NC1194 2016 Annual Report

Project No. and Title: NC1194 Nanotechnology and Biosensors

Period Covered: 10-2015 to 05-2016

Date of Report: 06/05/2016

Annual Meeting Dates: 04/07/2016

Summary of annual meeting

The NC1194 committee held its annual meeting on April 8th, 2016 at Greenville, SC, in conjunction with IBE 2016. The annual meeting as organized as a technical session with 13 oral presentations given by committee members as part of their annual station progress report (a list of the presentations are attached as appendix to this report), and a business meeting attended by the following committee members:

Chenxu Yu (ISU) Sundaram Gunasekaran (UW-Madison), Vance Bralts (Purdue), Tzuen-Rong Jeremy Tzeng (Clemson), Eric McLamore (UFL), Evangelyn Alocilja (MSU), Daniel Jenkins (Hawaii), Jeong-Yeol Yoon (Arizona), Jenna Rickus (Purdue), Anhong Zhou (USU), Mei He (K-State), Jonathan Claussen (ISU), Carmen Gomes (TAMU).

The meeting approved minutes from 2015 annual meeting, and elected new leadership for the next term. Gunasekaran is elected chair, Rickus vice-chair and Tzeng secretary for the 2016-2017 term. It is also being proposed that possibility of holding our 2017 meeting in Europe to promote discussion and collaboration with our European colleagues shall be explored. Gunasekaran and Alocilja are charged with the duty to look into potential venues and report back to the committee.

The committee discussed potential collaborative research to pursue high-impact work that can make a difference in food and environmental safety and security. Especially we would like to develop technologies that can be utilized to help address needs arisen from water crisis such as what happened in Flint. The committee recognize needs to fill gaps that current exist between research and realization/commercialization efforts, it is proposed that workshops should be organized to bring academic and industry together to identify what are the main obstacles that commercialization efforts are facing, and how can we seek helps from government agencies such as NIFA to overcome such obstacles, so that the research that the committee members are conducting can become truly beneficial and impactful to the general public. It is mentioned that part of the reasons why we want to hold our next annual meeting in Europe is to learn from our European colleagues how they pursue academic-industry dynamic.

The committee also discussed at length how to improve our teaching through a synergistic effort to benefit our students. It is proposed that a course-material sharing mechanism being implemented, firstly through file-sharing on dropbox, then a website to be developed that is dedicated to sharing teaching materials. McLamore will lead this effort.

The committee also discussed the open-bioinstrumentation potentiostat approach to facilitate student learning. Jenkins are developing a general purpose data acquisition and control system which he expects to be fully functional for Fall 2016 term. The potentiostat will be supported by an interface through an

Android app over Bluetooth to make it super flexible for graphical data presentation, manipulation and sharing. All committee members will be able to utilize this approach in our lab courses to enrich student learning, and to encourage team-work and networking between students from different institutions. This would be a priority item on the committee's action list to be implemented in 2017.

List 1: Technical presentations of NC1194 2016 annual meeting

II. NC-1194: Nanotechnology and Biosensors I: Zinfandel Room Chair: Dr. Chenxu Yu, Iowa State University

9:45 am An ultra-selective single base mismatch DNA biosensor on configurable chip device for detection of human genotype of Cryptosporidium DNA

Hoda Ilkhani, Han Zhang, Anhong Zhou, Utah State University

10:00 am Bio-Inspired Patterned networkS (BIPS) for development of wearable biosensors

E.S. McLamore, Agricultural and Biological Engineering, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL, USA; M. Convertino, HumNat Lab, Division of Environmental Health Sciences & PH Informatics Program, School of Public Health, Institute on the Environment, Institute for Engineering in Medicine, Biomedical Informatics and Computational Biology Program, University of Minnesota, Twin-Cities, MN, USA; J.C. Claussen, Department of Mechanical Engineering, Iowa State University, USA; D.C. Vanegas, Food Engineering Department, Universidad del Valle, Cali, Colombia

10:15 am Colorimetric and Electrochemical Sensing of Iron (III) Using Nile Red-Functionalized Graphene Film

Omer Sadak, Ashok Sundramoorthy, Sundaram Gunasekaran, University of Wisconsin-Madison

10:45 am DOTS qPCR: a handheld, rapid molecular diagnostic tool for Ebola

Ariana M. Nicolini, Dustin K. Harshman, Tyler D. Toth; M. Alejandra Mandel, David W. Galbraith, Jeong-Yeol Yoon, University of Arizona

11:00 am Integration of Engineered Biomolecules and Nanoparticles into Photopolymer Systems to Create Novel Optrodes and Optrode Arrays for Cell Physiology

Leyla Kahyaoglu, Agricultural and Biological Engineering, Purdue University; Jenna Rickus, Agricultural and Biological Engineering, Biomedical Engineering, Physiological Sensing Facility at the Bindley Bioscience Center and the Birck Nanotechnology Center

11:15 am Nano-phytotein: phytochemical-protein nanoparticles for bioavailability Shin Sik Choi, Md. Abdur Razzak, Kyung Mi Lee, Ha Eun Kim, Department of Energy Science and Technology, Department of Food and Nutrition, Myongji University, South Korea

4:30 pm Portable biosensors for in-field detection of pathogenic bacteria in foods and mycotoxins in grains

Yanbin Li, Zhuo Zhao, Zach Callaway, University of Arkansas; Lizhou Xu, Zhan Lu, Jianping Wang, Zunzhong Ye, Zhejiang University

4:45 pm Progress in Portable DNA Purification from Bulk Suspensions

Lena Diaz, Daniel M. Jenkins, Ryo Kubota, University of Hawaii

5:00 pm Raman spectroscopy in the detection of ionizing radiation damage in whole blood

Shaowei Ding, Chenxu Yu, Iowa State University; Vinita Chauhan, Barbara C. Kutzner, Ruth C. Wilkins, Consumer and Clinical Radiation Protection Bureau, Health Canada

5:15 pm Smartphone-based, sensitive uPAD detection of urinary tract infection and gonorrhea

Soohee Cho, Tu San Park, Tigran G. Nahapetian, Jeong-Yeol Yoon, University of Arizona

5:30 pm Synthesis and Verification of Multifunctional Antimicrobial Glyco-Amino Acid Compounds Against Bacterial Pathogen

Evangelyn C. Alocilja, Leann Lerie Matta, Kasey Pryg, John Shinners, Nathan Murray, Michigan State University

5:45 pm Multifunctional Biomimetic Receptors for Cell Binding and Concentration

Evangelyn Alocilja, Leann Matta, Mercy Quilantang, Kasey Pryg, Najwa Taylor, Octavio Almeida, Breno Pinheiro, Michigan State University

Accomplishments

This is a progress report for the period October 1, 2015-May 31, 2016 by participating institutions from various states. As a reminder, the objectives of this project are: 1. Develop new technologies for characterizing fundamental nanoscale processes 2. Construct and characterize self-assembled nanostructures 3. Develop devices and systems incorporating microfabrication and nanotechnology 4. Develop a framework for economic, environmental and health risk assessment for nanotechnologies applied to food, agriculture and biological systems 5. Produce education and outreach materials on nanofabrication, sensing, systems integration and application risk assessment. Progress reports are presented by state at the annual meeting. The findings have been disseminated to the scientific community via seminars, national/international conferences, manuscripts, and web sites.

Arizona (University of Arizona) Accomplishments from the University of Arizona were presented at the meeting by Dr. Jeong-Yeol Yoon (list 1). For details, please refer to http://biosensors.abe.arizona.edu/index.html. A written report is presented below.

NC-1194 Annual Report (CY 2015): Jeong-Yeol Yoon, University of Arizona

Issue:

- There is a growing need to develop a handheld, smartphone-based biosensor that can detect the type and concentration of pathogens from myriads of food (fresh produce and meat) and water (waste and irrigation) samples, as well as urine, blood, and tissue samples from animal and human subjects. These biosensors must be designed and manufactured to be easy-to-use, all-in-one, and extremely sensitive (down to single cell level or picogram protein level).

What has been done?:

- We designed, fabricated, and tested a revolutionary biosensor that detect the presence of nucleic acid from complicated tissue samples in less than 5 min, referred to as DOTS qPCR. This work has been highlighted in numerous news magazines and websites. The device has been demonstrated to detect the presence and concentration of antibiotic resistant bacteria from pig heart valve tissue and human whole blood.

- We designed, fabricated, and tested a paper-based strip coupled with a smartphone-based sensor that detect the presence of pathogens from wastewater, food, urine, and blood, with extreme sensitivity (single cell level or picogram proteins) and assay speed (1-2 min).

Impact:

- Economics: The DOTS qPCR device can further be tested to detect virtually any types of samples, including fresh produce, ground beef, wastewater, irrigation water, urine, whole blood, tissue biopsy, etc. Currently, the device is further being tested to detect Ebola and influenza A from human whole blood and mosquito samples.

- Economics: Our paper-based strip with a smartphone-based sensor can be used by general public, not just the healthcare or environmental professionals, due to its small size, ease-of-use, and rapid assay time.

- Community and Environment: Both devices can significantly save the cost, time, and effort necessary to conduct conventional assays, such as cell culture and PCR (polymerase chain reaction). In addition, both devices can be used in field, greatly reducing the sample-to-answer time from a couple of days to less than 10 min, protecting the general public from potential health risks from food and environment.

Output:

Journal papers

- Dustin K. Harshman, Brianna M. Rao, Jean E. McClain, George S. Watts and Jeong-Yeol Yoon, "Innovative qPCR Using Interfacial Effects to Enable Low Threshold Cycle Detection and Inhibition Relief," Science Advances, 2015, 1(8): e1400061.

- Soohee Cho, Tu San Park, Tigran G. Nahapetian and Jeong-Yeol Yoon, "Smartphone-Based, Sensitive µPAD Detection of Urinary Tract Infection and Gonorrhea," Biosensors and Bioelectronics, 2015, 74: 601-611.

- Scott V. Angus, Soohee Cho, Dustin K. Harshman, Jae-Young Song and Jeong-Yeol Yoon, "A Portable, Shock-Proof, Surface-Heated Droplet PCR System for Escherichia coli Detection," Biosensors and Bioelectronics, 2015, 74: 360-368.

- Christopher F. Fronczek and Jeong-Yeol Yoon, "Biosensors for Monitoring Airborne Pathogens," JALA - Journal of Laboratory Automation, 2015, 20(4): 309-410.

- Pei-Shih Liang, Ariana M. Nicolini, Kimberly L. Ogden and Jeong-Yeol Yoon, "Use of Biosensors in Secondary Education Classrooms," Transactions of the ASABE, 2015, 58(2): 181-190.

- Ariana M. Nicolini, Christopher F. Fronczek and Jeong-Yeol Yoon, "Droplet-Based Immunoassay on a 'Sticky' Nanofibrous Surface for Multiplexed and Double Detection of Bacteria Using Smartphones," Biosensors and Bioelectronics, 2015, 67: 560-569.

- Tu San Park and Jeong-Yeol Yoon, "Smartphone Detection of Escherichia coli from Field Water Samples on Paper Microfluidics," IEEE Sensors Journal, 2015, 15(3): 1902-1907.

Conference abstracts and proceedings:

- Jeong-Yeol Yoon, "Smartphone biosensors and organ-on-a-chip," 2014 KSBB Fall Meeting and International Symposium, October 5-7, 2014, Changwon, South Korea.

- Jeong-Yeol Yoon, "Mobile paper-based water quality monitoring via smartphones," ASABE Annual International Meeting, New Orleans, LA, July 26-29, 2015.

- Jeong-Yeol Yoon, "Innovative qPCR using interfacial effects to enable low threshold cycle detection and inhibition relief," ASABE Annual International Meeting, New Orleans, LA, July 26-29, 2015.

- Jeong-Yeol Yoon, "Smartphone biosensors and organ-on-a-chip," In In Vitro Cellular & Developmental Biology, Tucson, AZ, May 30 - June 3, 2015, 51: S6–S7.

- Jeong-Yeol Yoon, "IBE today: a platform for the future - niche areas for IBE," Annual Meeting of IBE, St. Louis, MO, March 5-7, 2015.

- Jeong-Yeol Yoon, "Biosensors for monitoring airborne pathogens," Annual Meeting of IBE, St. Louis, MO, March 5-7, 2015.

- Dustin K. Harshman, Brianna M. Rao, Jean E. McLain, George S. Watts and Jeong-Yeol Yoon, "Interfacial effects revolutionize qPCR by low threshold cycle detection and inhibition relief," Annual Meeting of IBE, St. Louis, MO, March 5-7, 2015.

- Ariana M. Nicolini, Soohee Cho and Jeong-Yeol Yoon, "Pro-adhesive extracellular matrix mimic for use on organ-on-a-chip," Annual Meeting of IBE, St. Louis, MO, March 5-7, 2015.

- Katherine E. McCracken, Scott V. Angus, Tu San Park, Kelley A. Reynolds and Jeong-Yeol Yoon, "Smartphone for water quality," Annual Meeting of IBE, St. Louis, MO, March 5-7, 2015.

Arkansas (University of Arkansas) Accomplishments were presented by Dr. Yanbin Li. A portable biosensors developed has been tested for onsite pathogen detection in various food markets and agricultural product retail stores in China. Its potential application as rapid first screen device to address food safety concerns has been demonstrated. Further work is proposed to address remaining weaknesses.

Florida (University of Florida) Output. Accomplishments from University of Florida were presented by Dr. Eric McLamore. They studied the bio-inspired patterned networks which can be utilized to generate wearable biosensors, which can see wide range of applications in environmental, food safety and health surveillance.

Indiana (Purdue University) Output. Accomplishments from Purdue University were resented at the meeting by Dr. Jenna Rickus (list 1). In the reporting year, principal investigators at Purdue University made advances in the area of nanotechnology and biosensors. These advances include novel and

improved technologies for both intracellular and extracellular measurements of dynamic biomolecule events within cells, with integrated biomolecules and nanoparticles serving as novel optrodes and optrode arrays. These physiological sensing technologies have a wide range of applications and impact in areas including environmental toxicology and monitoring, metabolic disease including diabetes, cancer, water monitoring and regeneration, and food.

Iowa (Iowa State University) Accomplishments from Iowa State University were presented at the meeting by Dr. Chenxu Yu (Table 1). For details, please refer to http://www.abe.iastate.edu/abe-department/directory/chenxu-yu/. The activities during this period included: (1) further development of Raman sensing scheme for the determination of irradiation exposure to cancer patients going through irradiative treatments. (2) evaluation of bioimaging potentials of fluorescent nanoparticles presented in commercial beverages (3) The development of nanovaccines. These findings were presented in several peer reviewed conferences and three journal articles. Impact. The spectroscopic sensing techniques developed in this project have the potential to meet the needs in various disciplines for high-accuracy target sensing, including early diagnosis of diseases (i.e., glaucoma), and rapid screening for foodborne pathogens. The nanovaccines would improve effectiveness of various vaccines against human and animal diseases.

Publications:

Kulchaiyawat C., C. Wang, C. Yu and T. Wang, Combination of Treatment to Improve Thermal Stability of Egg Albumen. LWT-Food Science and Technology 72, 267-276, 2016

Qi, H., Dong, X. Zhao, Y., Li, N., Fu, H., Feng, D., Liu, L., and C. Yu, ROS production in homogenate from the body wall of sea cucumber Stichopus japonicas under UVA irradiation: ESR spin-trapping study, Food chemistry, 192, 358-362, 2016

Liao, H., Jiang, C., Liu, W., Vera, J. M., Seni, O. D., Demera, K., C. Yu, and M. Tan, Fluorescent Nanoparticles from Several Commercial Beverages: Their Properties and Potential Application for Bioimaging, Journal of Agricultural and Food Chemistry, 63(38), 8527-8533, 2015

Yang, J., M. Yi, J. Pan, J. Zhao, L. Sun, X. Lin, Y. Cao, L. Huang, B. Zhu and C. Yu,Sea urchin (Strongylocentrotus intermedius) polysaccharide enhanced BMP-2 induced osteogenic differentiation and its structural analysis, Journal of Functional Foods, 14, 519-528, 2015

Ikoba, U., H. Peng, H. Li, C. Miller, C. Yu, Q. Wang, Nanocarriers in Therapy of Infectious and Inflammatory Diseases. Nanoscale, DOI: 10.1039/C4NR07682F.

Hawaii (University Hawaii) Accomplishments from the University Hawaii were presented at the meeting by Dr. Daniel Jenkins (list 1). Research for the project has focused on the development of technologies enabling rapid gene-based agricultural diagnostics directly in the field. A system to rapidly purify DNA from bulk suspension is being developed to meet needs in this field. Its success can have major impact on real-time, onsite detection of pathogens in food and agricultural products.

Michigan (Michigan State University) Michigan (Michigan State University) Accomplishments from Michigan State University were presented at the meeting by Dr. Evangelyn Alocilja (List 1). For details, please refer to http://www.egr.msu.edu/~alocilja/. Output. Research accomplishments at Michigan

State University include the development of nanoparticle-based biosensors for TB testing with low cost and easy-to-use and easy-to-store reagents that are suitable for deployment in developing countries where access to reliable refrigeration may be a limiting factor for biosensor applications.

Missouri (University of Missouri) output. A written report from University of Missouri prepared by Dr. MengShi Lin is presented below:

During the reporting period, we studied the consumer and food products sold on the market that contain various engineered nanomaterials (ENMs) such as silver nanoparticles (AgNPs) and gold nanoparticles (AuNPs). These nanomaterials possess novel physical and chemical properties that can be used for wide applications in agriculture and food safety. However, current analytical methods to detect and measure ENMs are time-consuming, labor-intensive, and expensive. Therefore, the objective of this study was to develop a novel, simple, rapid, and accurate method to detect AgNPs and AuNPs in consumer products using surface-enhanced Raman spectroscopy (SERS) coupled with an effective Raman indicator aminothiophenol (p-ATP). SERS measurement was conducted to detect AgNPs and AuNPs using p-ATP as an indicator. The pATP can strongly bind onto nanoparticles, generating enhance Raman signals that can be used for measurement. In this study, the p-ATP was combined with Ag/Au stock solution, AgNO3, AgNPs-citrate coating, AuNPs-citrate coating, AuCl, AgNPs, AuNPs, and five commercial products: Silver Throat Spray, Silver Dietary Supplement, Rejuvenating A Therapy Serum, Instant Wrinkle Filling Capsules, and Colloidal Gold Natural Supplement to study the differences in SERS spectral data. The observed spectra of AgNPs and AuNPs have similar peaks at ~390, ~1087, and ~1590 cm-1 that can be attributed to the C-S stretching vibration, C-C stretching vibration, and C-H stretching vibration, respectively. Partial least squares method was used to develop quantitative models for the analysis of spectral data. The results demonstrate that SERS measurement can be an effective method for detection of ENMs, and it can easily distinguish AgNPs and AuNPs from other non-nanoparticle species in the complex matrices.

Utah (Utah State University) Output. Accomplishments from Utah State University were presented by Dr. Anhong Zhou. They developed ultra-selective single base mismatch DNA biochips for detection of human genotype of Cryptosportidium DNA. The technology can be utilized to further improve food safety monitoring and to address public health concerns.

Wisconsin (University of Wisconsin) Accomplishments from University of Wisconsin were presented by Dr. Sundaram Gunasekaran. Colorimetric and electrochemical sensing methods were developed for the detection of Iron (III) using Nile-red functionalized Graphene have been developed. These methods are highly sensitive and accurate, they can be utilized for rapid environmental monitoring of iron contents.

Work plan for the next year: Research by each investigator at each participating institution will continue. New techniques will be developed for characterizing fundamental nanoscale processes. Self-assembled nanostructures will be designed and characterized. New biosensor devices and systems will be developed and will continue to incorporate microfabrication and nanotechnology. Economic frameworks and environmental and health risk assessments of nanomaterials as applied to food, agriculture and biological systems will become a priority. Expertise in these fields will be recruited to join the committee. And finally, educational and outreach materials on nanofabrication, sensing, systems integration and application risk assessment will be developed, and a web-based file-sharing mechanism to improve teaching and student learning. Also in the coming year we will continue looking

into commercialization of the technologies developed through this project to bring greater impact to serve the society.

Impacts

The technologies developed in this multi-state collaboration are designed to improve food safety, water quality, agricultural production, and health. Handheld biosensor devices utilizing nanomaterials and techniques are the major contributions in this report. Furthermore, transfer of some of the technologies to the private sector has generated jobs and will contribute to the economic progress of the country and respective states.