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RPPR Final Report
as of 17-Dec-2021

Agency Code: 21XD

Proposal Number: 74331MSREP **Agreement Number: W911NF-19-1-0459**
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Report Date: 15-Dec-2021 Date Received: 13-Dec-2021
Final Report for Period Beginning 16-Sep-2019 and Ending 15-Sep-2021
Title: Smart Manufacturing - Photonic Processing of Multifunctional Materials for Defense Applications
Begin Performance Period: 16-Sep-2019 **End Performance Period:** 15-Sep-2021
Report Term: 0-Other

Submitted By: Subramanian Ramakrishnan Email: srama@eng.famu.fsu.edu
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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: **STEM Participants:**

Major Goals: Statement of the Problem: The development of high quality, low cost flexible electronics is critically important to future technologies including monitoring and augmenting human performance, as well as enabling sensors, antennas, and multifunctional components for unmanned aerial vehicle (UAV) systems. The fundamental challenge to realizing robust, flexible electronics is in the development of strain resistant high quality conducting, semiconducting and insulating materials. The material quality is, many times, limited by the fact that typical semiconductor device fabrication processes require temperatures that exceed that of the melting temperature of conformal and flexible substrates, restricting the ability to directly grow the materials onto the flexible substrate of interest. To overcome this, the electronic materials must be synthesized at a lower temperature, transferred from a

semiconductor fabrication compliant substrate to the flexible substrate of interest, or post-processed by various techniques in order to achieve similar material quality and performance. 3D printing combined with transient heating through the use of continuous optical/laser annealing is a comprehensive solution that can overcome this critical barrier to flexible electronics processing. The ability to arrange, strategically place materials (e.g. sensors for damage detection) and to monitor performance of materials is key for DoD applications, and requires customized photonic integration. This will be the first customized lasering application with polymer-extrusion processing in the country and the first comprehensive annealing system at Florida A&M University.
Optical annealing has recently been applied (with 3D printing) to pattern highly conductive, ductile metallic interconnects, springs and free-standing spiral architectures on flexible and rigid substrates. This provides a rapid and "on the fly" one step process of printing and post processing to achieve desired properties. Recent work has also shown the ability of laser sintering to modify the electronic properties of ink-jet-printed graphene oxide to give rise to enhanced electrical conductivity. In this proposal we seek to acquire a printing/vision system coupled with laser annealing capabilities to augment our manufacturing capabilities. With the help of the National Science Foundation (NSF) CREST (centers of research excellence in science and technology) center at FAMU we have initiated key projects on additive manufacturing with DoD's Air Force (AFRL) and Army Research Labs (ARL). Such collaborations have highlighted the need for in-situ vision and laser systems to develop the next generation of electronic structures. We will work closely with AFRL and ARL in developing the lasering system and to couple it with our printing efforts.
It is our aim to take advantage of a customized Lasering nScrypt printer system to fabricate functional materials of interest to the DoD – in the area of flexible electronics. For example, we want to print controller circuits inside a tube that can be used by army and air force – the proposed system will help us do that. We will be able to pick and place materials, print on flexible and curved substrates and fabricate circuits with real time feedback control.
Education of Undergraduate and Graduate Students: It is our aim at FAMU to strategically improve the minority student numbers – both at undergraduate (UG) and graduate (G) level. In this aspect we have initiated a number of efforts and the proposed projects will play a key role in these efforts to support our basic scientific research efforts.

Accomplishments: 1)The equipment was successfully installed and training was provided to key personnel in the grant. Safety was key and all efforts and precautions are in place for proper functioning of the instrument.

The final installation was completed in spring 202

2) We have initiated a number of projects as mentioned in the proposal. In addition – we have been highly successful in a number of proposals by leveraging this instrument and what it can do. These are listed below. A big thanks to DOD for making this happen

1. Siegrist, T., Ramakrishnan, S., & Dickens, T. (Jun 2021–May 2022). Acquisition of a Dielectric Permittivity Measurement Systems up to 50GHz. Funded by DOD. Total award $207,323.
2. Arnett, Natalie (PI), Ramakrishnan, S., Siegrist, T., & Okoli, O. (Jun 2021–Jun 2024). Excellence in Research: MXene Hybrid Materials for Composite Application. Funded by NSF. Total award $700,000.
3. Ramakrishnan, S. (May 2021–Jul 2021). Structure Dynamics and Rheology of Preceramic Polymer Hairy Nanoparticles. Funded by DOD - AFRL. Total award $19,000. (Summer faculty fellowship program.)
4. Arnett, Natalie (PI), Sweat, Rebekah (PI), & Ramakrishnan, S. (Jan 2021–Dec 2021). Additive Manufacturing of Multimaterial Composites. Funded by NSF. Total award $100,000.
5. Ramakrishnan, Subramanian (PI), Dickens, T., & Siegrist, T. (Sep 2020–Aug 2023). Towards Light-Weight Composites for Defense Applications: Engineering Structure Dynamics and Rheological Properties of Functional Inks. Funded by DOD. Total award $659,858.
6. Arnett, Natalie (PI), Ramakrishnan, S., & Dickens, T. (Sep 2020–Jan 2021). NASA MUREP-NSF INCLUDES Fueling Opportunities for Successful Engineering Retention of Non-Traditional STEM (FOSTER-NTS) Majors into PhD Programs at the FAMU-FSU College of Engineering. Funded by NASA. Total award $50,000.
7. Ramakrishnan, S., Dickens, T., Siegrist, T., Ali, J., & Arnett, N. (Sep 2020–Jan 2021). Integrative Space Additive Manufacturing (In-Space AM): Opportunities for Workforce-development in NASA Related Materials Research and Education. Funded by NASA. Total award $40,000.
8. Okoli, Okenwa (PI), Dickens, T., & Ramakrishnan, S. (9/2021 – 8/2025). Integrated Additive Manufacturing – Establishing Minority Pathways: Opportunities for Workforce-development in Energy Research and Education (IAM-EMPOWEREd). DOE.
9. ($4 million).

We are excited about this center grant from department of energy – key to this grant was this laser 3D printer.

10. Ramakrishnan, S., Dickens, T., & Liang, Z. (Feb 2021). On-Demand Structural Healthy Monitoring Sensor Manufacturing for NASA Applications. Submitted to NASA. – 100K

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as of 17-Dec-2021

In response to Cooperative Agreement Notice (CAN).
This grant helps us work more closely with NASA and we are in the process of using the printer for manufacturing sensors.
3) Initial Publications
1. S. Jackson, T. Dickens, Rheological and structural characterization of 3D-printable polymer electrolyte inks, Polymer Testing, 2021, https://doi.org/10.1016/j.polymertesting.2021.107377.
There were also a number of grants which have been denied.

In summary – we are making exciting progress on the projects mentioned above and will be happy to report on publications in near future.

Training Opportunities: 3D printing and processing has played a key role in the education of students at FAMU and will continue to do so based on the success of the projects mentioned before. The current equipment is critical to our success and student's education.
1) Roneisha Haney who worked on the project and graduated with a PhD has been hired by Air Force Research Labs as a civilian during summer 2021. This is the first time this has happened at FAMU. A big thanks to the funding from DOD.
2) New graduate student Milan Rede has been recruited for the project starting summer 2021.
3) The project is playing a key role in the career of post doctoral student Dr. Ravi Kollarigowda.
4) Undergraduate Marissa Dickerson has also worked on the project over summer 2021 and is continuing the work as part of her undergraduate research experience. Over summer 2021 we also ran a successful summer Research experience for undergraduates which had 19 students. Marissa was part of the REU. Over coming summers we will utilize the REUS to recruit students to work on projects mentioned above. It should be mentioned here that out of 19 students 16 were minority students and were recruited from other HBCU's.

Results Dissemination: Nothing to Report

Honors and Awards: S. Ramakrishnan was named a 3M distinguished professor in the College of Engineering and at FAMU starting Jan 2021.

Protocol Activity Status:

Technology Transfer: Nothing to Report

Partners

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as of 17-Dec-2021

I certify that the information in the report is complete and accurate:
Signature: Subramanian Ramakrishnan
Signature Date: 12/13/21 6:43AM

Key Accomplishments

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