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The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

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RPPR Final Report
as of 09-Jul-2018

Agency Code:

Proposal Number: 69150PHII **Agreement Number: W911NF-16-1-0270**

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Report Date: 30-Apr-2017 Date Received: 08-Oct-2017
Final Report for Period Beginning 01-May-2016 and Ending 31-Jan-2017
Title: Nonlinear Topological Surface States in Meta-Crystals
Begin Performance Period: 01-May-2016 **End Performance Period:** 31-Jan-2017
Report Term: 0-Other
Submitted By: Natalia Litchinitser Email: natashal@buffalo.edu
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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 1 **STEM Participants:** 2

Major Goals: This project aimed at developing a set of theoretical and experimental tools for conducting systematic theoretical and experimental studies of topologically protected states enabled by the symmetries and nonlinear material response of the judiciously designed meta-crystals at optical frequencies.

Accomplishments: This STIR project allowed us to develop a set of tools, both analytical and numerical, as well as an experimental setup and fabrication procedures to study various types of topologically protected light propagation. These tools have been applied to design actively reconfigurable photonic topological insulators based on photonic meta-crystal built of optically (nonlinearly), electrically or thermally tunable meta-molecules designed.

Training Opportunities: One postdoctoral researcher and two graduate students (one PhD and one MS) have been trained to conduct research in the emerging field of topological photonics.
The postdoc and the PhD student attended several conferences to learn the state of the art in the field and to discuss their research with the experts in the field.
The MS student defended her MS thesis based on the results obtained in this project.

Results Dissemination: The research resulted from this project was presented at the SPIE Optics and Photonics conference, several invited seminars given by the PI, and internally at the poster competition in the EE department at the University at Buffalo.

Honors and Awards: The poster on the results of this research " High-Efficiency All-Dielectric Metasurfaces for Beam Manipulation in Transmission Mode" presented by Mikhail I. Shalaev won the first place in EE poster competition.

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: Graduate Student (research assistant)
Participant: Mikhail Shalaev
Person Months Worked: 5.00 **Funding Support:**
Project Contribution:

International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Yun Xu
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

CONFERENCE PAPERS:

Publication Type: Conference Paper or Presentation **Publication Status:** 0-Other
Conference Name: SPIE Optics &Photonics
Date Received: 07-Oct-2017 Conference Date: 06-Aug-2017 Date Published: 10-Aug-2017
Conference Location: San Diego, CA
Paper Title: Dynamically tunable topologically protected edge-states in silicon photonic crystals with liquid crystal background
Authors: Mikhail I. Shalaev, Wiktor T. Walasik, Sameerah Desnavi, Natalia M. Litchinitser
Acknowledged Federal Support: **Y**

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: SPIE Optics & Photonics
Date Received: 08-Oct-2017 Conference Date: 28-Aug-2016 Date Published: 01-Sep-2016
Conference Location: San Diego
Paper Title: All-dielectric meta-crystals with topologically protected edge-states
Authors: Mikhail I. Shalaev, Sameerah Desnavi, Wiktor T. Walasik, Natalia M. Litchinitser
Acknowledged Federal Support: **Y**

DISSERTATIONS:

Publication Type: Thesis or Dissertation
Institution: University at Buffalo, SUNY
Date Received: 08-Oct-2017 Completion Date: 5/1/17 7:18AM
Title: RECONFIGURABLE TOPOLOGICAL INSULATORS
Authors: Sameerah, Desnavi
Acknowledged Federal Support: **Y**

RPPR Final Report
as of 09-Jul-2018

FINAL REPORT

Natalia Litchinitser

STIR: Nonlinear Topological Surface States in Meta-Crystals

US Army Research Office Award W911NF1610270

Total Award Amount: $50,000

Report Period Begin Date: 05/01/16, Report Period End Date: 12/31/17

Photonics offer a unique platform for realizing many remarkable topological phenomena at room temperature and without strong magnetic field and, moreover, may bring them to the domain of practical applications, including robust energy transport in compact, integrated photonic devices, all-optical circuity, and optical communication systems. For many of these applications, scattering-free propagation combined with recongurability and the ability to control the propagation of light is essential. Nowadays, the majority of proposed photonic topological insulators operate in a fixed wavelength range and their mode of operation and topological properties cannot be dynamically reconfigured. The realization of actively reconfigurable photonic topological structures remains a grand challenge.

This STIR project allowed us to develop a set of tools, both analytical and numerical, as well as an experimental setup and fabrication procedures to study various types of topologically protected light propagation. These tools have been applied to design actively reconfigurable photonic topological insulators based on photonic meta-crystal built of optically (nonlinearly), electrically or thermally tunable meta-molecules designed. We numerically studied a reconfigurable photonic topological insulator based on photonic crystal design to realize the photonic analogue of the spin-Hall effect. The recongurability is facilitated by immersing the photonic crystal into a nematic liquid crystal background, as shown in Fig. 1. With the help of an external field applied to the liquid crystal, its molecules can be reoriented, causing variation in background refractive index and shifting the spectral position of edge states. However, topological properties of this initial design are set by design, i.e. the topological invariant, the Chern number, determining the number of edge states is fixed.

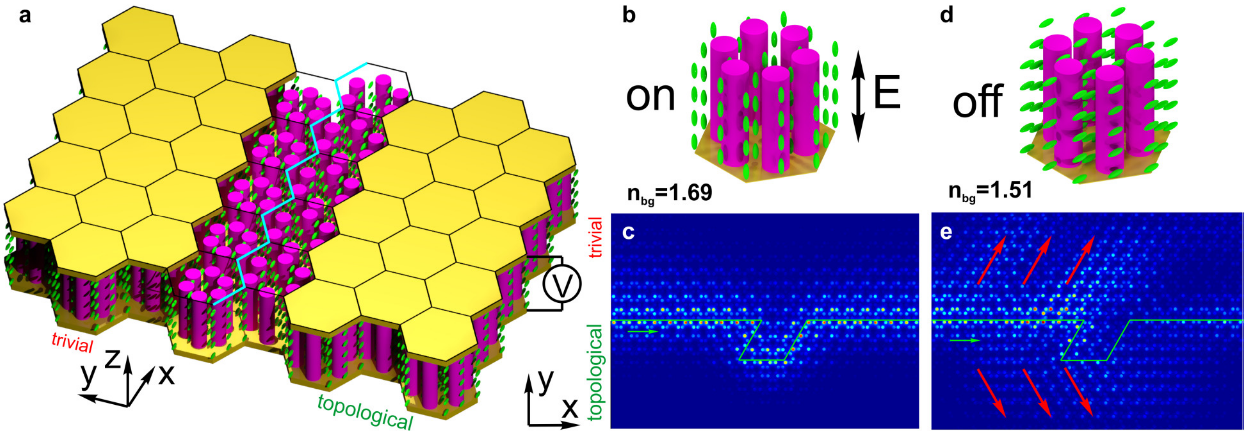

Figure 1. Schematic view of the structure and working principle of the recon_gurable photonic-crystal-based topological insulator. (a) The structure consists of silicon pillars (magenta) surrounded by a liquid crystal molecules (green) enclosed between conducting electrodes (yellow). It can be switched by applying voltage to the electrodes, such that when the voltage is applied, liquid crystal molecules orient along the pillars, resulting in the background refractive index n_{bg} = 1.69 (b) for transverse-magnetic polarization considered here (the corresponding electric field polarized along the pillars is indicated by ↕E). (c) The energy density distribution for the case when switch is ON: light is guided along rhombus-shaped path shown in green. (d) When there is no voltage applied, background refractive index, n_{bg} = 1.51, corresponding to the OFF-state, (e) Power penetrates to the crystal interior (shown in red) resulting in low transmittance along the interface path.

The designed structure supports edge states at the interface between the trivial and topological parts of the crystal. These edge states are topologically protected and robust against structural disorders and imperfections. Their propagation is supported along arbitrarily shaped paths and around defects. The reconfigurability is facilitated by immersing the photonic crystal into a nematic liquid crystal background. With the help of an external field applied to the liquid crystal, its molecules can be reoriented, causing variation in background refractive index and shifting the spectral position of edge states. Further studies are required to determine the magnitude of the field required to enable such reconfigurability as manipulating liquid crystals in such small nanostructures is challenging. Our current research is focused on these studies. We have shown that with rise of background permittivity, edge states exhibit red-shift due to rise in average refractive index of the crystal. The transmission characteristics through the structure can be dynamically tuned by modifying the spectral position of the non-trivial bandgap. Moreover, the topologically protected bandwidth decreases with an increase of the background refractive index because of the reduction in the index contrast between the background and high-index material.

We have defined the conditions that are necessary for supporting topologically protected propagation to be: the presence of non-trivial edge states, along with an absence of bulk state(s) at desired guided frequencies. When these conditions are satisfied, the structure supports topologically protected modes with transmittanceclose to 100%. Shifting the bandgap position results in scattering of light into the crystal interior, and a decrease in the transmittance through the structure. The reconfigurable photonic topological insulator proposed here is silicon based, and supports operation at telecommunication frequencies, making it attractive for practical applications.