SAND2013-8767P

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

Project Accomplishment Summary

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories
Operated for the U.S. Department of Energy by
Sandia Corporation
Albuquerque, New Mexico

PROJECT ACCOMPLISHMENTS SUMMARY

Cooperative Research and Development Agreement (#1573.104)

between **Sandia National Labs** and **Lockheed Martin Corporation**

Note: This Project Accomplishments Summary will serve to meet the requirements for a final abstract and final report as specified in Article XI of the CRADA.

Title: Structurally Doped Graphenoid Materials: Characterization and Fabrication

Final Abstract:

The purpose of this work was to establish the feasibility of patterning graphene to induce an electronic band gap, to characterize the material to verify the electronic properties, and to fabricate devices. The main objectives of this work are: (1) pattern graphene material to induce an electronic band gap, (2) characterize the patterned graphene material to verify it's properties, and (3) fabricate electronic devices from the patterned graphene material.

We developed an approach based on nanoimprint lithography to pattern nanometer scale features in single-layer graphene, and demonstrated the approach through structural and optical characterization of the patterned material. Roadblocks in performing nanoimprint lithography on graphene were identified and surmounted with new process developments. An approach for fabricating complete electronic devices was also implemented. These accomplishments establish nanoimprint lithography as an important wafer-scale approach for patterning of graphene. These results are important for DOE and LM applications in electronics and optoelectronics that could harness the properties of graphene.

Background:

Sandia and Lockheed-Martin partnered on this project because LM had the graphene material and Sandia had unique nanopatterning and electronic and optoelectronic testing capabilities. At the start of this project, there were no reports in the literature on the patterning of graphene with nanoimpring lithography, so this was a perfect area for the Sandia/LM CRADA. In addition, other approached for nanopatterning of graphene were not wafer scale, and have low throughput.

Description:

The purpose of this project was to pattern graphene using nanoimpring lithography and test the electronic properties. Material was provided by LM, and Sandia also acquired additional material from commercial sources for comparison. Conventional nanoimprint lithography was tried on the different graphene material, and while it was found to be somewhat successful, issues with the conventional process lead to low yield. Sandia developed a new process that solved these issues and lead to the demonstration of the patterning though structural and optical characterization. Following this demonstration, Sandia and LM agreed on a path to fabricate electronic devices. Procedures were developed to fabricate isolated graphene material on the wafer, pattern the material, and deposit electrical contacts. This lead to the fabrication of a wafer containing several complete devices.

Benefits to the Department of Energy:

Improved electronic and optoelectronic devices can impact several DOE missions. Nanomaterials such as graphene are promising for such applications, but learning how to fabricate and test such devices is an

important step. This project has demonstrated the ability to fabricate such nanodevices, and this capability will be useful for the future exploration of nanomaterials for DOE needs.

Economic Impact:

This project established a new approach for patterning of graphene devices which could be important for industry as a wafer-scale approach. Another impact is that two postdoctoral fellows were trained in nanomaterials characterization techniques, and they will be positioned to contribute to the US economy in the future with this new skill set.

Project Status:

Completed

ADDITIONAL INFORMATION

Laboratory/Department of Energy Facility Point of Contact for Information on Project

François Léonard
Sandia National Laboratories
MS9161
Livermore, CA 94551
925-294-3511
fleonar@sandia.gov

Company Size and Points of Contact

Peter V. Bedworth
Lockheed-Martin pace Systems
Palo Alto, CA
Advanced Technology Center
Org. ABBS, Bldg. 204
3251 Hanover St.
Palo Alto, CA 94304-1191
650-424-2554
peter.v.bedworth@lmco.com

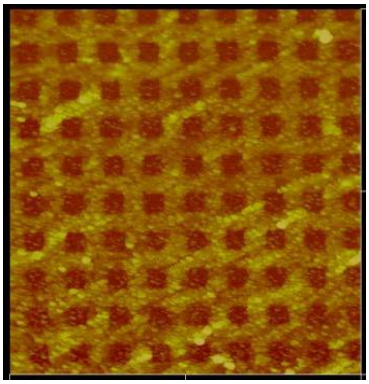
CRADA Intellectual Property

N/A

Technology Commercialization

No plans for commercialization

Project Examples



Atomic Force Microscope image of a patterned graphene. The dark red areas show the substrate where the graphene has been removed. Image size: 5x5 microns.

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This summary has been approved for public release by Sandia and Lockheed Martin Corporation

Sandia National Laboratories

By _____ 6/27/13
Francois Leonard Date
Principal Investigator

Sandia National Laboratories

By _____ 6·17·13
Manager Date
WFO/CRADA Agreements

Lockheed Martin Corporation

By _____ _____
Title: Date

In order to expedite the process, if we do not receive your signed reply by 08/17/2013 we will assume your concurrence for the release of this document to the public.