

ROBERT J. (BRUCE) WARMACK

PRESENT POSITION: Senior Research Staff
Sensors & Controls Research Group
Electrical and Electronics Systems Research Division
Oak Ridge National Laboratory

SYNOPSIS: Dr. Warmack's current expertise is in experimental neutron generator systems and in instrumentation for sensing technologies in a variety of physical and chemical applications. He earned his B.S. in Engineering Physics in 1970 and his Ph.D. in Physics in 1975 at the University of Tennessee. His early fields of activity at Oak Ridge National Laboratory have included studies in transport phenomena, molecular-beam kinetics, electron microscopy, microlithography, and dielectric properties of nanoparticles. In 1985, he pioneered a new laboratory at ORNL for scanning probe microscopy and co-invented the photon scanning tunneling microscope. In 1994, he was recognized by the American Physical Society, citing his work with biological imaging using scanning tunneling microscopy. His group's studies with the atomic-force microscope resulted in the development of microcantilever sensor arrays and were licensed by Graviton, where on entrepreneurial leave he served as Director of MEMS Development from 2000-2002. Dr. Warmack has coauthored numerous articles in the field of MEMS including seven patents in the field. In recent years, he has led and collaborated in programs to develop compact neutron generator systems and the associated high-voltage power supplies. He has been awarded various honors, including RD100 Awards, the Fabré-Gramont Award, and is a Fellow of the American Physical Society.

EDUCATION: B.S. - Engineering Physics, The University of Tennessee, Knoxville Tennessee (1970)
Ph.D. - Physics, The University of Tennessee, Knoxville, Tennessee (1975)

EMPLOYMENT:

April 1978 to date — Oak Ridge National Laboratory, Oak Ridge, Tennessee

2002 to present - Electrical and Electronics Systems Research Division, Senior Research Staff

2000 to 2002 - Director of MEMS Development. Graviton, Inc., La Jolla, California (entrepreneurial leave from ORNL)

1993 to 2000 - Life Sciences Division. Group Leader, Molecular Imaging Group, Biochemistry and Biophysics Section. Scanning probe microscopy and sensor research.

1981 to 1993 - Health and Safety Research Division. Staff Member, Liquid and Submicron Physics Group, Biological and Radiation Physics Section. Optical and charged particle interactions with submicron particles and thin films. Scanning probe microscopy.

1978 to 1981 - Analytical Chemistry Division. Research Staff Member, Mass Spectrometry Section. Mass spectrometry research and development.

HONORS AND MEMBERSHIPS IN PROFESSIONAL SOCIETIES:

2016 Technology Transfer Award: Smart Smoke Alarm
2015 ORNL Distinguished Inventor Award
2014 Journal of Phase Equilibria and Diffusion Editor Choice Award
2005 Federal Laboratory Consortium National Award of Excellence in Technology Transfer
2001 Excellence in Technology Transfer
1999 ORNL Development Accomplishment Award
1998 Discover Magazine Award for Technological Innovation
1998 Tennessee Technology Award, Consumer Electronics
1997 ORNL R&D Achievement Award
1997 ORNL Publication Award
1989, 1996 R&D 100 Award

- 1994 American Physical Society, Division of Biological Physics, Fellow
 1992 Brussel's World's Fair of Invention Award
 1992 International Hall of Fame Advanced Technology Award
 1989 Fabré-Gramont Award
 1988 ORNL Health and Safety Research Division Excellence in Research Award
 1986, 1988 Martin Marietta Energy Systems Inventor's Award

- PATENTS:** No. 5,018,865 (May 1991) "Photon Scanning Tunneling Microscopy"
 No. 6,005,400 (Dec. 1999) "High Resolution Three-Dimensional Doping Profiler"
 No. 6,118,124 (Sept. 2001) "Electromagnetic and nuclear radiation detector using micromechanical sensors"
 No. 6,167,748 (Jan. 2001) "A Capacitively Readout Multielement Sensor Array with Common-Mode Cancellation"
 No. 6,289,717 (Sept. 2001) "Micromechanical antibody sensor"
 No. 6,311,549 (Nov. 2001) "Micromechanical transient sensor for measuring viscosity and density of a fluid"
 No. 6,436,346 (Aug. 2002) "Micro-machined calorimetric biosensors"
 No. 6,545,495 (Apr. 2003) "Method and Apparatus for Self-Calibration of Capacitive Sensors"
 No. 6,650,319 (Nov. 2003) "Touch Screen Based Topological Mapping with Resistance Framing Design"
 No. 6,864,692 (Mar. 2005) "Sensor having improved selectivity"
 No. 6,977,511 (Dec. 2005) "Sensor and sensor array having improved selectivity"
 No. 7,243,548 (July 2007) "Surface wave chemical detector using optical radiation"
 No. 7,265,686 (Sept. 2007) "Touch sensor with non-uniform resistive band"
 No. 7,800,589 (Sept. 2010) "Touch screen with relatively conductive grid"
 No. 7,952,564 (May 2011) "Multiple-Touch Sensor"
 No. 8,049,740 (Nov. 2011) "Method and Apparatus for Laplace Constrained Touchscreen Calibration"
 No. 8,425,596 (Apr. 2013) "Retinal Instrument"
 No. 8,591,481 (Nov. 2013) "Microfabricated Instruments and Methods to Treat Recurrent Corneal Erosion"
 No. 8,617,372 (Dec. 2013) "Array-Type Ammonia Sensor"
 No. 9,019,109 (Apr. 2015) "Smart Smoke Alarm"
 No. 9,044,299 (Jun. 2015) "Microfabricated Instruments and Methods to Treat Recurrent Corneal Erosions"
 No. 9,171,453 (Oct. 2015) "Smoke Detection"
 No. 9,437,092 (Sept. 2016) "Smoke Detection"
 No. 9,792,795 (Oct. 2017) "Smoke Detection"
 No. 10,110,119 (Oct. 2018) "Power Supply & Method of Manufacturing"
 No. 10,147,289 (Dec. 2018) "Magnetic Field Sensing for Tamper-Indicating Devices"

PUBLICATIONS: Over 180 open-literature publications on subjects ranging from organic semiconductors, charge exchange reactions in crossed molecular beams, mass spectrometry, scanning probe microscopy, nanomaterials, and sensor physics.

Kulkarni NS, Warmack RJB, Radhakrishnan B, Hunter JL, Sohn Y, Coffey KR, Murch GE, Belova IV. Overview of SIMS-Based Experimental Studies of Tracer Diffusion in Solids and Application to Mg Self-Diffusion. *Journal of Phase Equilibria and Diffusion* 35:8, pp 762-78.

Hardy JE, Warmack BJ, Lavrik N, Datskos PG, Britton CL. 2009. Sensor Science for National Security. In: Baraton MI, Editor *Sensors for Environment, Health and Security: Advanced Materials and Technologies*. p 461-478.

Hardy JE, Warmack BJ, Lavrik N, Datskos PG, Britton CL. NATO Advanced Study Institute on Sensors for Environment, Health and Security - Advanced Materials and Technology, Vichy, FRANCE, Sept 16-27, 2007 2007, pp 461-478.

Hafeman DG, Harkins JB, Witkowski CE, Lewis NS, Warmack RJ, Brown GM, Thundat T. 2006. Optically directed molecular transport and 3D isoelectric positioning of amphoteric biomolecules. Proceedings of the National Academy of Sciences of the United States of America 103:6436-6441.

Warmack B, Korsah K, Hardy J. 2005. A Survey of Commercially Available Humidity and Carbon Dioxide Sensors for Use with Thermally Activated Technologies. ORNL TM-2005/190.

McCorkle DL, Warmack RJ, Patel SV, Mlsna T, Hunter SR, Ferrell TL. 2005. Ethanol vapor detection in aqueous environments using micro-capacitors and dielectric polymers. Sensors and Actuators B-Chemical 107:892-903.

Britton CL, Bryan WL, Wintenberg AL, Clonts LG, Warmack RJ, McKnight TE, Frank SS, Cooper RG, Dudney NJ, Veith GM. 2005. A detector for 2-d neutron imaging for the spallation neutron source. In: Yu B, Editor 2005 IEEE Nuclear Science Symposium Conference Record, Vols 1-5. p 616-618.

Britton CL, Bryan WL, Wintenberg AL, Clonts LG, Warmack RJ, McKnight TE, Frank SS, Cooper RG, Dudney NJ, Veith GM. Nuclear Science Symposium/Medical Imaging Conference, Fajardo, PR, Oct 23-29 2005, pp 616-618.

Lereu AL, Passian A, Warmack RJ, Ferrell TL, Thundat T. 2004. Effect of thermal variations on the Knudsen forces in the transitional regime. Applied Physics Letters 84:1013-1015.

Britton CL, Bryan WL, Wintenberg AL, Warmack RJ, McKnight TE, Frank SS, Cooper RG, Dudney NJ, Veith GM, Stephan AC. 2004. A detector for neutron imaging. IEEE Transactions on Nuclear Science 51:1016-1019.

Passian A, Warmack RJ, Wig A, Farahi RH, Meriaudeau F, Ferrell TL, Thundat T. 2003. Observation of Knudsen effect with microcantilevers. Ultramicroscopy 97:401-406.

Passian A, Warmack RJ, Ferrell TL, Thundat T. 2003. Thermal transpiration at the microscale: A Crookes cantilever. Physical Review Letters 90.

Britton CL, Bryan WL, Wintenberg AL, Warmack RJ, McKnight TE, Frank SS, Cooper RG, Dudney NJ, Veith GM, Stephan AC. IEEE Nuclear Science Symposium/Medical Imaging Conference, Portland, OR, Oct 19-25, 2004 2003, pp 360-364.

Baselt DR, Fruhberger B, Klaassen E, Cemalovic S, Jr. CLB, Patel SV, Mlsna TE, McCorkle D, Warmack B. 2003. Design and performance of a microcantilever-based hydrogen sensor. Sensors and Actuators B: Chemical 88:120-131.

Subramanian A, Oden PI, Kennel SJ, Jacobson KB, Warmack RJ, Thundat T, Doktycz MJ. 2002. Glucose biosensing using an enzyme-coated microcantilever. Applied Physics Letters 81:385-387.

- Liang CD, Yuan CY, Warmack RJ, Barnes CE, Dai S. 2002. Ionic liquids: A new class of sensing materials for detection of organic vapors based on the use of a quartz crystal microbalance. *Analytical Chemistry* 74:2172-2176.
- Hu ZY, Thundat T, Warmack RJ. 2001. Investigation of adsorption and absorption-induced stresses using microcantilever sensors. *Journal of Applied Physics* 90:427-431.
- Hoyt PR, Doktycz MJ, Warmack RJ, Allison DP. 2001. Spin-column isolation of DNA-protein interactions from complex protein mixtures for AFM imaging. *Ultramicroscopy* 86:139-143.
- Hoyt PR, Doktycz MJ, Modrich P, Warmack RJ, Allison DP. 2000. Identifying sequence similarities between DNA molecules. *Ultramicroscopy* 82:237-244.
- Britton CL, Jones RL, Oden PI, Hu Z, Warmack RJ, Smith SF, Bryan WL, Rochelle JM. 2000. Multiple-input microcantilever sensors. *Ultramicroscopy* 82:17-21.
- Thundat T, Finot E, Ji H-F, Dabestani R, Britt PF, Bonnesen PV, Brown GM, Warmack RJ. 1999. Highly Selective Microcantilever Sensor for Cesium Ion Detection. In: M. Butler NY, P. Vanysek, and M. Aizawa, Editor *Chemical Sensors IV*. NJ: Electrochemical Society. p 314-319.
- Oden PI, Thundat T, Warmack RJ. 1999. Electrochemical Deposition Induced Stress Measurements on a Microcantilever Investigated with Cyclic Voltammetry. *Scanning Microscopy* 10.
- Britton CL, Warmack RJ, Smith SF, Oden PI, Jones RL, Thundat T, Brown GM, Bryan WL, DePriest JC, Ericson MN, Emery MS, Moore MR, Turner GW, Wintenberg AL, Threatt TD, Hu Z, Clonts LG, Rochelle JM. *Government Microcircuits Applications (GOMAC)*, Monterey, CA, March 8-11, 1999 1999.
- Britton CL, Warmack RJ, Smith SF, Oden PI, Jones RL, Thundat T, Brown GM, Bryan WL, DePriest JC, Ericson MN, Emery MS, Moore MR, Turner GW, Wintenberg AL, Threatt TD, Hu Z, Clonts LG, Rochelle JM. *Advanced Research in VLSI*, Atlanta, GA, March, 1999 1999.
- Meriaudeau F, Goudonnet JP, Carver E, Parks JE, Jacobson KB, Warmack RJ, Ferrell TL. 1998. Photon scanning-tunneling microscopy of unstained mammalian cells and chromosomes. *Applied Optics* 37:7276-7288.
- Maya L, Thompson JR, Song KJ, Warmack RJ. 1998. Thermal conversion of an iron nitride silicon nitride precursor into a ferromagnetic nanocomposite. *Journal of Applied Physics* 83:905-910.
- Britton CL, Warmack RJ, Smith SF, Oden PI, Brown GM, Bryan WL, Clonts LG, Duncan MG, Emery MS, Ericson MN, Hu Z, Jones RL, Moore MR, Moore JA, Rochelle JM, Threatt TD, Thundat TG, Turner GW, Wintenberg AL. *Proc. SPIE, Smart Structures and Materials 1998: Smart Electronics and MEMS*, 7/1998 1998, pp 112-123.
- Thundat T, Oden PI, Warmack RJ, Wachter EA. 1997. Uncooled Infrared Imager.
- Thundat T, Oden PI, Warmack RJ. 1997. Microcantilever sensors. *Microscale Thermophysical Engineering* 1:185-199.

- Thundat T, Oden PI, Warmack RJ. 1997. Chemical, Physical, and Biological Detection Using Microcantilevers. In: Hesketh PJ, Barna G, Hughes HG, Editors. *Microstructures and Microfabricated Systems III*. Pennington, NJ: The Electrochemical Society. p 179-187.
- Thundat T, Oden PI, Warmack RJ. 1997. NanoSensor Array Chips. In: Minden SA, Editor *Molecular Nanotechnology*. San Diego: Int. Business Comm. p 3.1.1-30.
- Pai WW, Zhang J, Wendelken JF, Warmack RJ. 1997. Magnetic Nanostructures Fabricated by Scanning Tunneling Microscope-Assisted Chemical Vapor Deposition. *Journal of Vacuum Science & Technology B* 15:785-787.
- Maya L, Paranthaman M, List FA, Warmack RJ. 1997. Sputtered Cu/Co films for giant magnetoresistance: Effect of plasma gas and annealing treatment. *Journal of Vacuum Science & Technology a-Vacuum Surfaces and Films* 15:2807-2811.
- Maya L, Paranthaman M, List FA, Warmack RJ. 1997. Sputtered Cu/Co Films for Giant Magnetoresistance (GMR) — Effect of Plasma Gas and Annealing Treatment. *J. Vac. Sci. Technol. A* 15:2807-2811.
- Jesson DE, Chen KM, Pennycook SJ, Thundat T, Warmack RJ. 1997. Mechanisms of strain induced roughening and dislocation multiplication in SixGe_{1-x} thin films. *Journal of Electronic Materials* 26:1039-1047.
- Jesson DE, Chen KM, Pennycook SJ, Thundat T, Warmack RJ. 1997. Mechanisms of strain-induced surface ripple formation and dislocation multiplication in SixGe_{1-x} thin films. In: *Microscopy of Semiconducting Materials 1997*. p 239-246.
- Chen KM, Jesson DE, Pennycook SJ, Thundat T, Warmack RJ. 1997. Critical nuclei shapes in the stress-driven 2D-to-3D transition. *Physical Review B* 56:R1700-R1703.
- Allison DP, Thundat T, Warmack RJ. 1997. Scanning Probe Microscopy in Genomic Research. In: Beugelsdijk TJ, Editor *Automated Technologies for Genome Characterization*. Wiley. p 167-188.
- Allison DP, Kerper PS, Doktycz MJ, Thundat T, Modrich P, Larimer FW, Johnson DK, Hoyt PR, Mucenski ML, Warmack RJ. 1997. Mapping Individual Cosmid DNAs by Direct AFM Imaging. *Genomics* 41:379-384.
- Welipitiya D, He YL, Zhang J, Oden PI, Thundat T, Warmack RJ, Gobulukoglu I, Shan ZS, Sellmyer DJ, Dowben PA. 1996. Fabrication of Large Arrays of Micron-Scale Magnetic Features by Selective-Area Organometallic Chemical-Vapor-Deposition. *J. Appl. Phys.* 80:1867-1871.
- Wachter EA, Thundat T, Datskos PG, Oden PI, Sharp SL, Warmack RJ. 1996. Remote Optical Detection Using Microcantilevers. *Review of Scientific Instruments* 67:3434-3439.
- Oden PI, Datskos PG, Thundat T, Warmack RJ. 1996. Uncooled Thermal Imaging Using a Piezoresistive Microcantilever. *Appl. Phys. Lett.* 69:3277-3279.
- Oden PI, Chen GY, Steele RA, Warmack RJ, Thundat T. 1996. Viscous Drag Measurements Utilizing Microfabricated Cantilevers. *Applied Physics Letters* 68:3814-3816.

Jesson DE, Chen KM, Pennycook SJ, Thundat T, Warmack RJ. 1996. Morphological evolution of strained films by cooperative nucleation. *Physical Review Letters* 77:1330-1333.

Ferrell TL, Allison DP, Thundat T, Warmack RJ. 1996. Scanning Probe Microscopy in Sequencing of DNA. In: Meyers RA, Editor *Molecular Biology and Biotechnology: A Comprehensive Desk Reference*. New York: VCH Publishers, Inc. p 401-410.

Datskos PG, Oden PI, Thundat T, Wachter EA, Warmack RJ, Hunter SR. 1996. Remote Infrared Radiation Using Piezoresistive Microcantilevers. *Applied Physics Letters* 69:2986-2988.

Chen KM, Jesson DE, Pennycook SJ, Thundat T, Warmack RJ. 1996. Self-Limiting Growth Kinetics of 3D Coherent Islands. In: Zanwill A, Jesson D, Chambliss D, Clarke R, Editors. *Evolution of Epitaxial Structure and Morphology*. Pittsburgh, Pennsylvania: Materials Research Society. p 271.

Chen KM, Jesson DE, Pennycook SJ, Thundat T, Warmack RJ. 1996. New Insights into the Kinetics of the Stress-Driven Two-Dimensional to Three-Dimensional Transition. *Journal of Vacuum Science & Technology B* 14:2199-2202.

Chen GY, Warmack RJ, Oden PI, Thundat T. 1996. Transient Response of Tapping Scanning Force Microscopy in Liquids. *Journal of Vacuum Science & Technology B* 14:1313-1317.

Chen GY, Oden PI, Thundat T, Warmack RJ, Krieg RD. 1996. Natural Frequency Analysis of V-Shaped Scanning Microscopy. *Rev. of Sci. Inst.* (Not Published).

Allison DP, Kerper PS, Doktycz MJ, Spain JA, Modrich P, Larimer FW, Thundat T, Warmack RJ. 1996. Direct Atomic Force Microscope Imaging of EcoRI Endonuclease Site Specifically Bound To Plasmid DNA Molecules. *Proc. Natl. Acad. Sci.* 93:8826-8829.

Allison DP, Bottomley LA, Warmack RJ, Thundat T. 1996. Spreading and Immobilizing DNA on Au III. In: *Procedures in Scanning Probe Microscopies*. Sussex, United Kingdom: John Wiley and Sons, Ltd.

Zheng X-Y, Ding Y, Bottomley LA, Allison DP, Warmack RJ. 1995. Discontinuous Gold Island Films on Mica. *Journal of Vacuum Science & Technology B* 13:1320-1324.

Thundat T, Wachter EA, Sharp SL, Warmack RJ. 1995. Detection of Mercury Vapor Using Resonating Cantilevers. *Applied Physics Letters* 66:1695-1697.

Thundat T, Sharp SL, Fisher WG, Warmack RJ, Wachter EA. 1995. Micromechanical Radiation Dosimeter. *Applied Physics Letters* 66:1563-1565.

Thundat T, Chen GY, Warmack RJ, Allison DP, Wachter EA. 1995. Vapor Detection Using Resonating Microcantilevers. *Analytical Chemistry* 67:519-521.

Lee I, Lee JW, Warmack RJ, Allison DP, Greenbaum E. 1995. Molecular Electronics of a Single Photosystem I Reactor Center: Studies with Scanning Tunneling Microscopy and Spectroscopy. *Proceedings of the National Academy of Sciences* 92:1965-1969.

Kreutz TJ, Clausing RE, L. Heatherly J, Warmack RJ, Thundat T, Feigerle CS, Wandelt K. 1995. Growth Mechanisms and Defects in Boronated CVD Diamond as Identified by Scanning Tunneling Microscopy. *Physical Review B* 51:14554-14558.

Jesson DE, Chen K, Pennycook SJ, Thundat T, Warmack RJ. 1995. Crack-Like Sources of Dislocation Nucleation and Multiplication in Thin Films. *Science* 268:1161-1163.

Ferrell TL, Allison DP, Thundat T, Warmack RJ. 1995. Scanning Tunneling Microscopy in Sequencing of DNA. In: Meyers RA, Editor *Molecular Biology and Biotechnology: A Comprehensive Desk Reference*. New York: VCH Publishers, Inc. p 851-853.

Chen KM, Jesson DE, Pennycook SJ, Thundat T, Warmack RJ. 1995. Cuspidal Pit Formation During the Growth of $\text{Si}_x\text{Ge}_{1-x}$ Strained Layers. *Applied Physics Letters* 66:34-36.

Chen K, Jesson DE, Pennycook SJ, Mostoller M, Kaplan T, Thundat T, Warmack RJ. 1995. Step Instabilities: A New Kinetic Route to 3D Growth. *Physical Review Letters* 75:1582-1585.

Chen GY, Warmack RJ, Huang A, Thundat T. 1995. Harmonic Response of Near-Contact Scanning Force Microscopy. *Journal of Applied Physics* 78:1465-1469.

Chen GY, Thundat T, Wachter EA, Warmack RJ. 1995. Adsorption-induced surface stress and its effect on resonance frequency of microcantilevers. *J. Appl. Phys.* 77:3618-3622.

Allison DP, Thundat T, Modrich P, Isfort RJ, Doktycz MJ, Kerper PS, Warmack RJ. 1995. Mapping site-specific endonuclease binding to DNA by direct imaging with AFM. *SPIE* 2386:24-29.

Zuo J-K, Zehner DM, Wendelken JF, Warmack RJ. 1994. TaC(110): A Periodic Facet Reconstruction Studied by LEED and STM. *Surf. Sci.* 301:233-244.

Warmack RJ, Zheng X-Y, Thundat T, Allison DP. 1994. Friction Effects in the Deflection of Atomic Force Microscope Cantilevers. *Review of Scientific Instruments* 65:394-399.

Thundat T, Warmack RJ, Chen GY, Allison DP. 1994. Thermal and Ambient-Induced Deflections of Scanning Force Microscope Cantilevers. *Applied Physics Letters* 64:2894-2896.

Thundat T, Warmack RJ, Allison DP, Jacobson KB. 1994. Critical Point Mounting of Kinetoplast DNA for Atomic Force Microscopy. *Scanning Microscopy* 8:23-30.

Thundat T, Allison DP, Warmack RJ. 1994. Stretched DNA structures observed with atomic force microscopy. *Nucleic Acids Research* 22:4224-4228.

Lowndes DH, DeSilva M, Godbole MJ, Pedraza AJ, Thundat T, Warmack RJ. 1994. Smooth Polycrystalline Ceramic Substrates with Enhanced Metal Adhesion by Pulsed Excimer Laser Processing. *Appl. Phys. Lett.* 64:1791-1793.

Lee I, Warmack RJ, Ferrell TL. 1994. Laser Lithography by Photon Scanning Tunneling Microscopy. In: Miller JC, Geohegan DB, Editors. *Proc. Second International Conference on Laser Ablation*. American Institute of Physics Press. p 544.

- Jacobson SC, Hergenroder R, Koutny LB, Warmack RJ, Ramsey JM. 1994. Effects of Injection Schemes and Column Geometry of the Performance of Microchip Electrophoresis Devices. *Analytical Chemistry* 66:1107-1113.
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