TODD W. MURRAY
University of Colorado Boulder
Department of Mechanical Engineering
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RESEARCH INTERESTS

Elastic Wave Propagation, Ultrasonic Imaging, Materials Process Monitoring and Control, Biomedical Optics, Optical Sensors, Nanoscale Materials Characterization, Optical Techniques for Nondestructive Evaluation, Nanoelectromechanical Systems, Laser Ultrasonics, Photorefractive Materials and Devices.

EDUCATION

Johns Hopkins University **Baltimore, MD**
Ph.D. Materials Science and Engineering, 1998
M.S.E. Materials Science and Engineering, 1994
B.S. Biomedical Engineering, 1992

EXPERIENCE

Department of Mechanical Engineering **Boulder, CO**
University of Colorado Boulder
Professor 2018-
Associate Professor (tenured), September, 2009- 2018
Associate Chair, Mechanical Engineering, 2013-2015
Director: Laser Acoustics Lab

Research Center for Nondestructive Testing **Linz, Austria**
RECENDT
Visiting Research Scientist, September, 2015- January, 2016

Department of Mechanical Engineering **Boston, MA**
Boston University
Associate Professor (tenured), September, 2007- 2009
Assistant Professor, August, 2001-August, 2007

National Institute of Standards and Technology (NIST) **Boulder, CO**
Materials Reliability Division
Visiting Research Scientist, September, 2007- September 2008

Department of Mechanical Engineering **Evanston, IL**
Northwestern University
Research Assistant Professor, September 2000 - July 2001
Research Associate, 1999-2000
Postdoctoral Research Fellow, 1998-1999
Appointments under Dr. Jan Achenbach and Dr. Sridhar Krishnaswamy

Department of Materials Science and Engineering **Baltimore, MD**
Johns Hopkins University
Graduate Student/ Research Assistant, Fall 1992-Spring 1998
Advisor: Dr. James Wagner

AWARDS/ SYNERGISTIC ACTIVITIES

- CEAS Imaging Science IRT Director (2019-2020)
- Mechanical Engineering Outstanding Undergraduate Educator Award (2015).
- IPPA (International Photoacoustic and Photothermal Association) Junior Research Award (2009) for "outstanding contributions to high sensitivity ultrasonically based inspection techniques, applications to the mechanical characterization of thin films, plates, and membranes, functionally graded coatings, and micro- and nanoelectromechanical systems; development of laser array approaches for the optical generation and detection of elastic waves; and development of a novel photorefractive crystal based technique to detect ultrasound modulated light in diffuse media."
- NSF *CAREER* Award Recipient (2005).
- Recipient of a Boston University *Technology Development Award* (2004).
- Recipient of a *Special Service Citation* from the AIAA for "superbly planning, organizing, and assisting with the hosting of the 2004 Region I Northeast Student Conference" (2004).
- Recipient of a University of Colorado *Innovative Seed Grant Award* (2012).
- Recipient of a Boston University College of Engineering Certificate of Appreciation (through the Class of 2006 Gift Program for making a positive impact on the life of a student).
- Recipient of a Boston University *SPRInG Award* (2002).
- Regional Editor-North America, Journal of Nondestructive Testing and Evaluation (2006-).
- Scientific Committee Member: International Symposium on Laser Ultrasonics: Science, Technology and Applications (2008-).
- Scientific Committee Member: International Conference on Photoacoustic and Photothermal Phenomena (ICPPP), (2009-).
- Board of Directors, International Photoacoustic and Photothermal Association (2011-).
- Scientific Advisory Board: IPTRADE Inc., Newton, MA (2007-2009).
- Founding member: BU Center for Nanoscience and Nanobiotechnology (CNN).
- Founder of the LENS (Learning Experiences for New Scientists) outreach program for junior high students.
- Korea University of Education and Technology, invited to present week long short-course entitled "Laser-based techniques in Nondestructive Evaluation," (January, 2002 and August, 2002)
- Session Chair/Discussion Leader Invitation to Gordon Research Conference on Photoacoustic and Photothermal for the session on laser ultrasonic processes and applications. Conference held June 8-13, (2003)
- ARCS (Achievement Rewards for College Scientists) Foundation scholarship winner (1994)
- Selected to participate in international exchange program at the University of Ljubljana in Ljubljiana, Slovenia by Johns Hopkins University (1994)
- Reviewer: Optics Letters, Optics Express, Journal of the Acoustical Society of America, Optical Engineering, Applied Physics Letters, Research in Nondestructive Evaluation, and NDT&E International, Chemical Reviews, Acoustics Research Letters Online (ARLO), Journal of Optics A, Measurement Science and Technology.

PATENTS

*students and post-docs included on patents

Optical acoustic substrate assessment system and method
TW Murray, M Mehendale, M Kotelyanskii, R Mair, P Mukundhan
US Patent 9,576,862
Exclusive licensing agreement reached with Rudolph Technologies in May 2014. This agreement generates royalty income for the university each year.

Device for laser-ultrasonic detection of flip chip attachment defects

M Klein, T Murray
US Patent 8,269,979

Non-contact pressure sensing using laser-induced dielectric breakdown
RG Holt, TW Murray, JR Sukovich*
US Patent 8,240,215

Non-destructive imaging, characterization or measurement of thin items using laser-generated lamb waves
TW Murray, C Prada, O Balogun*
US Patent 7,798,000

Enhanced detection of acousto-photonic emissions in optically turbid media using a photo-refractive crystal-based detection system
CA DiMarzio, RA Roy, TW Murray, FJ Blonigen*, LA Nieva*, L Sui*, G. Maguluri*
US Patent 7,652,773

Characterization of micro-and nano scale materials by acoustic wave generation with a CW modulated laser
TW Murray
US Patent 7,649,632

Laser-ultrasonic detection of flip chip attachment defects
M Klein, T Murray
US Patent 7,327,448

Imaging through scattering media with high signal to noise ratio and resolution
R Piestun, H Ju*, J Dove*, AM Caravacca-Aguirre*, T Murray, D Conkey*
US Patent 10,036,735

Non-Destructive acoustic metrology for void detection
M. Mehendale, M. Kotelyanskii, T.W. Murray, R. Mair, P. Mukundhan, J.D. Dove*, R. Xueping, J. Cohen, T. Kryman
US Patent 9,991,176

High Resolution photoacoustic imaging in scattering media using structured illumination
T. Murray, P. Burgholzer, and M. Haltmeier
US Patent 10,551,357

JOURNAL PUBLICATIONS

1. M.A. Inzunza-Ibarra, J.A. Navarro-Becerra, V. Narumanchi, N. Bottenus, T.W .Murray, M.A. Borden, "Enhanced visibility through microbubble-induced photoacoustic fluctuation imaging," *JASA Express Letters*, 2 (1), 012001 (2022).
2. E.N. Mueller, M. Kuriakose, S. Ganguly, K. Ma, M.A. Inzunza-Ibarra, T.W. Murray, J.N. Cha, and A.P. Goodwin, "Hydrophobically Modified Silica-Coated Gold Nanorods for Generating Nonlinear Photoacoustic Signals," *ACS Applied Nano Materials* 4 (11), 12073-12082 (2021).

3. A.N. Thomas, K. Song, A. Upadhyay, V. Papadopoulou, D. Ramirez, R.K.B. Benninger, M. Lowerison, P. Song, T.W. Murray, and M.A. Borden, “Contrast-enhanced sonography with biomimetic lung surfactant nanodrops,” *Langmuir* 37(7) 2386 (2021).
4. V. Daeichin, M.A. Inzunza-Ibarra, J.S. Lum, M.A. Borden, and T.W. Murray, “Photoacoustic impulse response of lipid-coated ultrasound contrast agents,” *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, 68(6) 2311 (2021).
5. O. Supponen, A. Upadhyay, J. Lum, F. Guidi, T. Murray, H.J Vos, P. Tortoli, and M. Borden “The effect of size range on ultrasound-induced translations in microbubble populations,” *J. Acoust. Soc. Am.*, 147(7) 3236 (2020).
6. M.A. Inzunza-Ibarra, E. Premillieu, C. Grünsteidl, R. Piestun, and T.W. Murray, “Sub-acoustic resolution optical focusing through scattering using photoacoustic fluctuation guided wavefront shaping,” *Optics express* 28 (7), 9823-9832 (2020)
7. J.S. Lum, V. Daeichin, D.F. Kienle, D.K. Schwartz, T.W. Murray, and M.A. Borden, “Changes in microbubble dynamics upon adhesion to a solid surface,” *Appl. Phys. Lett*. 116(12) 123703 (2020).
8. D.M. Stobbe, C. Grunsteidl, and T.W. Murray, “Propagation and scattering of Lamb waves at conical points in plates,” Scientific Reports 9(1) 1-10 (2019)
9. J.P. Kilgore, A. Deolia, L. Robins, and T.W. Murray, “Experimental reconstruction of the contact resonance shape factor for quantification and amplification of bias-induced strain in atomic force microscopy,” *Appl. Phys. Lett*. 114(13) 133108 (2019).
10. J. Lum, D. Stobbe, M. Borden, and T.W. Murray, “Photoacoustic Evaluation of Temperature Effects on Microbubble Properties,” *Appl. Phys. Lett*. 112(11) 11905 (2018).
11. T.W. Murray and D. Stobbe, “Conical Dispersion of Lamb Waves in Elastic Plates,” *Phys. Rev. B* 96, 144101 (2017).
12. T.W. Murray, M. Haltmeier, T. Berer, E. Leiss-Holzinger, and P. Burgholzer, "Super-resolution photoacoustic microscopy using blind structured illumination," *Optica* 4, 17-22 (2017).
13. C. Grunsteidl, T. W. Murray, T. Berer, and I. A. Veres, “Inverse characterization of plates using zero group velocity Lamb modes,” *Ultrasonics* 65, 1 (2016).
14. M.A. Borden, J.D. Dove, and T.W. Murray, “Plasmonic nanoparticle coated microbubbles for theranostic applications,” in *Nanotheranostics for Personalized Medicine*, World Scientific (2016).
15. I.A. Veres, C. Grunsteidl, D.M. Stobbe, and T.W. Murray, “Broad angle negative reflection and focusing of elastic waves from a plate edge,” *Phys. Rev. B*, 93 (17), 174304 (2016).
16. J.S. Lum, J.D. Dove, T.W. Murray, and M.A. Borden, “Single Microbubble Measurements of Lipid Monolayer Viscoelastic Properties for Small-Amplitude Oscillations, *Langmuir* 32(37) 9410-9417 (2016).
17. T.W. Murray, A. Bakir, D.M. Stobbe, M.J. Kotelyanskii, R.A. Mair, M. Mehendale, X. Ru, J.D Cohen, M.T. Schulberg, P. Mukundhan, and T.J. Kryman, “A New In-Line Laser-Based Acoustic

Technique for Pillar Bump Metrology," *Journal of Microelectronics and Electronic Packaging*, 13(2) pp. 58-63 (2016).

18. D.B. Conkey, A.M. Caravaca-Aguirre, J.D. Dove, H. Ju, T.W. Murray, and R. Piestun, "Super-resolution imaging through a scattering wall," *Nature Communications* 6, 7902 (2015).
19. F.D. Philippe, T.W. Murray, and C. Prada, "Focusing on Plates: Controlling Guided Waves using Negative Refraction," *Scientific Reports* (5) 11112 (2015).
20. C. Grunsteidl, I. A. Veres, and T. W. Murray, "Experimental and numerical study of the excitability of zero group velocity Lamb waves by laser-ultrasound," *J. Acoust. Soc. Am.* 138(1) p. 242 (2015).
21. J.D. Dove, M.A. Borden, and T.W. Murray, "Optically induced resonance of nanoparticle-loaded microbubbles," *Opt. Lett.* **39**, 3732-3735 (2014).
22. J.D. Dove, P.A. Mountford, T.W. Murray, and M.A. Borden, "Engineering optically triggered droplets for photoacoustic imaging and therapy," *Biomedical optics express 5*(12) pp. 4417 (2014).
23. A.M. Caravaca-Aguirre, D.B. Conkey, J.D. Dove, H. Ju, T.W. Murray, and R. Piestun, "High contrast three-dimensional imaging through scattering media by localized optical fluence enhancement," *Opt. Express* 21(22) pp. 26671 (2013).
24. J.D. Dove, T.W. Murray, and M.A. Borden, "Enhanced photoacoustic response with plasmonic nanoparticle-templated microbubbles," *Soft Matter* 9 (32), pp. 7743 (2013).
25. H. Ju, R.A. Roy, and T.W. Murray, "Gold nanoparticle targeted photoacoustic cavitation for potential deep tissue imaging and therapy, "*Biomedical optics express* 4(1) pp. 66 (2013).
26. C. Grunsteidl, I.A. Veres, J. Roither, P. Burgholzer, T.W. Murray, and T. Berer, "Spatial and temporal frequency domain laser-ultrasound applied in the direct measurement of dispersion relations of surface acoustic waves," *Appl. Phys. Lett.* 102(1) 011103 (2013).
27. T.W. Murray, P. Lai, and R.A. Roy, "Measuring tissue properties and monitoring therapeutic responses using acousto-optic imaging," *Ann. Biomed. Eng*. 40(2) pp. 474-485 (2012).
28. S. Bramhavar, C. Prada, A.A. Maznev, A.G. Every, T.B. Norris, and T.W. Murray, "Negative refraction and focusing of elastic Lamb waves at an interface," *Phys. Rev. B*, 83, 014106 (2011).
29. O. Balogun and T.W. Murray, "Frequency domain photoacoustics using intensity modulated laser sources," *Nondestructive Testing and Evaluation*, 26(3) pp. 335-351 (2011).
30. A. SampathKumar, K.L. Ekinci, and T.W. Murray, "Multiplexed optical operation of distributed nanoelectromechanical systems," *Nano Lett*. 11(3) pp. 1014-1019 (2011).
31. P. Anderson, A. Sampathkumar, T.W. Murray, D.F. Gaitan, and R.G. Holt, "Optical nucleation of bubble clouds in a high pressure spherical resonator," *J. Acoust. Soc. Am.* 130 (5) pp. 3389-3395 (2011).

32. P. Lai, J.R. McLaughlan, A.B. Draught, T.W. Murray, R.O. Cleveland, and R.A. Roy, “Real time monitoring of high-intensity focused ultrasound lesion formation using acousto-optic sensing,” *Ultrasound Med. Biol.* 37(2) pp. 239-252 (2011).

33. O. Balogun, G.D. Cole, R. Huber, D. Chinn, T.W. Murray, and J.B. Spicer, “High spatial resolution sub-surface imaging using a laser based acoustic microscopy technique,” *IEEE Trans. Ultrason. Ferroelectr. Freq. Control* 58(1) (2011).

34. J.R. McLaughlan, R.A. Roy, H. Ju, and T.W. Murray, “Ultrasonic enhancement of photoacoustic emissions by nanoparticle-targeted cavitation,” *Opt. Lett.* 35(13) (2010).

35. P. Lai, R.A. Roy, T.W. Murray, “Quantitative characterization of turbid media using pressure contrast acousto-optic imaging,” *Opt. Lett*. (34) 18 (2009).

36. S. Bramhavar, B. Pouet, and T.W. Murray, "Superheterodyne detection of laser generated acoustic waves", *Appl. Phys. Lett.* , (94) 114102 (2009).

37. C. Prada, D. Clorennec, T.W. Murray, and D. Royer, “Influence of the anisotropy on zero-group velocity Lamb modes,” *J. Acoust. Soc. Am*. (126) 620 (2009).

38. T.W. Murray, R.A. Roy, and R.G. Holt, “Laser-Ultrasonic Cavitation,” *McGraw Hill Yearbook of Science and Technology 2008,* McGraw Hill (2008) (invited).

39. O. Balogun, T.W. Murray, and C. Prada, “Simulation and measurement of the optical excitation of the S1 zero group velocity Lamb wave resonance in plates,” *J. Appl. Phys.* 102, 064914 (2007)

40. T.W. Murray and R.A. Roy, “Illuminating sound: Imaging tissue optical properties with ultrasound,” *Acoustics Today*, 3(3) pp. 17-23 (2007). (invited)

41. D. Clorennec, C. Prada, D. Royer, and T.W. Murray, “Laser impulse generation and interferometer detection of zero-group velocity Lamb mode resonance,” *Appl. Phys. Lett.* 89, 024101 (2006).

42. A. Kumar, T.W. Murray, and K.L. Ekinci, “Photothermal Operation of High Frequency Nano-electromechanical Systems,” *Appl. Phys. Lett.* 88, 223104 (2006).

43. O. Balogun and T.W. Murray, “A Frequency Domain Laser Based Ultrasonic System for Time Resolved Measurement of Broadband Acoustic Transients,” *J. Appl. Phys.* 100,034902 (2006).

44. H. Yu, O. Balogun, B. Li, T.W. Murray and X. Zhang, “Fabrication of Three-dimensional Microstructures Based on Singled-layered SU-8 For Lab-on-chip Applications,” *Sensors and Actuators A: Physical*, 127(2), pp. 228-234 (2006).

45. T.L. Steen, S.N. Basu, V.K. Sarin, and T.W. Murray, “Inspection of Ceramic Coatings Using Nanoindentation and Frequency Domain Photoacoustic Microscopy,” *Journal of the Korean Society of Nondestructive Testing*, 26(6) pp. 390-402 (2006). *(invited)*

46. Murray, T.W. and Roy, R.A., “Illuminating sound: Imaging tissue optical properties with ultrasound,” *Echoes* 16(4), pp. 1-3, (2006). *(invited).*

47. C. Prada, O. Balogun and T.W. Murray, "Laser Based Ultrasonic Generation and Detection of Zero Group Velocity Lamb Waves in Thin Plates," *Appl. Phys. Lett.*, **87**, 194109 (2005).

48. T.W. Murray, O. Balogun, T.L. Steen, S. N. Basu and V. K. Sarin, "Inspection of Compositionally Graded Mullite Coatings Using Laser Based Ultrasonics", *International Journal of Refractory and Hard Materials*, **23**, pp. 322-329 (2005).

49. L. Sui, R. A. Roy, C. A. DiMarzio, and T. W. Murray, "Imaging in Diffuse Media using Pulsed-Ultrasound-Modulated Light and the Photorefractive Effect," *Appl. Opt.* **44** (19), pp. 4041-4048 (2005).

50. E. Bossy, L. Sui, T. W. Murray, and R. A. Roy, "Fusion of conventional ultrasound imaging and acousto-optical imaging using a standard pulsed ultrasound scanner," *Opt. Lett.* **30** (7), pp. 744-746, (2005).

51. F. J. Blonigen, A. Nieva, C. A. DiMarzio, S. Manneville, L. Sui, G. Maguluri, T. W. Murray, and R. A. Roy, "Computations of the acoustically-induced phase shifts of optical paths in acousto-photonic imaging with photorefractive-based detection", *Appl. Opt.* **44**(18), pp. 3735-3746 (2005).

52. C. Farny, T. Wu, R.G. Holt, T.W. Murray, and R.A. Roy, "Nucleating Cavitation from Laser Illuminated Nanoparticles," *Acoust. Res. Lett. Online* **6**(3), pp. 138-143 (2005).

53. T. W. Murray, L. Sui, G. Maguluri, R. A. Roy, A. Nieva, F. Blonigen and C. A. DiMarzio, "Detection of Ultrasound Modulated Photons in Diffuse Media Using the Photorefractive Effect," *Opt. Lett.* **29** (21), pp. 2509-2511, (2004).

54. T.W. Murray and O. Balogun, "High sensitivity laser based acoustic microscopy using a modulated laser source," *Appl. Phys. Lett.* **85**(14), pp. 2974 (2004).

55. H. Yu, O. Balogun, B. Li, T.W. Murray and X. Zhang, "Building embedded microchannels using a single layered SU-8, and determining Young's modulus using a laser acoustic technique," *J. Micromech. Microeng*. **14**(11), pp. 1576 (2004).

56. C.A. DiMarzio and T.W. Murray, "Medical Imaging Techniques Combining Light and Ultrasound," *Subsurface Sensing Technologies and Applications*, **4**(4), pp. 289-309 (2003).

57. T.W. Murray and O. Balogun, "Laser ultrasonic inspection of environmental barrier coatings," *Journal of the Korean Society of Nondestructive Testing*," **22**(6) pp. 599-608 (2002). (*Invited)*

58. Y. Zhou, T.W. Murray, and S. Krishnaswamy, "Photoacoustic imaging of surface acoustic wave slowness using multiplexed two-wave mixing interferometry," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, **49**(8), pp. 1118-1123 (2002).

59. P. Fomitchov, T.W. Murray, and S. Krishnaswamy, "Intrinsic fiber-optic ultrasonic sensor array using multiplexed two-wave mixing interferometry," *Applied Optics*, **41**(7) pp. 1262-1266 (2002).

60. C. Hernandez, T.W. Murray, and S. Krishnaswamy, "Photo-acoustic characterization of the Mechanical Properties of Thin Films," *Appl. Phys. Lett.* **80** (4), pp. 691-693 (2002).

61. T.W. Murray and S. Krishnaswamy, “Multiplexed interferometer for ultrasonic imaging applications,” *Optical Engineering* **40**(7), pp.1321-1328 (2001).

62. A. Cheng, T.W. Murray, and J.D. Achenbach, “Simulation of laser generated ultrasonic waves in layered plates,” *J. Acoust. Soc. Am.* **110**(2), pp. 848-855 (2001).

63. T.W. Murray, H. Tuovinen, and S. Krishnaswamy, “Adaptive optical array receivers for detection of surface acoustic waves,” Applied Optics **39**(19), pp. 3276-3284 (2000).

64. T.W. Murray, S. Krishnaswamy, and J.D. Achenbach, “Laser generation of ultrasound in films and coatings,” *Appl. Phys. Lett*. **74**(23), pp.3561-3563 (1999).

65. T.W. Murray and J.W. Wagner, “Laser generation of acoustic waves in the ablative regime,” *J. Appl. Phys*. **85**(4), pp. 2031-2040 (1999).

66. D.H. Hurley, J.B. Spicer, J.W. Wagner, and T.W. Murray, “Investigation of the anisotropic nature of laser-generated ultrasound in zinc and unidirectional carbon epoxy composites,” *Ultrasonics* **36**(1-5), pp. 355-360 (1998).

67. T.W. Murray, K.C. Baldwin and J.W. Wagner, “Laser ultrasonic chirp sources for low damage and high detectability without loss of temporal resolution,” *J. Acoust. Soc. Am.* **102**(5), pp. 2742-2746 (1997).

68. T.W. Murray, J.B. Deaton Jr., and J.W. Wagner, “Experimental evaluation of enhanced generation of ultrasonic waves using an array of laser sources,” *Ultrasonics* **34,** pp. 69-77 (1996).

69. J.S. Steckenrider, T.W. Murray, and J.W. Wagner, and J.B. Deaton, “Sensitivity enhancement in laser ultrasonics using a versatile laser array system,” *J. Acoust. Soc. Am*, **97**(1), pp. 273-279 (1995).