

## Wesley Hackenberger

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### Education:

Bachelor of Science in Nuclear Engineering  
Ph.D. in Materials

Pennsylvania State University, 1989  
Pennsylvania State University, 1995

### Work History:

Co-op Engineer  
Director of Research and Development  
President  
Consultant

American Electric Power, 1988, 1989, 1990  
TRS Ceramics, Inc., 1995 – 2003  
TRS Technologies, Inc., 2003-6/30/2022  
Applied Piezo Consulting, LLC 7/1/2022-Present

### Major Accomplishments at TRS:

- 1) Led development of single crystal piezoelectric technology, a revolutionary advance for electromechanical devices exhibiting greater than 5X performance improvement over legacy technology
- 2) Managed team that commercialized single crystal piezoelectric technology for medical ultrasound imaging and underwater transducers (managed scale-up of crystal size from 1" to 4" in diameter)
- 3) Led team that won and executed over \$50 million in federally funded R&D contracts
- 4) Managed transition of TRS Technologies from > 80% of revenues derived from federally funded R&D contracts to > 80% of revenues from commercial manufacturing in 3 years (currently 99% of TRS revenues are from commercial manufacturing)
- 5) Grew TRS Technologies from < \$2 million to > \$13 million in yearly revenue.
- 6) Orchestrated sale of TRS Technologies, Inc. to Tayca Corporation (a public company in Japan) for \$31 million, and managed the subsequent integration of the two companies

### Experience:

- Proven track record of technical innovation, technical and business problem solving, and business development and growth
- Led development and commercialization at TRS of high-quality, advanced piezoelectric ceramics and novel single crystal piezoelectric materials
- Commercialized piezoelectric ceramic materials for vibration sensors and led TRS to be one of the main global suppliers of shear mode vibration sensing elements
- Commercialized single crystal piezoelectric materials at TRS for medical ultrasound imaging transducers
- Led TRS to be one of two major suppliers of single crystal materials to medical ultrasound and underwater transducer markets
- Managed development projects at TRS for advanced piezoelectric ceramics, novel piezoelectric single crystals, high frequency imaging transducers, specialty high-displacement actuators, underwater SONAR projectors, energy storage capacitors, and shock-discharge materials
- Led implementation of ERP system at TRS (2020)
- Managed 62 employees in a 30,000 sq ft. manufacturing facility at conclusion of tenure at TRS

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- Awarded 20 Patents (U.S., Europe & Japan)
- Over 75 technical and scientific publications
- Oversaw all aspects of TRS business operations
  - Research and development including securing intellectual property and commercialization of new technologies
  - Manufacturing & process engineering
  - Production including planning, scheduling, resource allocation, and scale-up
  - Facilities including equipment specification, purchase, and installation
  - Quality system implementation and maintenance including ISO 9001 certification
  - Regulatory compliance for environmental, health, and safety issues as well as RoHS, REACH, and conflict materials compliance
  - Human resources
  - Export control compliance
  - Sales and marketing, including planning, targeted marketing, cost modeling, pricing, contract negotiation, and quoting
  - Financial reporting and planning including budget, P&L, and cash flow responsibility
- In June of 2022 I stepped down from my management role at TRS and established a consulting company to advise corporate clients on the development, design, and manufacturing of technologies based on piezoelectric materials.

### Other Details and Interests:

- 1) U.S. Citizen
- 2) Prior to 2018 I held a security clearance at the secret level; it is currently inactive.
- 3) I am proficient in using Microsoft Office applications (Word, Excel, PowerPoint, and Project).
- 4) I am proficient in using Infor Visual ERP software.
- 5) I am an avid reader of history and science.
- 6) I enjoy a range of outdoor activities including hiking, biking, canoeing, snow shoeing, and cross-country skiing.

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### *Publications and Patents*

#### Scientific Journal and Conference Proceedings Publications:

F. Li, M. Cabral, B. Xu, Z. Cheng, E. Dickey, J. Lebeau, J. Wang, J. Luo, S. Taylor, W. Hackenberger, L. Bellaiche, Z. Xu, L. Chen, T. Shrout, and S. Zhang, "Giant Piezoelectricity of Sm-doped  $\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3\text{-PbTiO}_3$  Single Crystals", *SCIENCE*, Vol 364, Issue 6437, pp. 264-268, April 2019.

S. Shkuratov, J. Baird, V. Antipov, J. Chase, and W. Hackenberger, "Stress-induced depolarization of single-layer PZT 95/5 ferroelectric films", *Appl. Phys. Lett.*, vol. 114, pp. 172902, April 2019.

S. Shkuratov, J. Baird, V. Antipov, W. Hackenberger, J. Luo, S. Zhang, C. Lynch, J. Chase, H. Jo, and C. Roberts, "Complete stress-induced depolarization of relaxor ferroelectric crystals without transition through a non-polar phase", *Appl. Phys. Lett.*, vol. 112, pp. 122903, March 2018.

S. Shkuratov, J. Baird, V. Antipov, E. Talantsev, J. Chase, W. Hackenberger, J. Luo, H. Jo, and C. Lynch, "Ultrahigh energy density harvested from domain-engineered relaxor ferroelectric single crystals under high strain rate loading", *Sci. Rep.*, vol. 7, pp. 46758, April 2017.

S. Shkuratov, J. Baird, V. Antipov, E. Talantsev, W. Hackenberger, A. Stults, and L. Altgilbers, "High Voltage Generation With Transversely Shock-Compressed Ferroelectrics: Breakdown Field on Thickness Dependence", *IEEE Transactions on Plasma Science*, vol. 44, issue 10, pp. 1919 – 1927, October 2016.

N. Kumar, A. Ionin, T. Ansell, S. Kwon, W. Hackenberger, and D. Cann, "Multilayer ceramic capacitors based on relaxor  $\text{BaTiO}_3\text{-Bi}(\text{Zn}_{1/2}\text{Ti}_{1/2})\text{O}_3$  for temperature stable and high energy density capacitor applications", *Appl. Phys. Lett.*, vol.106(25), pp. 252901, June 2015.

J. Luo, S. Zhang, W. Hackenberger and T. Shrout, "PIN-PMN-PT piezoelectric crystals with increased rhombohedral-to-tetragonal phase transition temperature", *J. of Adv. Dielectr.*, vol. 04, No. 01, pp. 1450001, January 2014.

F. Zheng, C. Chiu, C. Hu, H. Choi, Y. Li, K. Snook, Y. Liang, W. Hackenberger, R. Liu, X. Geng, X. Jiang, and K. Shung, "Micro defect detection on silicon carbide mirror with high frequency ultrasound array scanning", in *2012 IEEE International Ultrasonics Symposium, 7-10 Oct. 2012, Dresden, Germany*, IEEE, October 2012.

H. Li, V. Khilkevich, T. Li, D. Pommerenke, S. Kwon, and W. Hackenberger, "Nonlinear capacitors for ESD protection", *IEEE Electromagnetic Compatibility Magazine*, vol. 1, issue: 4, October, 2012.

S. Shkuratov, J. Baird, E. Talantsev, E. Alberta, W. Hackenberger, A. Stults, and L. Altgilbers, "Miniature 100-kV Explosive-Driven Prime Power Sources Based on Transverse Shock-Wave Depolarization of PZT 95/5 Ferroelectric Ceramics", *IEEE Transactions on Plasma Science*, vol. 40, issue 10, pp. 2512 – 2516, October 2012.

F. Zheng, C. Hu, L. Zhang, K. Snook, Y. Liang, W. Hackenberger, R. Liu, X. Geng, X. Jiang, and K. Kirk Shung, "Development of a C-Scan phased array ultrasonic imaging system using a 64-element 35MHz transducer", *Proceedings Volume 7983, Nondestructive Characterization for Composite Materials*,

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*Aerospace Engineering, Civil Infrastructure, and Homeland Security 2011*, SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring, San Diego, California, United States, SPIE, April 2011.

S. Kwon, W. Hackenberger, E. Alberta, E. Furman, and M. Lanagan, "Nonlinear dielectric ceramics and their applications to capacitors and tunable dielectrics", *IEEE Electrical Insulation Magazine*, Vol. 27, issue: 2, pp. 43 – 55, March-April 2011.

S. Zhang, F. Li, N. Sherlock, J. Luo, H. Lee, R. Xia, R. Meyer, Jr., W. Hackenberger, and T. Shrout, "Recent developments on high Curie temperature PIN-PMN-PT ferroelectric crystals", *J. Cryst. Growth*, vol. 318, issue 1, pp. 846-850, March 2011.

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J. Luo, W. Hackenberger, S. Zhang, and T. Shrout, "A high QM relaxor ferroelectric single crystal: Growth and characterization", in *2010 IEEE International Ultrasonics Symposium, 11-14 Oct. 2010, San Diego, CA, USA*, IEEE, 2010.

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X. Jiang, K. Snook, R. Liu, X. Geng, and W. Hackenberger, "Fabrication and characterization of high frequency phased arrays for NDE imaging", *Proceedings Volume 7649, Nondestructive Characterization for Composite Materials, Aerospace Engineering, Civil Infrastructure, and Homeland Security 2010*, SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring, San Diego, California, United States, SPIE, April 2010.

J. Luo, W. Hackenberger, S. Zhang, and T. Shrout, "The progress update of relaxor piezoelectric single crystals", in *2009 IEEE International Ultrasonics Symposium, 20-23 Sept. 2009, Rome, Italy*, IEEE, 2009.

X. Jiang, W. Cook, and W. Hackenberger, "Cryogenic piezoelectric actuators", *Proceedings Volume 7439, Astronomical and Space Optical Systems*, SPIE Optical Engineering + Applications, San Diego, California, United States, SPIE, September 2009.

S. Zhang, J. Luo, W. Hackenberger, N. Sherlock, R. Meyer Jr., and T. Shrout, "Electromechanical characterization of  $\text{Pb}(\text{In}_{0.5}\text{Nb}_{0.5})\text{O}_3\text{-Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3\text{-PbTiO}_3$  crystals as a function of crystallographic orientation and temperature", *J. Appl. Phys.*, vol. 105, pp. 104506, May 2009.

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K. Snook, X. Jiang, C. Hu, X. Geng, R. Liu, J. Welter, K. Shung, and W. Hackenberger, "A 35 MHz PCMUT phased array for NDE ultrasound", *Proceedings Volume 7294, Nondestructive Characterization for Composite Materials, Aerospace Engineering, Civil Infrastructure, and Homeland Security 2009*, SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring, San Diego, California, United States, SPIE, April 2009.

J. Luo, W. Hackenberger, S. Zhang, and T. Shrout, "Elastic, piezoelectric and dielectric properties of PIN-PMN-PT crystals grown by Bridgman method", in *2008 IEEE Ultrasonics Symposium, 2-5 Nov. 2008, Beijing, China*, IEEE, 2008.

S. Zhang, J. Luo, W. Hackenberger, and T. Shrout, "Characterization of  $\text{Pb}(\text{In}_{1/2}\text{Nb}_{1/2})\text{O}_3$   $\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3$ - $\text{PbTiO}_3$  ferroelectric crystal with enhanced phase transition temperatures", *J. Appl. Phys.*, vol. 104, pp. 064106, September, 2008.

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X. Jiang, J. Yuan, A. Cheng, K. Snook, and W. Hackenberger, "Micro/Nano Piezoelectric Composites for Advanced M/NEMS", in *2007 First International Conference on Integration and Commercialization of Micro and Nanosystems, 10–13 Jan. 2007, Sanya, Hainan, China*, ASME, January 2007.

J. Yuan, X. Jiang, K. Snook, P. Rehrig, T. Shrout, W. Hackenberger, A. Cheng, P. Cao, G. Lavarelle, and X. Geng, "Microfabrication of Piezoelectric Composite Ultrasound Transducers (PC-MUT)" in *2006 IEEE Ultrasonics Symposium, 2-6 Oct. 2006, Vancouver, BC, Canada*, IEEE, 2006.

P. Rehrig, K. Snook, W. Hackenberger, R. Meyer Jr., and D. Markley, "Tailored Single Crystal Orientations for Improved Tonpizl Transducer Performance", in *2006 IEEE Ultrasonics Symposium, 2-6 Oct. 2006, Vancouver, BC, Canada*, IEEE, October 2006.

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X. Jiang, P. Rehrig, W. Hackenberger, S. Perini, M. Lanagan, X. Xi, E. Furman, E. Prophet, B. Willemsen, and B. Hammond, "Single Crystal Piezoelectric Actuators for Tunable HTS Filters", *AIP Conference Proceedings*, vol. 823, pp. 928, ADVANCES IN CRYOGENIC ENGINEERING: Transactions of the Cryogenic Engineering Conference – CEC, 29 Aug.-2 Sep. 2005, Keystone, Colorado, USA, AIP, April 2006.

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Materials + Nondestructive Evaluation and Health Monitoring, San Diego, California, United States, SPIE, May 2005.

S. Zhang, E. Alberta, R. Eitel, P. Rehrig, W. Hackenberger, C. Randall, and T. Shrout, "High temperature piezoelectric materials for actuators and sensors", *Proceedings Volume 5761, Smart Structures and Materials 2005: Active Materials: Behavior and Mechanics*, SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring, San Diego, California, United States, SPIE, May 2005.

X. Jiang, P. Rehrig, W. Hackenberger, E. Smith, S. Dong, D. Viehland, J. Moore Jr., and B. Patrick, "Advanced piezoelectric single crystal based actuators", *Proceedings Volume 5761, Smart Structures and Materials 2005: Active Materials: Behavior and Mechanics*, SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring, San Diego, California, United States, SPIE, May 2005.

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W. Hackenberger, E. Alberta, P. Rehrig, S. Zhang, C. Randall, R. Eitel, and T. Shrout, "High temperature electrostrictive ceramics for a Venus ultrasonic rock sampling tool", in *14th IEEE International Symposium on Applications of Ferroelectrics*, ISAF-04, 23-27 Aug. 2004, Montreal, Quebec, Canada, IEEE, August 2004.

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X. Jiang, P. Rehrig, W. Hackenberger, and T. Shrout, "Large-stroke low-profile single-crystal piezoelectric actuators", *Proceedings Volume 5053, Smart Structures and Materials 2003: Active Materials: Behavior and Mechanics*, Smart Structures and Materials, San Diego, California, United States, SPIE, August 2003.

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M. Pan, P. Rehrig, J. Kucera, S. Park, and W. Hackenberger, "Comparison of actuator properties for piezoelectric and electrostrictive materials", *Proceedings Volume 3992, Smart Structures and Materials 2000: Active Materials: Behavior and Mechanics*, SPIE's 7th Annual International Symposium on Smart Structures and Materials, Newport Beach, CA, United States, SPIE, June, 2000.

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W. Hackenberger and R. Speyer, "A Fast-firing Shrinkage Rate Controlled Dilatometer using an Infrared Image Furnace," *Rev. Sci. Instrum.* vol. 65, issue 3, pp. 701-706, March 1994.

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