mm wavelength antennas using photonic curing of printed metal nanopowders on flexible substrates" **WRF. PI: Rahul Panat**. (\$25,000)
- 2014: "Equipment grant at WSU to add Laser/UV capability to printed electronics equipment and plasma cleaning equipment", **Northern Trust Program, PI: Rahul Panat**. (\$39,000)

MEDIA:

2015: Research on stretchable Indium conductors was highlighted in several tech magazines

Robot Magazine: [Indium-Plastic Film Could Lead to Stretchier Skin for Robots](#)

Physics.org: [Researchers create super-stretchable metallic conductors for flexible electronics](#)

Space Daily: [Super-stretchable metallic conductors for flexible electronics](#)

Gizmodo: [A New Stretchable Conductor Can Extend to Twice Its Length](#)

Semiconductor Engineering Mag: [Stretchy Metal](#)

Manufacturing.net: [Study: New Metal Fabric Can Stretch To Double Its Original Size](#)

2017: Research on 3D microarchitectures was highlighted in several tech magazines

WSU News: <https://news.wsu.edu/2017/03/03/novel-3-d-manufacturing/>

German Media: [Huge Nanostructures](#)

I4U News: [Researchers 3D Print Lightweight But Ultra-Strong New Material Like Wood And Bone](#)

Materials Today: [Novel 3D printing method goes up and down the scale](#)

3-D Printing Industry: [“Groundbreaking advance” in nanoparticle 3D printing mimics natural construction in the desert](#)

Science Daily: <https://www.sciencedaily.com/releases/2017/03/170303143221.htm>

Yahoo News: <https://sg.news.yahoo.com/scientists-create-ultra-light-super-190700874.html>

Physics.org: <https://phys.org/news/2017-03-d-highly-complex-bio-like-materials.html>

AWARDS AND HONORS:

- Divisional recognition award at Intel for outstanding efforts in development of new solder paste metallurgy, 2010
- Divisional recognition award at Intel for tape-out and production of Intel’s first six core Xeon® server microprocessor, 2008
- Technology and Manufacturing Group (TMG) excellence award for innovation in packaging to achieve \$2.6 billion in package, assembly and test savings, 2008
- Divisional recognition award at Intel for developing manufacturing process for world’s first fully green (halogen free and lead free) integrated circuit (IC) chip, 2007
- Lean Six Sigma Green Belt Certification at Intel, 2014
- Henry L. Langhaar Graduate Award, UIUC, 2004
- Stanley J. Weiss Outstanding Dissertation Award, UIUC 2004
- Dissertation Completion Fellowship 2003-04, UIUC
- Materials Research Society (MRS) Gold Medal, 2002
- Mavis Memorial Fund Scholarship Award, 2002 and 2003, UIUC
- Research Fellowship, TAM Department, UIUC (1999–2000)
- National Merit Scholarship by the Government of India (1991)

CONFERENCES/TALKS:

1. Invited Seminar at the Mechanical, Industrial, and Manufacturing Engineering Department, Oregon State University, Corvallis, OR, Nov 2016.
2. Invited Seminar at the Air Force Research Laboratory, Dayton, OH, June 2016.
3. Seminar at the NextManufacturing center at the Carnegie Mellon University (CMU) - ME department, Pittsburgh, PA, titled “Printed and Flexible Microelectronics Manufacturing for Smart Devices and Systems”, April 2016
4. Poster presentation at DOE/NETL [crosscutting project review meeting](#), Pittsburgh PA, April 2016
5. Seminar at the [43rd ICMCTF](#) (International Conference of Metallurgical Coatings and Thin Films) in San Diego, CA, “Electrical Characterization of Additively Manufactured Metal Films for High Temperature Sensor Applications”, April 2016
6. Department Seminar “Printed and Flexible Microelectronics Manufacturing for Smart Devices and Systems” at the School of Mechanical and Materials Engineering, WSU, Nov 2015
7. Two presentations at the ASME InterPACK Conference, San Francisco, CA, July 2015

8. Invited Seminar at the Sharp Labs, Camas, WA, "Some Problems in Flexible and Printed Electronics and Flexible Li-ion Batteries" June 2015
9. Invited Seminar at the [42nd ICMCTF](#) (International Conference of Metallurgical Coatings and Thin Films) in San Diego, CA, "On the Surface Evolution in Stressed Films: From Metal Films at High Temperature to Electrode Films in LiBs", April 2015
10. Invited Seminar at the Mechanical Engineering Department, University of Washington, Seattle, WA, "On the Integration of Microelectronic Devices on Rigid and Flexible Platforms", April 2015
11. Invited Seminar at the NSF PERM seminar series, University of Texas at El Paso, "Energy Storage Devices for Ultra-High Performance Microprocessors and Flexible Electronic Devices", June 2014
12. Invited Seminar at the Mechanical and Aerospace Seminar Series, Arizona State University "Mechanics of Microelectronic Packaging", Aug 2010
13. "Bond coat surface rumpling in thermal barrier coatings"
 - MRS, Boston, MA (Dec. 2002) – won MRS gold medal for this presentation.
 - 'Materials Interest Group' seminar given at the Department of Mechanical Engineering, UIUC, Urbana, IL (Oct. 2003)
 - Seminar in the Department of Civil Engineering, Cornell University, Ithaca (June 2004)
 - Seminar in the Department of Physics, Pune University, Pune, India (June 2005)
14. "Sharp particle impact damage in functionally graded ceramics" oral presentation at the *American Ceramic Society* meeting, Indianapolis, IN, April 1999

SERVICE AND OUTREACH:

- **Co-organizer of a workshop on Smart Goods Manufacturing**, sponsored by the CMMI division of NSF, 2015
- **Developed educational partnership with the Yakama National Tribal School, Toppenish WA.** This work will directly address the low level of motivation for K12 students in Native American lands in choosing STEM areas in their careers.
- **Faculty search committee chair**, School of MME, WSU, 2015. Hired 2 tenure track assistant professors in the areas of robotics and energy.
- Faculty mentor for Louis Stokes Alliance for Minority Participation (LSAMP) at WSU
- **Symposium chair** at the 2015 ASME Applied Mechanics and Materials Conference, Seattle, WA (session: Mechanics of Materials in Energy Technologies), July 2015.
- Proposal reviewer for NSERC (Natural Sciences and Engineering Research Council of Canada), Ottawa, Canada, 2015
- NSF panelist (CMMI division), 2006
- Reviewer for IEEE Adv Mat Tech, Transactions on Advanced Packaging, IEEE Transactions on Device and Materials Reliability, Journal of Materials Sciences and Engineering A, and Journal of Engineering Tribology

STUDENT ADVISING:

Three PhD students (1 completed, 2 current), 3 MS students (2 completed, 1 current), 2 UG students (1 current and 1 past).