資料4－4
科学技術・学術審議会 研究計画・評価分科会
量子科学技術委員会（第10回）
平成29年4月10日

話題提供

岩本　敏
東京大学 生産技術研究所 光電子融合研究センター
e-mail: iwamoto@iis.u-tokyo.ac.jp

トピックス

① Integrated Quantum Photonics

② Topological Photonics (& Structured Light)

NanoQuine QUantum INformation Electronics　CPEC　東京大学 THE UNIVERSITY OF TOKYO

Integrated Quantum Photonics

- ✓ 量子光源、導波路、検出器等からなる量子光回路のon-chip集積化とそのための技術
  →小型高密度化、スケーラビリティ、可搬、堅牢化・・・
- ✓ 国内外で既に幾つかのプロジェクト
  →国内（CREST北山領域）、海外（資料１ほか）
- ✓ topical meetingやspecial issueも企画
  eg) OSA Integrated Semiconductor Quantum Photonic Devices (2017/6/18-20)
  Frontiers 特集号
- ✓ プラットフォーム　（Si、SiON、SiC、ダイアモンド、III-V etc… 原子系、NV、量子ドット)

都合により掲載できません

関連技術のベンチャーも出来つつある

都合により掲載できません

（資料2）

Topological Photonics (& Structured Light)

- ✓ 物質科学(トポロジカル絶縁体)のコンセプトを光技術に展開
  - →トポロジカルに守られた局在状態：導波路や共振器などへの応用
  - →Acoustics, Phononics, Mechanicsにも波及しつつある
- ✓ 海外では盛り上がりを見せている(資料3，4他)。レビュー論文、特集号(J. Opt. 2017).
  - →国内ではほとんど研究が進んでいないのが現状
- ✓ 具体的な応用可能性の議論・実証、作製しやすい構造の探索が課題
- ✓ 物質(トポロジカル絶縁体含む)との相互作用も含めた広い展開の可能性
- ✓ 光渦やベクトルビーム(Structured light)もその一部と捉えてもよいのでは
  - →こちらは国内でも進展(CREST伊藤領域ほか)

＊トポロジー：図形の特徴を抽出しその性質を研究する数学の一分野。ドーナツとボールの例が有名
今の場合は、光モードの“図形”としての性質が対象。その特徴が異なるものはトポロジカルな性質が異なるという

都合により
掲載できません

都合により
掲載できません

“Topological photonics” by L. Lu *et al.*, Nat. Photon. **8**, 821 (2014).
“Topological states in photonic systems”
by Lu *et al.*, Nat. Phys. **12**, 626 (2016).　ほか

Structured Light (トポロジカル光波)

光渦

都合により
掲載できません

L. Marrucci *et al.*, PRL **96**, 163905 (2006).

偏光渦

都合により
掲載できません

尾松、光学 42, 586 (2013)

都合により
掲載できません

K. Toyoda *et al.* Nano Lett. **12**, 3645 (2012).

基礎科学、光加工、
物性探索、通信ほか

資料4－4－1
科学技術・学術審議会　研究計画・評価委員会
量子科学技術委員会(第10回)
平成29年4月10日

Award Abstract #1641099

EFRI ACQUIRE: A Scalable Integrated Quantum Photonic Interconnect

NSF Org:	EFMA Emerging Frontiers & Multidisciplinary Activities
Initial Amendment Date:	August 2, 2016
Latest Amendment Date:	August 2, 2016
Award Number:	1641099
Award Instrument:	Standard Grant
Program Manager:	Dominique M. Dagenais EFMA Emerging Frontiers & Multidisciplinary Activities ENG Directorate For Engineering
Start Date:	September 1, 2016
End Date:	August 31, 2020 (Estimated)
Awarded Amount to Date:	$2,000,000.00
Investigator(s):	Qiang Lin qiang.lin@rochester.edu (Principal Investigator) David Awschalom (Co-Principal Investigator) Jurgen Michel (Co-Principal Investigator) John Howell (Co-Principal Investigator) Philip Feng (Co-Principal Investigator)
Sponsor:	University of Rochester 518 HYLAN, RC BOX 270140 Rochester, NY 14627-0140 (585)275-4031
NSF Program(s):	EFRI RESEARCH PROJECTS
Program Reference Code(s):	8990
Program Element Code(s):	7633

ABSTRACT

Abstract Title: EFRI ACQUIRE: A Scalable Integrated Quantum Photonic Interconnect

Non-Technical Description: Quantum information science employs the fundamental quantum mechanical principles for information processing, which, with the advances in the past decades, has now come to the engineering era of real practical application. A key challenge for practical implementation of distributed quantum network lies in the technical difficulty in realizing multifunctional integrated quantum photonic circuits that are not only able to perform diverse quantum functionalities, but are also able to share and exchange quantum information between disparate and/or physically separated parts of a network system.

The proposed research aims to address this challenge, by exploring and developing integrated hybrid quantum photonic circuits on the silicon carbide (SiC) platform for high-fidelity and energy-efficient quantum information processing, which interface seamlessly with fiber-optic communication links for secure communication and distribution of quantum information. The ultimate goal is to realize a versatile chip-scale multifunctional integrated hybrid quantum photonic processor with robust operation at room temperature that forms the fundamental building blocks to construct a scalable integrated quantum

photonic interconnect.

The proposed research promises a transformative avenue towards integrated quantum photonics that may ultimately transform the complexity and capacity of quantum information processing for secure communication, metrology, sensing, and advanced computing. The proposed research is expected to result in a new class of device technologies with previously inaccessible attributes and merits that may eventually have profound commercial impact on the industrial sectors. The development of SiC photonics may open up a novel avenue for the roadmap of the recently installed American Institute for Manufacturing Integrated Photonics (AIM Photonics). Findings in the fascinating device physics and system integration will generate extraordinary educational materials and inspiration for education of students from K-12 to graduate students. The team PIs have established strong records and sustained creative efforts in broadening the participation from underrepresented and economically disadvantageous groups. The PIs will incorporate the educational efforts with the educational workforce development of the AIM Photonics Academy.

Technical Description: The proposed research aims to explore and develop a fully integrated scalable quantum photonic interconnect that consists of chip-scale integrated silicon carbide (SiC) quantum photonic processors functioning as localized quantum nodes for high-fidelity manipulation, processing, storage, and transduction of quantum states, which interface seamlessly with fiber-optic quantum channels for secure communication and distribution of quantum information between quantum nodes. The proposed research utilizes a design and fabrication methodology that recognizes and leverages the fact that outstanding material properties and unique defect characteristics of SiC, together with innovative device designs and advanced nanofabrication, offer a promising chip-scale platform for broad quantum photonic applications. With the synergetic research effort among a team of world-leading experts, we propose to carry out innovative device/circuit/system engineering to realize strong photon-defect and photon-photon interactions that would enable efficient generation and manipulation of photonic quantum states and scalable quantum bits, and chip-to-chip distribution of quantum information over fiber-optic communication links, aiming to realize a versatile chip-scale multifunctional integrated hybrid quantum photonic processor with robust operation at room temperature that forms the fundamental building blocks to construct a scalable integrated quantum photonic interconnect. The strong expertise and extensive experiences of our team position us uniquely for achieving this goal.

Please report errors in award information by writing to: awardsearch@nsf.gov.

QuILMI

Project ID: 295293
Funded under: FP7-ICT

Quantum Integrated Light Matter Interface

From 2012-10-01 **to** 2016-03-31, closed project | QuILMI Website

Project details

Total cost:	Topic(s):
EUR 1 624 571	ICT-2011.9.3 - FET Young Explorers
EU contribution:	**Call for proposal:**
EUR 1 228 876	FP7-ICT-2011-C See other projects for this call
Coordinated in:	**Funding scheme:**
United Kingdom	CP - Collaborative project (generic)

Objective

This project brings together an interdisciplinary team of young, ambitious and internationally recognized researchers. The aim of the proposed research is to create a highly integrated device, which permits to manipulate, store and control light on a single-photon level using tailored quantum matter. Specifically, we will implement a three-dimensional optical lattice on an atom chip together with sophisticated waveguides for single-photon manipulation and detection, all integrated on the very same chip. Our vision is that this device becomes the centerpiece of novel hybrid light-matter networks, with which quantum information processing can be approached from a highly modularized standpoint. Our objective is to develop a far-reaching theoretical framework for light-matter interaction on an atom chip and to conduct experiments that, for the first time, demonstrate both coherent light-matter coupling and single-photon detection in an integrated device. This proof-of-principle demonstration will push quantum technology and methods beyond the current state-of-the-art. To achieve this ambitious goal we will exploit the combined expertise of our team in theoretical and experimental quantum optics, atomic physics and many-body physics. The proposed project promises high benefit for the European Research Area, as its prospective achievements will advance applications in quantum technology, and strongly enhance the competitive edge of European Research. The envisioned program will promote young researchers from different European countries and will allow them to forge a new international research alliance. This contributes to the exploitation of synergies in the European science scene, thereby building and securing leadership of Europe in ICT research.

Coordinator

THE UNIVERSITY OF NOTTINGHAM

United Kingdom

King's Meadow Campus, Lenton Lane
NG7 2NR Nottingham
United Kingdom

EU contribution: EUR 521 813

Activity type: Higher or Secondary Education Establishments

Administrative contact: Paul Cartledge
Tel.: +44 115 8466757
Fax: +44 115 9513633
E-mail

Participants

UNIVERSITAT WIEN

Austria

UNIVERSITATSRING 1
1010 WIEN
Austria

EU contribution: EUR 422 330

Activity type: Higher or Secondary Education Establishments

Administrative contact: Helmut Schaschl
Tel.: +43 1 4277 182 18
E-mail

FRIEDRICH-SCHILLER-UNIVERSITAT JENA

Germany

FURSTENGRABEN 1
07743 JENA
Germany

EU contribution: EUR 52 200

Activity type: Higher or Secondary Education Establishments

Administrative contact: Alexander Szameit
Tel.: +49 3641 947985
E-mail

MAX PLANCK GESELLSCHAFT ZUR FOERDERUNG DER WISSENSCHAFTEN E.V.

Germany

Hofgartenstrasse 8
80539 MUENCHEN
Germany

EU contribution: EUR 232 533

Activity type: Research Organisations

Administrative contact: Ilona Auguszt
Tel.: +493518711104
Fax: +493518711189
E-mail

Subjects

Information and communication technology applications

Last updated on 2016-09-08
Retrieved on 2017-04-02

Permalink: http://cordis.europa.eu/project/rcn/103707_en.html

資料４－４－２
科学技術・学術審議会 研究計画・評価分科会
量子科学技術委員会（第１０回）
平成２９年４月１０日

都合により掲載できません

資料４－４－３
科学技術・学術審議会　研究計画・評価分科会
量子科学技術委員会（第１０回）
平成２９年４月１０日

都合により掲載できません

Award Abstract #1509546

Collaborative Research: Nonlinear Optics of Photonic Topological Insulators

NSF Org:	ECCS Div Of Electrical, Commun & Cyber Sys
Initial Amendment Date:	July 17, 2015
Latest Amendment Date:	July 17, 2015
Award Number:	1509546
Award Instrument:	Standard Grant
Program Manager:	Dominique M. Dagenais ECCS Div Of Electrical, Commun & Cyber Sys ENG Directorate For Engineering
Start Date:	September 1, 2015
End Date:	August 31, 2018 (Estimated)
Awarded Amount to Date:	$285,000.00
Investigator(s):	Mikael Rechtsman mcr22@psu.edu (Principal Investigator)
Sponsor:	Pennsylvania State Univ University Park 110 Technology Center Building UNIVERSITY PARK, PA 16802-7000 (814)865-1372
NSF Program(s):	ELECT, PHOTONICS, & MAG DEVICE
Program Reference Code(s):	094E
Program Element Code(s):	1517

ABSTRACT

Collaborative Research: Endowing nonlinear optical devices with unprecedented robustness: overcoming fabrication disorder by "topological protection" against parasitic scattering

Non-technical section of abstract:

Technology based on controlling and manipulating light affects our lives in countless ways: from the optical fibers that enable ultrafast internet speeds, laser manufacturing of automobiles, to solar cells that provide clean energy - optical devices are ubiquitous. Very often, the performance of a given device is limited by fabrication imperfections: random defects that cause unwanted scattering of light, which impedes its flow and adds unwanted noise. Investigators Rechtsman and Chen will demonstrate a method to completely suppress such scattering: so-called "photonic topological protection" of light beams. This concept, borrowed from solid-state physics (in which the goal was to protect electronic current from scattering) has already been demonstrated to work, and offers the possibility of endowing a wide class of devices with unprecedented robustness. In order to test these concepts in the lab, the investigators will fabricate waveguide arrays (a series of "wires" for light that together form a desired device) embedded in a type of glass that is particularly useful for so-called "nonlinear" optical devices. With proper design of the waveguide array, suppression of scattering will be demonstrated in multiple different

devices. The implications to optical devices are clear: increased device efficiencies or cheaper fabrication costs (or both). Moreover, the authors expect their work to "shed light" on the general wave phenomenon of topological protection against scattering in many contexts, including acoustic waves, microwaves, optical waves, and even electron waves.

Technical section of abstract:

The field of "topological insulators" has captivated condensed matter physics for ten years, due to these materials' universal properties, and striking applications in spintronics and quantum computing. It was recently demonstrated that their key property - "topological protection" against scattering by disorder- could be achieved with photons in waveguide arrays with engineered linear dispersion properties to preserve edge modes.

This proposal will explore the nonlinear optical properties of Photonic Topological Insulators (PTIs). Through the fabrication of high quality PTI waveguide arrays in nonlinear optical substrates such as chalcogenide glass, this research project will explore a nonlinear properties of edge modes and their potential applications. Since PTIs have a fundamentally different dispersion, a novel understanding of nonlinear optics in these structures is bound to yield new scientific knowledge and device applications, which will be of great interest to a highly cross-disciplinary set of intellectual communities.

The activities of this project are: (1) theoretical work to analytically and numerically model nonlinear effects (i.e., modulation instability and solitons) in photonic topological systems; (2) fabrication (laser-written photonic crystal-type structures) in chalcogenide glass, which has a high nonlinear response; (3) characterizing the structures by injecting high-peak-power near-infrared light and observing spatial diffraction patterns.

The collaboration between PI and co-PI with complementary expertise will enable the success of the proposed project from theoretical studies to device fabrication to characterization. If successful, photonic topological protection can potentially be used to dramatically improve the performance of optical devices such as multiplexing systems, all-optical switches and beam-shaping systems - and indeed any optical application limited by fabrication disorder.

PUBLICATIONS PRODUCED AS A RESULT OF THIS RESEARCH

Note: *When clicking on a Digital Object Identifier (DOI) number, you will be taken to an external site maintained by the publisher. Some full text articles may not yet be available without a charge during the embargo (administrative interval).*

Some links on this page may take you to non-federal websites. Their policies may differ from this site.

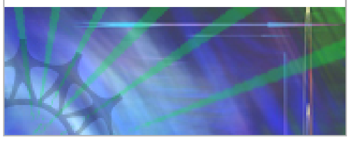
Zhang, Jian-Xiao, Mikael C. Rechtsman, and Chao-Xing Liu. "Invited Article: Topological Crystalline Protection in a Photonic System," *APL Photonics*, v.1, 2016.

Bandres, Miguel A., Mikael C. Rechtsman, and Mordechai Segev. "Topological Photonic Quasicrystals: Fractal Topological Spectrum and Protected Transport," *Physical Review X*, v.6, 2016.

Leykam, Daniel, M.?C. Rechtsman, and Y.?D. Chong. "Anomalous Topological Phases and Unpaired Dirac Cones in Photonic Floquet Topological Insulators," *Physical Review Letters*, v.117, 2016.

Y. Plotnik, M. A. Bandres, S. Stützer, Y. Lumer, M. C. Rechtsman, A. Szameit, and M. Segev. "Analogue of Rashba Pseudo-Spin-Orbit Coupling in Photonic Lattices by Gauge Field Engineering," *Physical Review B*, v.94, 2016.

Blanco-Redondo, Andrea, Imanol Andonegui, Matthew J. Collins, Gal Harari, Yaakov Lumer, Mikael C. Rechtsman, Benjamin J. Eggleton, and Mordechai Segev. "Topological Optical Waveguiding in Silicon and the Transition between Topological and Trivial Defect States," *Physical Review Letters*, v.116, 2016.



Award Abstract #1410435

Topological Physics and Light Matter Interactions: From Floquet Topological Insulators to Solar Cells

NSF Org:	DMR Division Of Materials Research
Initial Amendment Date:	July 27, 2014
Latest Amendment Date:	June 20, 2016
Award Number:	1410435
Award Instrument:	Continuing grant
Program Manager:	Daryl W. Hess DMR Division Of Materials Research MPS Direct For Mathematical & Physical Scien
Start Date:	September 1, 2014
End Date:	August 31, 2017 (Estimated)
Awarded Amount to Date:	$326,711.00
Investigator(s):	Gil Refael refael@caltech.edu (Principal Investigator)
Sponsor:	California Institute of Technology 1200 E California Blvd PASADENA, CA 91125-0600 (626)395-6219
NSF Program(s):	OFFICE OF MULTIDISCIPLINARY AC, CONDENSED MATTER & MAT THEORY, QIS - Quantum Information Scie
Program Reference Code(s):	7203, 7237, 7644
Program Element Code(s):	1253, 1765, 7281

ABSTRACT

NON-TECHNICAL SUMMARY

The Division of Materials Research and the Division of Physics contribute funds to this award which supports theoretical research and education focused on means to stabilize and utilize topological behavior through light-matter interactions in a variety of systems. Topological insulators possess some amazing properties such as the ability to conduct electricity without dissipation at their boundaries while being insulating through their interior. The research which will be carried out under this award is geared toward extending concepts of topological behavior of matter when it interacts with light. This presents a fertile ground for fundamental and applied research.

The research will concentrate on three themes. The first is to employ topological insulator surfaces for energy harvesting and detection of infra-red light. The second is to use light to turn an ordinary insulator into a topological insulator. The third is to create unique edge states in a hybrid system of a semiconductor in a cavity that could bridge semiconductor and optical technologies.

This research has the potential of introducing new techniques for energy harvesting and

light detection and paving the way to new photonic devices based on topological principles. The award will allow training of graduate students and postdocs in an interdisciplinary research environment at the intersection of materials physics and optics. The PI will involve undergraduate students in this research and incorporate the research material into the undergraduate level course that he has developed at Caltech.

TECHNICAL SUMMARY

The Division of Materials Research and the Division of Physics contribute funds to this award which supports theoretical research and education focused on means to stabilize and utilize topological behavior through light-matter interactions in a variety of systems. The first part of the project is focused on turning the surface of three-dimensional (3D) topological insulators into a photovoltaic platform aimed at the elusive mid-wavelength infrared spectrum. The surface electrons of 3D topological insulators typically have a minute photocurrent response to incident light in spite of the fact that many electron-hole pairs form. The PI will exploit the spin-orbit locking on the surface to turn it into a photocurrent rectifier. This can be done using a magnetic grating deposited on the surface which should result in a substantial photocurrent response to circularly polarized light. The PI will consider the manifestations of this effect in realistic topological insulators, its optimization with respect to the magnetic pattern deposited, and its extension to other systems, such as two-dimensional (2D) topological insulators and 2D quantum wells with Rashba interaction.

In the second part the PI will study ways to induce topological behavior in trivial semiconductors using coherent light. Electrons in semiconductors driven into a topological phase exhibit a non-equilibrium energy distribution determined by the strength of the drive and various relaxation mechanisms. By deriving these distributions, the PI will investigate under what circumstances the non-equilibrium effects do not obstruct the topological behavior of the driven system, and analyze schemes to detect this so-called Floquet topological phase.

The third part of the project is focused on the possibility of creating topological polariton states in optical waveguides coupled to trivial semiconductors. Relying on the idea of the Floquet topological insulator, the PI will examine whether it is possible to have a topological bound state of a cavity photon and an exciton in a topologically trivial semiconducting quantum well. A topological polariton state may exhibit strongly enhanced lifetimes, as well as could be used as a nanophotonic isolator.

This research has the potential of introducing new techniques for energy harvesting and light detection and paving the way to new photonic devices based on topological principles. The award will allow training of graduate students and postdocs in an interdisciplinary research environment at the intersection of materials physics and optics. The PI will involve undergraduate students in this research and incorporate the research material into the undergraduate level course that he has developed at Caltech.

PUBLICATIONS PRODUCED AS A RESULT OF THIS RESEARCH

Note: *When clicking on a Digital Object Identifier (DOI) number, you will be taken to an external site maintained by the publisher. Some full text articles may not yet be available without a charge during the embargo (administrative interval).*

Some links on this page may take you to non-federal websites. Their policies may differ from this site.

P. Titum, N.H. Lindner, M.C. Rechtsman, and G. Refael. "Disorder-Induced Floquet Topological Insulators," *Phys. Rev. Lett.*, v.114, 2015, p. 056801.

Charles-Edouard Bardyn, Torsten Karzig, Gil Refael, Timothy C. H. Liew. "Topological Polaritons and Excitons in Garden Variety Systems," *Phys. Rev. B (R)*, v.91, 2015, p. 161413(R).

{Bardyn}, C.-E. and {Karzig}, T. and {Refael}, G. and {Liew}, T.~C.~H.. "{Topological polaritons and excitons in garden-variety systems}," *\prb*, v.91, 2015, p. 161413. doi:10.1103/PhysRevB.91.161413

{Bardyn}, C.-E. and {Karzig}, T. and {Refael}, G. and {Liew}, T.~C.~H.. "{Chiral Bogoliubov excitations in nonlinear bosonic systems}," *\prb*, v.93, 2016, p. 020502. doi:10.1103/PhysRevB.93.020502

{Karzig}, T. and {Bardyn}, C.-E. and {Lindner}, N.~H. and {Refael}, G.. "{Topological Polaritons}," *Physical Review X*, v.5, 2015, p. 031001. doi:10.1103/PhysRevX.5.031001

{Seetharam}, K.~I. and {Bardyn}, C.-E. and {Lindner}, N.~H. and {Rudner}, M.~S. and {Refael}, G.. "{Controlled Population of Floquet-Bloch States via Coupling to Bose and Fermi Baths}," *Physical Review X*, v.5, 2015, p. 041050. doi:10.1103/PhysRevX.5.041050

{Titum}, P. and {Berg}, E. and {Rudner}, M.~S. and {Refael}, G. and {Lindner}, N.~H.. "{Anomalous Floquet-Anderson Insulator as a Nonadiabatic Quantized Charge Pump}," *Physical Review X*, v.6, 2016, p. 021013. doi:10.1103/PhysRevX.6.021013

{Titum}, P. and {Lindner}, N.~H. and {Rechtsman}, M.~C. and {Refael}, G.. "{Disorder-Induced Floquet Topological Insulators}," *Physical Review*