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as of 01-Nov-2018

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Proposal Number: 65934MSII

Agreement Number: W911NF-15-1-0477

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Final Report for Period Beginning 01-Sep-2015 and Ending 31-May-2016

Title: Enhancement of Light Trapping and Optical Absorption in Complex ZnO Nanostructures

Begin Performance Period: 01-Sep-2015

End Performance Period: 31-May-2016

Report Term: 0-Other

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STEM Degrees:

STEM Participants:

Major Goals: The major goals of the proposed project is to study and demonstrate the enhanced light trapping and optical absorption in complex ZnO nanostructures with novel geometries and morphologies based on new solution-phase bottom-up nanosynthesis methods, in order to gain fundamental understanding of light trapping and light-matter interactions in complex semiconductor nanostructures and plasmonics enhanced light trapping in metallic particles, and advance Army's capabilities in research areas of highly complex multifunctional materials with unprecedented properties and enhanced light-matter interactions.

The specific objectives of this project include:

(1) Design, fabricate, and characterize complex ZnO nanostructures for the enhancement of light trapping and optical absorption. Complex ZnO nanostructures will be designed and synthesized with new solution-phase structure-orientated nanosynthesis methods. The optical properties of complex ZnO nanostructures for enhanced light trapping and optical absorption will be analyzed. Optical spectra measurements and photoelectrochemical measurements will be conducted to characterize the optical absorption properties of complex ZnO nanostructures.

(2) Investigate plasmonics enhanced light trapping and optical absorption in complex metallic nanostructures. Metallic nanostructures will be studied for potential coupling with complex ZnO nanostructures. Numerical simulations will be performed to understand the plasmonics effects on the light scattering, light trapping and optical absorption in metallic nanostructures and ZnO nanostructures. The plasmonics enhanced optical absorption will be investigated with optical spectra measurements and photoelectrochemical measurements.

Accomplishments: Based on our research activities and progress in theoretical analysis, numerical simulation, sample nanofabrication and optical characterization in ZnO nanostructures and metallic nanostructures, we have focused on 4 major research topics and summarized the research results into 6 high-quality journal publications.

(1) Total nanosyntheses of stepwise ZnO nanobranched microstadiums for omnidirectionally light-trapping photocatalysts

We propose a new structure-oriented total nanosynthesis method and develop alternating heterogeneously selective nucleation, protection, growth, dissolution and regrowth processes in order to fabricate stepwise ZnO nanostructures. We demonstrate a solution-based total nanosynthesis for the stepwise growth of oriented arrays of photocatalytic microdisks, then selective dissolution of the microdisks into microstadiums, and finally the simultaneous grafting of photocatalytic nanocones in an orderly fashion on the microstadiums' inner- and outer-

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incidence. The nonlocal effective permittivity and permeability tensors are analyzed in detail as functions of the wavelength, the angle of incidence, and the multilayer period. Our generalized nonlocal effective medium theory in consideration of both permittivity and permeability can accurately predict the dispersion relation, the transmission and reflection spectra, and the optical field distributions of symmetric metal–dielectric multilayer stacks with either subwavelength or wavelength-scale period of the unit cell. The results are published in Journal of Optics.

In addition, the optical nonlocality near the Dirac point in infinite periodic metal-dielectric multilayer metamaterials is investigated through the dispersion relation analysis according to the transfer-matrix method. It is revealed that both the symmetric and asymmetric surface plasmon polariton modes present the zero nonlocal effective permittivity, and the degeneracy of these two modes results in the emergence of the Dirac point. Furthermore, the Zitterbewegung effect near the Dirac point induced by the optical nonlocality is demonstrated due to the coherent coupling between the symmetric and asymmetric modes. The results are published in Optics Express.

Training Opportunities: The proposed research provides comprehensive training for graduate students and postdocs to learn and develop their expertise in the research area of ZnO semiconductor syntheses, plasmonic nanostructures, optical spectroscopy, and photoelectrochemical photocurrent measurement. One PhD student has been involved in the project, Huixu Deng. Two MS students have been trained in the project, Garrett Torix, and Tyler Chism. Three postdocs have partially participated in the project, Huajun Zhou, Lei Sun, and Fei Cheng. Students and postdocs have learned how to conduct scientific research independently and how to conduct collaborative research work. They have detailed full training in all the aspects of design, sample fabrication and characterization, data analysis and paper writing. Students and postdoc also have opportunities to interact with leading scientists and develop team work skills through collaborations with other institutions, including the University of Arkansas, Argonne National Laboratory and the University of St Andrews.

Results Dissemination: The research results are disseminated broadly through journal publications, invited talks, presentations, and our group websites. There are 5 high-quality journal publications and 1 manuscript to be submitted. All the publications are also posted in the group websites. The PI has given presentations on campus and several invited talks about these research work. Graduate students and postdocs work with collaborators at other universities and national laboratories, including the University of Arkansas, Argonne National Laboratory and the University of St Andrews. The PI continues to integrate a three-hour learning module about optical materials and structures into the thermal radiation part of the undergraduate course “Heat Transfer” (ME 3525) to enhance the curriculum and students have shown great interests to learn more about our research work. The PI has successfully developed a new graduate level course named “Advanced Optical Materials and Structures” at Missouri S&T. There are 9 PhD students enrolled in this course during the Fall 2015 semester. This new course introduces the fundamentals of nanophotonics, plasmonics and metamaterials, and their applications in the areas of metamaterial perfect absorbers and thermal emitters, integrated photonic circuits, optomechanics, optical communications, and optical sensors. The research results from this project have been included in the lectures successfully. The PI has actively participated in “Outreach and Pre-college Programs” at Missouri S&T in the past years, especially the “Summer Research Academy” program to train high school students. During this reporting period, the PIs hosted one high school student, to learn the developed six-week optics short course and project and COMSOL numerical simulation in metamaterials.

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI

Participant: Xiaodong Yang

Person Months Worked: 2.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

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Participant Type: Co-Investigator

Participant: Ryan Tian

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: Huixu Deng

Person Months Worked: 3.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Postdoctoral (scholar, fellow or other postdoctoral position)

Participant: Huajun Zhou

Person Months Worked: 4.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Postdoctoral (scholar, fellow or other postdoctoral position)

Participant: Lei Sun

Person Months Worked: 2.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Postdoctoral (scholar, fellow or other postdoctoral position)

Participant: Fei Cheng

Person Months Worked: 2.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Garrett Torix

Person Months Worked: 3.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

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Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Tyler Chism

Person Months Worked: 3.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Nothing to report in the uploaded pdf (see accomplishments)