

Rahul P Panat

Phone: (480) 415 6093

Email: rahul.panat@wsu.edu

URL: <http://www.mme.wsu.edu/people/faculty/faculty.html?panat>
<https://labs.wsu.edu/advancedmanufacturing/>

RESEARCH INTERESTS:

- Advanced Manufacturing
 - Additive Manufacturing
 - Printed Electronics
 - Flexible Electronics
- Sensors
- Li-ion Batteries

EDUCATION:**Doctor of Philosophy (Ph.D.)**

Sept. 99-May 04

Department of Theoretical and Applied Mechanics,
Frederick Seitz Materials Research Laboratory
University of Illinois at Urbana-Champaign, Urbana, IL
Thesis: *On the Rumpling Instability in Thermal Barrier Systems*

Master of Science in Mechanical Engineering (M.S.)

Sept. 97-Sept. 99

Department of Mechanical Engineering,
University of Massachusetts at Amherst, MA
Thesis: *Sharp Particle Impact damage in fused quartz and functionally graded ceramics*

Bachelor of Engineering (B.E.) in Mechanical Engineering

Aug. 93 - Jul. 97

Pune University, India

WORK EXPERIENCE:

- Aug 2014-Present: 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 (Intel's R&D division for Microelectronic Packaging), Intel Corporation
- Oct 2012- June 2014: Adjunct Research Faculty, School of Engineering of Matter, Transport, and Energy, Arizona State University, Tempe, AZ

TEACHING:

- Developed and taught courses through Intel University while at Intel
- Courses taught at WSU
 - 'Manufacturing Processes' for Fall 2014, Spring 2015
 - 'Machine Design' in Fall 2015
 - 'Design for Manufacturing' in Spring 2016
 - 'Design for Machine Components' and 'Materials Laboratory' in Fall 2016
 - 'Fracture Mechanics' planned for Spring 2017

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) ([paper](#))
- **2006:** Lead process engineer for a team that developed world's first fully green (halogen free as well as lead free) integrated circuit chip. This was a flash memory chip and the technology was then 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:** Currently developing a new fabrication technique for hierarchical porous materials with structural control over 5 orders of magnitudes in length scale for applications such as energy storage, surface modification, bio-scaffolds/implants, actuation, etc. (obtained [NSF/CMMI funding](#) to explore the idea for batteries, [patent filed](#))

PUBLICATIONS:

Submitted:

1. M. T. Rahman, J. Gomez, K. Mireles, P. Wo, J. Marcial, M. Kessler, J. McCloy, C. Ramana, and R. Panat, submitted (Oct 2016)
2. J. Li, M. Leu, R. Panat and J. Park, "A hybrid 3-D structured electrode for Lithium-ion batteries via 3D printing", submitted (Oct 2016)
3. M. Sadeq Saleh, C. Hu, R. Panat, submitted (Oct 2016)
4. J. Geng, M. T. Rahman, R. Panat, and L. Li "Self-assembled axisymmetric microscale periodic wrinkles on elastomer fibers", submitted (Sept. 2016)

Published:

1. 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](#)
2. 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](#)
3. 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](#)
4. 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](#)
5. 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](#)
6. 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](#)
7. 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](#)
8. R. Panat, "A model for crack initiation in the Li-ion battery electrodes", **Thin Solid Films**, Vol. 596, pp. 174-178 (2015) [Link](#)

9. 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](#)
10. 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](#)
11. 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](#)
12. 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](#)
13. 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](#)
14. 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](#).
15. 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](#)
16. 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](#)
17. 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](#)
18. 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](#)
19. 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](#)
20. 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](#)
21. 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](#)
22. R. Panat, S. Zhang and K.J. Hsia, "Bond coat surface rumpling in thermal barrier coatings" **Acta Materialia**, Vol. 51, 239-249 (2003). [Link](#)
23. 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](#)
24. 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](#)
25. J.E. Ritter, K. Jakus, R. Panat, "Impact damage and strength degradation of fused silica," **MRS Symposium Proceedings**, 531, pp. 53 (1998). [Link](#)

PATENTS:

1. **R. Panat** and L. Lei, “Low-cost fiber optic sensor for large strain”, Patent Filed (April 2016)
2. **R. Panat**, “Additive manufacturing of porous scaffold structures”, US Patent Application No. 14/957,849 (Filed Nov 2015). [Link](#)
3. **R. Panat** and D. Heo, “Three dimensional passive components”, US Patent Application No. 14/964,451 (Filed Nov 2015) [Link](#)
4. **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”, US Patent Application No. 14/964,635 (Filed Nov 2015) [Link](#)
5. I. Dutta and **R. Panat**,” Highly stretchable interconnect devices and systems”, US Patent Application No. 14/839,933 (Filed August 2015). [Link](#)
6. N. Raravikar and **R. Panat**, “Nanolithographic method of manufacturing an embedded passive device for a microelectronic application, and microelectronic device containing the same”, US Patent #8068328, Issued (2014). [Link](#)
7. **R. Panat** and B. Jaiswal, “Nanowires coated on traces in electronic devices” International patent publication #WO2013095663, (2013). [Link](#)

RESEARCH FUNDING (Total as PI: \$876k; My share: \$536k since Aug 2014):

- **NSF/CMMI: \$300,000** (Received March 2016; Duration: 2016-2019). **PI: Rahul Panat**, WSU; co-PI: Prof. Jonghyun Park, MUST, Rolla; GOALI Partner: Dr. Michael Renn, CTO, Optomec Inc., Minneapolis MN. Project title: “GOALI/Collaborative Research: Additive Manufacturing of Mechanically Strong and Electrochemically Robust Porous Electrodes for Ultra-High Energy Density Batteries”. (my share: \$150,000)
- Alaska Airlines travel grant for sustainability research, February 2016
- **DOE: \$ 488,738 (399,932 from DOE + 88,806 matching from WSU)** (Received Aug 2015; Duration: 2015-2018). **PI: Rahul Panat**, WSU, and co-PI: Prof. C. V. Ramana, University of Texas, El Paso. Project title: “Low-Cost, Efficient and Durable High Temperature Wireless Sensors by Direct Write Additive Manufacturing for Application in Fossil Energy Systems”. (my share: ~\$300,000).
- **Washington Research Foundation (WRF): \$23,000** (July 2015). **PI: Rahul Panat**. Project title: “A low-cost super-stretchable polymer optical fiber strain sensor and Fiber-Bragg-Grating (FBG)”.
- **NSF/CMMI: \$33,401** (Feb 2015). **PI: Brian Paul**, **co-PI: Rahul Panat**, David Johnson, Christina Mastrangelo, Dae-Wook Kim. Grant for “Workshop: Advanced Manufacturing for Smart Goods; Vancouver, Washington, May 2015”, CMMI Division,
- **WRF: \$25,000** (Jan 2015). **PI: Rahul Panat**. Project title: “Three dimensional sub-mm wavelength antennas using photonic curing of printed metal nanopowders on flexible substrates”.
- **Northern Trust Program: \$39,000** (Oct. 2014). **PI: Rahul Panat**. Equipment grant from the VCEA to add Laser/UV capability to printed electronics equipment and plasma cleaning equipment

MEDIA:

Research on stretchable 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](#)

Digital Trends: [WSU scientists have developed stretchable metal, paving the way for flexible electronics](#)

Engineering and Technology News: [Stretchable metal film breakthrough expands possibilities](#)

Chemie Europe: [WSU researchers create super-stretchable metallic conductors for flexible electronics](#)

Dutch Press: [UITREKBAAR METAAL VOOR FLEXIBELE ELEKTRONICA](#)

Greek Press: [Ερευνητές ανακάλυψαν "ελαστικό" μέταλλο, ανοίγοντας νέους δρόμους στην κατασκευή wearables](#)

Ukranian Press: [Создана модель сверхрастяжимого металлического проводника](#)

CONFERENCES/TALKS:

1. Invited Seminar at the Air Force Research Laboratory, Dayton, OH, June 2016.
2. Invited 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
3. Poster presentation at DOE/NETL [crosscutting project review meeting](#), Pittsburgh PA, April 2016
4. 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
5. Department Seminar "Printed and Flexible Microelectronics Manufacturing for Smart Devices and Systems" at the School of Mechanical and Materials Engineering, WSU, Nov 2015
6. Two presentations at the ASME InterPACK Conference, San Francisco, CA, July 2015
7. Symposium Chair at the *2015 ASME Applied Mechanics and Materials Conference*, Seattle, WA. Symposium title: "Mechanics of Materials in Energy Technologies" ([Link](#)), 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. Co-organizer a of workshop on Smart Goods Manufacturing, which was sponsored by the *CMMI division of NSF*. Twenty companies (Google, Intel, STMicro, HP, Amazon, Simplexity, Optomec, etc) working in areas such as wearables, sensors, and additive manufacturing for smart goods attended the workshop. A report on the workshop ([PDF](#)) identifies various industry-relevant research areas that NSF can focus on for future funding on this topic, May 2015
10. 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
11. 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
12. 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
13. Invited Seminar at the Mechanical and Aerospace Seminar Series, Arizona State University "Mechanics of Microelectronic Packaging", Aug 2010.
14. "Bond coat surface rumpling in thermal barrier coatings"
 - o MRS, Boston, MA (Dec. 2002).
 - o 'Materials Interest Group' seminar given at the Department of Mechanical Engineering, UIUC, Urbana, IL (Oct. 2003)
 - o Seminar in the Department of Civil Engineering, Cornell University, Ithaca (June 2004)
 - o Seminar in the Department of Physics, Pune University, Pune, India (June 2005)

15. “Sharp particle impact damage in functionally graded ceramics” oral presentation at the *American Ceramic Society* meeting, Indianapolis, IN (April 1999)

SERVICE:

- Faculty search committee chair in the School of MME at WSU. Hired 2 tenure track assistant professors in the areas of dynamics and control and energy
- Obtained NSF funding to develop educational partnership with the Yakama National Tribal School, Toppenish WA where site visits/lectures are planned starting 2017
- Faculty mentor for LSAMP and SWE for UG research at Pullman

STUDENT ADVISING:

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

AWARDS AND HONORS:

1. Several awards at Intel Corporation including one for developing manufacturing process for world’s first fully green (halogen free and lead free) flash memory chip, 2007.
2. Lean Six Sigma Green Belt Certification, 2014
3. Henry L. Langhaar Graduate Award, UIUC, 2004
4. Stanley J. Weiss Outstanding Dissertation Award, UIUC 2004
5. Materials Research Society Gold Medal, 2002.
6. Dissertation Completion Fellowship 2003-04, UIUC.
7. Mavis Memorial Fund Scholarship Award, 2002 and 2003, UIUC
8. Research Fellowship, TAM Department, UIUC, Urbana (1999–2000)
9. National Merit Scholarship by the Government of India (1991)