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12-04-2018	Final Report	1-Nov-2010 - 31-Oct-2017

4. TITLE AND SUBTITLE
Near and Far-Field Interfaces to DNA-Guided Nanostructures from RF to Lightwave: Exploiting the Spectrum

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W911NF-11-1-0024

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
611103

6. AUTHORS

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
University of California - Irvine
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Irvine, CA 92697 -7600

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U.S. Army Research Office
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58162-EL-MUR.152

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Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Peter Burke
UU	UU	UU	UU		19b. TELEPHONE NUMBER 949-824-9326

RPPR Final Report
as of 25-Jul-2018

Agency Code:

Proposal Number: 58162ELMUR **Agreement Number: W911NF-11-1-0024**
INVESTIGATOR(S):

Name: Peter Burke
Email: pburke@uci.edu
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Principal: Y

Organization: **University of California - Irvine**
Address: 141 Innovation Drive, Suite 250, Irvine, CA 926977600
Country: USA

DUNS Number: 046705849 EIN: 952226406
Report Date: 31-Jan-2018 Date Received: 12-Apr-2018
Final Report for Period Beginning 01-Nov-2010 and Ending 31-Oct-2017
Title: Near and Far-Field Interfaces to DNA-Guided Nanostructures from RF to Lightwave: Exploiting the Spectrum
Begin Performance Period: 01-Nov-2010 **End Performance Period:** 31-Oct-2017
Report Term: 0-Other

Submitted By: Peter Burke Email: pburke@uci.edu
Phone: (949) 824-9326

Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 2 **STEM Participants:** 8

Major Goals: The final technical progress report will be submitted under separate cover as a compilation of published peer-reviewed journal articles summarizing key findings of this project as per verbal agreement with the program manager.

The major goals and accomplishments are summarized in the annual progress reports that have been submitted during the course of this grant, and are explicitly included in this report.

Accomplishments: The final technical progress report will be submitted under separate cover as a compilation of published peer-reviewed journal articles summarizing key findings of this project as per verbal agreement with the program manager.

The major goals and accomplishments are summarized in the annual progress reports that have been submitted during the course of this grant, and are explicitly included in this report.

Training Opportunities: The final technical progress report will be submitted under separate cover as a compilation of published peer-reviewed journal articles summarizing key findings of this project as per verbal agreement with the program manager.

The major goals and accomplishments are summarized in the annual progress reports that have been submitted during the course of this grant, and are explicitly included in this report.

Results Dissemination: The final technical progress report will be submitted under separate cover as a compilation of published peer-reviewed journal articles summarizing key findings of this project as per verbal agreement with the program manager.

Honors and Awards: N.C.S Elected member of American Academy of Arts and Sciences (Ned Seeman)

Protocol Activity Status:

Technology Transfer: Work with Mario Ancona and Joseph Melinger at NRL (Ned Seeman)

PARTICIPANTS:

RPPR Final Report
as of 25-Jul-2018

Participant Type: Undergraduate Student
Participant: Tanner Way
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Non-Student Research Assistant
Participant: Ruojie Sha
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Yudong Hao
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

ARTICLES:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: ACS Nano
Publication Identifier Type: DOI Publication Identifier: 10.1021/nn201828y
Volume: 5 Issue: 11 First Page #: 8471
Date Submitted: Date Published:
Publication Location:
Article Title: High-Performance Semiconducting Nanotube Inks: Progress and Prospects
Authors:
Keywords: semiconducting carbon nanotube, solution-based deposition, randomnetwork, thin film transistor, mobility,on/off ratio, nanotube network density, radio frequency, circuit demonstration
Abstract: While the potential for high mobility printed semiconducting nanotube inks has been clear for over a decade, a myriad of scientific and technological issues has prevented commercialization and practical use. One of the most challenging scientific problems has been to understand the relationship between the pristine, individual nanotube mobility (known to be in the 10 000 cm2/V 3 s range) and the as-deposited random network mobility (recently demonstrated in the 100 cm2/V 3 s range). An additional significant scientific hurdle has been to understand, manage, and ultimately eliminate the effects of metallic nanotubes on the network performance, specifically the on/off ratio. Additional scientific progress is important in understanding the dependence of nanotube length, diameter, and density on device performance. Finally, the development of ink formulations that are of practical use in manufacturing is of paramount importance, especially with regard to drying time and uniformity, and ult
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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Lab on a Chip
Publication Identifier Type: DOI Publication Identifier: 10.1039/c2lc40086c
Volume: 12 Issue: 15 First Page #: 2719
Date Submitted: Date Published:
Publication Location:
Article Title: Wafer-scale mitochondrial membrane potential assays
Authors:
Keywords: lab on chip, biosensor, mitochondria
Abstract: It has been reported that mitochondrial metabolic and biophysical parameters are associated with degenerative diseases and the aging process. To evaluate these biochemical parameters, current technology requires several hundred milligrams of isolated mitochondria for functional assays. Here, we demonstrate manufacturable wafer-scale mitochondrial functional assay lab-on-a-chip devices, which require mitochondrial protein quantities three orders of magnitude less than current assays, integrated onto 499 standard silicon wafer with new fabrication processes and materials. Membrane potential changes of isolated mitochondria from various well-established cell lines such as human HeLa cell line (Heb7A), human osteosarcoma cell line (143b) and mouse skeletal muscle tissue were investigated and compared. This second generation integrated lab-on-a-chip system developed here shows enhanced structural durability and reproducibility while increasing the sensitivity to changes in mitochondrial mem
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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Nano Research
Publication Identifier Type: Publication Identifier:
Volume: 0 Issue: 0 First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Terahertz Graphene Optics
Authors:
Keywords: Graphene, Terahertz
Abstract: The magnitude of the optical sheet conductance of single layer graphene is universal, and equal to e2/4?. As the optical frequency decreases, the conductivity decreases. However, at some frequency in the THz range, the conductivity increases again, eventually reaching the dc value, where the magnitude of the dc sheet conductance generally displays a sample and doping-dependent value between ~ e2/h and 100 e2/h. Thus, the THz range is predicted to be a non-trivial region of the spectrum for the electron transport in graphene, and may have interesting technological applications. In this paper, we present the first frequency domain measurements of the absolute value of multilayer graphene (MLG) and single-layer graphene (SLG) sheet conductivity and transparency from DC to 1 THz, and establish a firm foundation for future THz applications of graphene.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Sensors Journal
Publication Identifier Type: DOI Publication Identifier: 10.1109/JSEN.2012.2229387
Volume: 13 Issue: 5 First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Quantum-Dot-Based Aptamer Beacons for <formula formulatype="inline"> <tex Notation="TeX" >${\rm K}^{+}$</tex></formula> Detection
Authors:
Keywords: Aptamer, deoxyribonucleic acid, molecularbeacon, nanotechnology, potassium ion, quantum dot, tetraplex,thrombin-binding aptamer.
Abstract: Herein, aptamer-based quantum-dot detectors of K+ made of two-different K+ aptamers are compared. These deoxyribonucleic acid-based aptamers are TBA (5┐ GGT TGG TGT GGT TGG 3┐) and AG3 (5┐ GGG TTA GGG TTA GGG TTA GGG 3┐). The nanoscale aptamer-quantum-dot-based detectors described in this paper are synthesized and tested in DI water aliquots that contain KCl. The results including data suggest that beacons made of AG3 and TBA serve better as an ion indicator in different potassium level regions. As a result, aptamer beacon made of AG3 has better potential in the design of take-home diagnostic devices for hyperkalemia and hypokalemia.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: IEEE Transactions on NanoBioScience
Publication Identifier Type: DOI Publication Identifier: 10.1109/TNB.2013.2242484
Volume: 12 Issue: 2 First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Raman and Surface-Enhanced Raman Scattering (SERS) Studies of the Thrombin-Binding Aptamer
Authors:
Keywords: Aptamer, DNA, nanobiotechnology, nanoparticle,surface-enhanced Raman scattering.
Abstract: Surface-enhanced Raman scattering is used to study the Raman spectra and peak shifts the thrombin-binding aptamer (TBA) on substrates having two different geometries; one with a single stranded sequence and one with double stranded sequence. The Raman signals of the deoxyribonucleic acids on both substrates are enhanced and specific peaks of bases are identified. These results are highly reproducible and have promising applications in low cost nucleic acid detection.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Journal of Computational Electronics
Publication Identifier Type: DOI Publication Identifier: 10.1007/s10825-012-0400-4
Volume: 11 Issue: 3 First Page #: 293
Date Submitted: Date Published:
Publication Location:
Article Title: Phonon bottleneck effects in rectangular graphene quantum dots
Authors:
Keywords: Graphene, Quantum dots, Confined phonons
Abstract: For a graphene sheet with confining structures in the orthogonal directions of zigzag- and armchair-edge, the confined carrier states are determined. These wavefunctions and eigenvalues are used to study carrier-longitudinal optical (LO)-phonon interactions in these graphene quantum dots. The optical deformation potential is derived for these graphene quantum dots as the basis for the study of these carrier-LO-phonon interactions. Phonon bottleneck effects are identified and the Fermi golden rule transition rates are formulated.
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Publication Type: Journal Article Peer Reviewed: N **Publication Status:** 1-Published
Journal: Nano Research
Publication Identifier Type: Publication Identifier:
Volume: 5 Issue: 10 First Page #: 667
Date Submitted: Date Published:
Publication Location:
Article Title: Terahertz Graphene Optics
Authors:
Keywords: Single-layer graphene, terahertz, conductance, multilayer graphene, broadband
Abstract: The magnitude of the optical sheet conductance of single-layer graphene is universal, and equal to e2/4? (where 2?? = h (the Planck constant)). As the optical frequency decreases, the conductivity decreases. However, at some frequency in the THz range, the conductivity increases again, eventually reaching the DC value, where the magnitude of the DC sheet conductance generally displays a sample- and doping-dependent value between ~e2/h and 100 e2/h. Thus, the THz range is predicted to be a non-trivial region of the spectrum for electron transport in graphene, and may have interesting technological applications. In this paper, we present the first frequency domain measurements of the absolute value of multilayer graphene (MLG) and single-layer graphene (SLG) sheet conductivity and transparency from DC to 1 THz, and establish a firm foundation for future THz applications of graphene.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support:

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Nature Photonics
Publication Identifier Type: Publication Identifier:
Volume: Issue: First Page #:
Date Submitted: 10/19/17 12:00AM Date Published:
Publication Location:
Article Title: Strong light-matter coupling to a 2D material in the THz domain
Authors: Phi. H. Q. Pham, W-D. Zhang, N. V. Quach, W-W. Zhou, J-F. Li, D. Scarmardo, E. R. Brown and P. J.
Keywords: Strong light-matter coupling to a 2D material in the THz domain
Abstract: The coupling of an electromagnetic plane wave to a thin conductor depends on the sheet conductance of the material: a poor conductor interacts only weakly with the incoming light, allowing the majority of the incident radiation to pass, whereas a good conductor also does not absorb any light, reflecting the wave almost entirely1. For a suspended film, the transition from reflector to transmitter occurs when the sheet resistance is approximately the characteristic impedance of free space (Z0 = 377 ?). On a dielectric substrate, the impedance at which absorption is maximized is somewhere between the characteristic impedance of free space, and that of the medium (i.e. Z0/n, where n is the index of refraction of the dielectric substrate). Near this point, the interaction is maximized, and the conductor absorbs strongly. Here we show that monolayer graphene, a tunable thin conductor2, can be electrically and chemically modified to reach this transition, thereby achieving the maximum absorpt
Distribution Statement: 1-Approved for public release; distribution is unlimited.
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BOOKS:

Publication Type: Book Peer Reviewed: Y **Publication Status:** 1-Published
Publication Identifier Type: ISBN Publication Identifier: 9780521764483
Book Edition: Volume: Publication Year: 2016 Date Received:
Publication Location:
Publisher: Cambridge University Press
Book Title: Structural DNA Nanotechnology
Authors: N.C. Seeman
Editor:
Acknowledged Federal Support: Y

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CONFERENCE PAPERS:

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2015 European Microwave Conference (EuMC 2015)
Date Received: 02-Sep-2016 Conference Date: 07-Sep-2015 Date Published:
Conference Location: Paris, France
Paper Title: Detection of DNA by graphene-on-silicon FET structures simultaneously at DC and 101 GHz
Authors: Elliot R. Brown, Weidong Zhang, David Neff, Nathaniel S. Green, Michael. L. Norton, Phi Huy Quoc Pha
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2015 International Conference on Electromagnetics in Advanced Applications (ICEAA)
Date Received: 02-Sep-2016 Conference Date: 07-Sep-2015 Date Published:
Conference Location: Torino, Italy
Paper Title: Electromagnetic coupling to nano-devices: 2D vs. 1D
Authors: Electromagnetic Coupling to Nano-devices: 2D vs. 1D
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: SPIE Defense + Security
Date Received: 02-Sep-2016 Conference Date: 18-Apr-2016 Date Published:
Conference Location: Baltimore, Maryland, United States
Paper Title: A millimeter-wave reflectometer for whole-body hydration sensing
Authors: W-D. Zhang, E. R. Brown
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 14th Annual Conference on Foundations of Nanoscience: Self-Assembled Architectures and Devices
Date Received: 17-Oct-2017 Conference Date: 10-Apr-2017 Date Published: 10-Apr-2017
Conference Location: Snowbird, Utah
Paper Title: The Sapphire (0001) Surface: A Transparent Substitute for Mica for DNA Nanostructure Imaging
Authors: David Neff, Masudur Rahman, Michael Norton
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: IRMMW 42th
Date Received: 19-Oct-2017 Conference Date: 28-Aug-2017 Date Published:
Conference Location: Cancun, Mexico
Paper Title: Advances in 1550-nm driven THz, GaAs Photoconductive switches
Authors: A. Mingardi ; W-D. Zhang ; E. R. Brown
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: IRMMW 42th
Date Received: 19-Oct-2017 Conference Date: 27-Aug-2017 Date Published:
Conference Location: Cancun, Mexico
Paper Title: Effects of Bound Water Molecules on Molecular Vibrations
Authors: W-D. Zhang, A. Bykhovski, E. R. Brown
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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: SPIE Defense + Security
Date Received: 19-Oct-2017 Conference Date: 08-May-2017 Date Published:
Conference Location: Anaheim, California, United States
Paper Title: Ultrafast photoconductive devices based upon GaAs:ErAs nanoparticle composite driven at 1550 nm
Authors: • W-D. Zhang, A. Mingardi, E. R. Brown, A. Feldman,T. Harvey, and R. P. Mirin
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2016 41st International Conference on Infrared, Millimeter, and Terahertz waves (IRMMW-THz)
Date Received: 19-Oct-2017 Conference Date: 25-Sep-2016 Date Published:
Conference Location: Copenhagen, Denmark
Paper Title: Red-shift in THz resonant signatures induced by hydration
Authors: W-D. Zhang and E. R. Brown
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2016 41st International Conference on Infrared, Millimeter, and Terahertz waves (IRMMW-THz)
Date Received: 19-Oct-2017 Conference Date: 25-Sep-2016 Date Published:
Conference Location: Copenhagen, Denmark
Paper Title: Model for ultrafast extrinsic photoconductivity in Er-doped GaAs
Authors: E. R. Brown and W-D. Zhang
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: Latin America Optics and Photonics Conference
Date Received: 19-Oct-2017 Conference Date: 01-Aug-2016 Date Published:
Conference Location: Medellin
Paper Title: THz Photoconductivity in GaAs:Er at 1550 nm, and Comparison with Cross-Gap Performance
Authors: E. R. Brown, W-D. Zhang, A. Feldman, T. Harvey, and R. Mirin
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2016 IEEE National Aerospace and Electronics Conference (NAECON) and Ohio Innovation Summit (OIS)
Date Received: 19-Oct-2017 Conference Date: 25-Jul-2016 Date Published:
Conference Location: Dayton, OH, USA
Paper Title: Imaging the hydration level of human skin with a millimeter-wave reflectometer
Authors: W-D. Zhang and E. R. Brown
Acknowledged Federal Support: **Y**

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Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: 2016 IEEE National Aerospace and Electronics Conference (NAECON) and Ohio Innovation Summit (OIS)
Date Received: 19-Oct-2017 Conference Date: 25-Jul-2016 Date Published:
Conference Location: Dayton, OH, USA
Paper Title: Non-contact, antenna-free probe for characterization of THz devices and components
Authors: A. Mingardi, W-D. Zhang and E. R. Brown
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 2-Awaiting Publicat
Conference Name: International Microwave Symposium
Date Received: 16-Mar-2018 Conference Date: 10-Jun-2018 Date Published:
Conference Location: Philadelphia, Pennsylvania
Paper Title: Scanning Microwave Microscopy of Vital Mitochondria in Respiration Buffer
Authors: Jinfeng Li, Zahra Nemati, Kamel Haddadi, Douglas C. Wallace, Peter J. Burke
Acknowledged Federal Support: **Y**

DISSERTATIONS:

Publication Type: Thesis or Dissertation
Institution:
Date Received: 30-Aug-2012 Completion Date:
Title: ON-CHIP MITOCHONDRIAL ASSAY MICROFLUIDIC DEVICES AND PROTEIN NANOPORE/NANOTUBE HYBRID TRANSISTOR
Authors:
Acknowledged Federal Support:

Publication Type: Thesis or Dissertation
Institution:
Date Received: 30-Aug-2012 Completion Date:
Title: Carbon-Based Transistors and Nanoelectronic Devices
Authors:
Acknowledged Federal Support:

Publication Type: Thesis or Dissertation
Institution:
Date Received: 23-Aug-2013 Completion Date:
Title: IMMOBILIZATION of MITOCHONDRIA on GRAPHENE
Authors:
Acknowledged Federal Support:

Publication Type: Thesis or Dissertation
Institution:
Date Received: 30-Aug-2013 Completion Date:
Title: Bull's-Eye Structure with a Sub-Wavelength Circular Aperture
Authors:
Acknowledged Federal Support:

RPPR Final Report
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Publication Type: Thesis or Dissertation
Institution:
Date Received: 28-Aug-2014 Completion Date:
Title: Limit of Detection of Silicon BioFETs
Authors:
Acknowledged Federal Support:

Publication Type: Thesis or Dissertation
Institution:
Date Received: 31-Aug-2015 Completion Date:
Title: Graphene Based Transistors and Supported Lipid Bilayer
Authors:
Acknowledged Federal Support:

Publication Type: Thesis or Dissertation
Institution:
Date Received: 01-Sep-2015 Completion Date:
Title: Surface Plasmon Based Engineering of Semiconductor Nanowire Optics
Authors:
Acknowledged Federal Support:

Publication Type: Thesis or Dissertation
Institution:
Date Received: 01-Sep-2015 Completion Date:
Title: Graphene-based Nanostructures and DNA-based Biomolecule Sensors
Authors:
Acknowledged Federal Support:

Publication Type: Thesis or Dissertation
Institution: Yale University
Date Received: 19-Oct-2017 Completion Date: 9/1/17 10:56PM
Title: Direct and indirect sensing of biological interactions using pH-sensitive silicon nanoscale field effect transistors
Authors: Luye Mu
Acknowledged Federal Support: **N**

The final technical progress report will be submitted under separate cover as a compilation of published peer-reviewed journal articles summarizing key findings of this project as per verbal agreement with the program manager.

The major goals and accomplishments are summarized in the annual progress reports that have been submitted during the course of this grant, and are explicitly included in this report.