Novel Memory Devices Based on Silicon Nanocrystal Pyramid-Dot Complexes

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ABSTRACT:

The process of the design and manufacture of hi-tech products currently involves a global effort and multinational teams. In this environment, US engineering students should be proficient in the technical subjects, technological trends and business practices that are exist in different countries and cultures.

In this research project, which is focused on fabrication and studies of novel nanostructures based on highly organized arrays of size and shape controlled silicon nanocrystals in the form of pyramid-dot complexes and strained Si nanolayers, the PI uses the existing ties to the University of Tokyo and provides a meaningful international experience for NJIT undergraduate students. Series of samples are prepared by NJIT students using our Japanese collaborator unique nano-fabrication facilities. The same group of students are performing in-depth studies of the sample properties and fabricating memory device prototypes in Newark, NJ. Our industrial collaborators are in the process of evaluation of these novel memory device prototypes.

INTRODUCTION

- *Name of awardee institution for current NSF award*
  New Jersey Institute of Technology

- *A bief smmary of work being carried out under crrent NSF Award*

The research project is focused on fabrication and studies of novel nanostructures based on highly organized arrays of size and shape controlled silicon nanocrystals (NCs). These three-dimensional nanostructures are prepared in the form of (i) pyramid-dot complexes and (ii) strained Si nano-layers (NLs) and proposed to be used in new memory devices utilizing resonant carrier injection via discrete energy levels of nanometer diameter Si quantum dots.

- *Reasons/Rationale for International Cooperation Carried Out Under IREE*

A new class of nanostructures with vertically and laterally organized Si nanocrystals is proposed to develop using collaboration with the University of Tokyo and the PI group at NJIT. This work utilizes a Focused Ion Beam (FIB) apparatus to pattern a Si substrate and create heavily B-doped wells with average dimensions of ~ 20 nm as well as molecular beam epitaxy (MBE) based growth.

- *Provide an explanation of how the researcher was selected and why he/she was the best qualified candidate*

Mr. Darren Coppola, an NJIT student and US citizen is selected based on his outstanding academic performance and deep interests in nanotechnology.

- *Anticipated research and education outcomes*

A phenomenon known as self-organization in lattice mismatched strained thin-film heteroepitaxy is known to induce surface reconstruction and the formation of ordered cluster arrays with a high degree of uniformity. So far, this mechanism is believed to be restricted solely to pure epitaxial crystal growth. The proposed attempt to form built-in strain in a multilayer system comprised of Si nanocrystals separated by nanometer-thick layers of amorphous silicon dioxide is completely novel. If we will be able to show that the strain indeed propagates throughout these layered structures and can be used to induce a specific shape, crystallographic orientation and vertical ordering in Si nanocrystals, then a new avenue toward better controlled self-organized nanostructures will be developed.

As a part of preparation for the trip and research assignment, Mr. Coppola successfully completed his theoretical and practical training under direct supervision of the PI.

- *Information about host and host laboratory*

Professor Masakazu Ichikawa is currently Director of Quantum-Phase Electronics Center at the Department of Applied Physics of the University of Tokyo School of Engineering. His research is focused on group four semiconductors such as Si and Ge that are crucial materials for electronic devices. His major research objective is the formation of ultrahigh density Si and SiGe-based nanodots, their superlattice, and their artificial structures. He is also working on the development of optical measurements of individual nano-objects. The Center and Prof. Ichikawa's Laboratory are equipped by FIB, HR TEM and other fabrication and characterization systems that will be used in this project.

- *Name of travelers*

Leonid Tsybeskov (PI) and Darren Coppola (student)

- *Dates of tavel*

May 2008 (Tsybeskov) and June-September 2008 (Coppola)

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

- *Program of research carried out during international research experience*

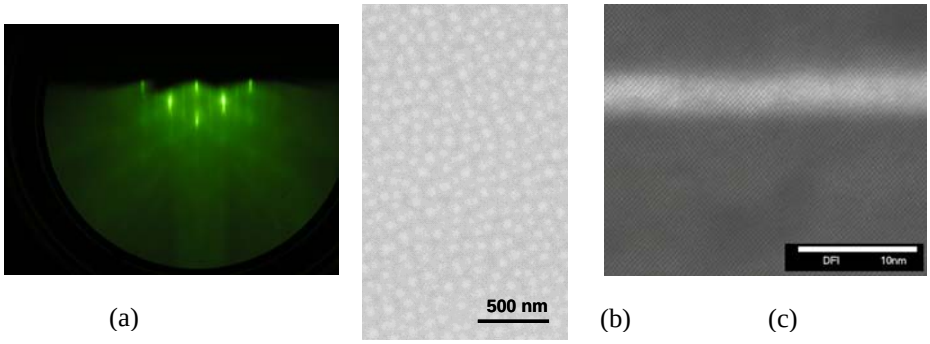
Series of new samples were grown using direct patterning and the MBE fabrication technique at the University of Tokyo by NJIT student Darren Coppola.

- *How the work on-site is related to the work of the current NSF award?*

This work is extended the original approach previously limited to low-pressure chemical vapor deposition growth proposed by the PI.

- *A description of the general interaction between researcher and host laboratory during the international research experience*

Samples were grown by the NJIT visitor using the host laboratory equipment. In Japan, Mr. Coppola received extended training in MBE-growth and nanoscale characterization. The sample optical properties were studied in Newark, NJ and recommendations were provided for their optimization. Reflection high-energy electron diffraction (RHEED) technique, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were used to characterize the grown nanostructures (Fig. 1).



(a) (b) (c)

Figure 1. (a) RHEED pattern, (b) top SEM view and (c) TEM cross-sectional picture of samples grown in Tokyo.

BROADER IMPACTS OF THE INTERNATIONAL COOPERATION

This research program supports the NJIT's goal of becoming a world-class research and education institution. Direct collaboration with the University of Tokyo (currently ranked number one among top 100 Asia-Pacific universities) opens additional opportunities for NJIT graduate and undergraduate students, and helps them to start a successful global engineering carrier. The proposed by our Japanise collaborators additional series of samples fabricated by molecular beam epitaxy (MBE) have trigerred interesting studies of unusually abrupt interfaces of these nanostructures. Also, this project helps in establishing a long-term collaborative research programs between the PI's group at NJIT and the group of Professor Ichikawa at Tokyo University. Mr. Coppola, who spent 3 months in Japan under the NSF IREE Program, presented a report to NJIT students summarizing his interesting research and cultural experience. In near future, NJIT plans to develop and offer a short-term engineering study abroad program in Japan, in addition to already existing programs in Austria, the Czech Republic, Germany, Hungary, Poland and Slovakia. With its ethnically diverse student body and urban location, NJIT has a unique opportunity to pursue groups historically under-represented in science and engineering. NJIT's track record in attracting, educating and graduating minority students (over 40% in the student population) is a source of distinction and pride.

ACKNOWLEDGEMENTS AND GRANT INFORMATION

We would like to acknowledge support to this project provided by our Japanise collaborator and host, Professor Masakazu Ichikawa at the Tokyo University School of Engineering.

The award number: ECCS-0422039
Award duration: 5 years
Starting date: 07/31/2004
Termination date: 07/31/2009
Due to the Tokyo University schedule, the PI and student trips initial dates were changed, and the project received additional 12 months no-cost extension.
Travel information: PI, Leonid Tsybeskov, May 2008, Tokyo, Japan
Student, Darren Coppola, June-September 2008, Tokyo, Japan

BRIEF BIOGRAPHIES OF RESEARCHERS

Leonid Tsybeskov obtained his Ph.D. in applied physics from Odessa Mechnikov University, USSR in 1986. From 1986 to 1993 he was a Staff Scientist at the Laboratory for Non-crystalline Semiconductors at Odessa Mechnikov University. From 1993 to 2001 he was a Post-doctoral Research Fellow and Visiting Research Professor at the University of Rochester in Rochester, NY. In 1999 he received German Academic Exchange Service (DAAD) Fellowship and was a Visiting Researcher at Technical University of Munich in Munich, Germany. In 2001 he accepted a faculty position at New Jersey Institute of Technology (NJIT) in Newark, NJ. At NJIT Tsybeskov's research has centered on Group IV semiconductor nanostructures. He has made seminal contributions to the development of novel fabrication techniques and understanding of the properties of silicon and silicon/germanium nanostructures and is internationally recognised for his expertise in Group IV nanostructure photonics. Professor Tsybeskov has published more than 120 scientific articles in journals and books and has 2 U.S. patents. He is a Fellow of the American Physical Society.

Darren Coppola received the BSE in Electrical Engineering from New Jersey Institute of Technology in 2008. He currently helds an enginnering position at BAE Systems in Wayne, NJ and works on his MSE degree at NJIT.