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プロジェクト番号　P-2１

Development of Infrared sensor based on 3D photonic crystal

[1] Organization

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Prof. Saulius Juodkazis (Centre of Microphotonics, Swinburne University of Technology, Melbourne, Australia)
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[2] Research progress

This project is aimed at development of micro-scale infra-red (IR) sensor for detection and imaging applications. Traditionally, IR sensors are implemented using i)solid-state devices based on narrow-band gap semiconductors, or ii) bolometric devices. While (i) has high speed, but needs cryogenic conditions for high sensitivity operation, (ii) allows uncooled operation, but its sensitivity is lower, and response speed is also low due to high thermal mass. Here we aim to develop a super-compact uncooled IR bolometric detector ensuring both high sensitivity at room temperature and fast response time. Such a device may offer considerable advantages in cost and operational convenience, e.g., higher reliability, reduced power consumption, smaller size and reduced weight, as well as multispectral response capability, while sacrifice in performance is minimal. The micro-scale IR sensing device is based on a recently proposed new principle for micro-scale thermal imaging, which exploits temperature-dependent reflectance (at visible wavelengths) of a 3D photonic crystal (PhC) structure.

Realization of this goal requires coordinated efforts in several areas of research, namely nanophotonics, micro-/nano-fabrication, thermal imaging, and polymer science. As a first step during the first year of implementation of this project, a mini workshop was organized on January 23, 2014 at Research Institute of Electronics, Shizuoka University. The workshop was attended by participants of the project, experts in the relevant fields, and was open for students and researchers interested in these fields.

The presentations and discussions during the workshop were centered on the following topics:

1) Physical mechanism of IR sensitivity of photonic crystals and its proof-of-principle experimental implementation (V. Mizeikis)
2) Enhancement of optical absorption in photonic crystals with chirped lattice period (K. Staliunas)
3) Tailoring of optical micro-/nano-structures and photonic crystals by direct laser write technique (M. Malinauskas)
4) Femtosecond laser fabrication of micro- and nano-photonic devices (S. Juodkazis)
5) Thermal and optical properties of bulk and structured photoresists (J. Morikawa)

[3] Results

(3-1) Research results

Photonic crystals (PhC) are dielectric materials with periodic refractive index modulation along one two, or three dimensions, and a forbidden photonic band gap (PBG) for electromagnetic optical waves. In the PBG spectral region light cannot enter the PhC, and strong spectral reflectivity peak is observed in the PBG wavelength range, whose central wavelength is comparable and directly proportional to the PhC lattice period. External factors, for example pressure or heat, capable of modifying the PhC lattice period will lead to

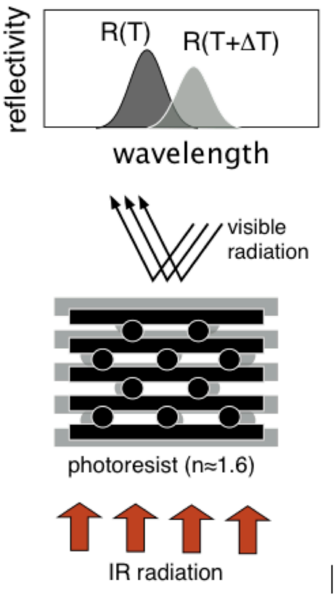

Fig. 1. Bolometric sensing with photonic crystals: proportional swelling of the PhC lattice due to IR absorption and heating (bottom) leads to spectral shift of PBG reflectance peak (top). By monitoring change in the visible reflectivity spectrum, detection of IR radiation is possible.

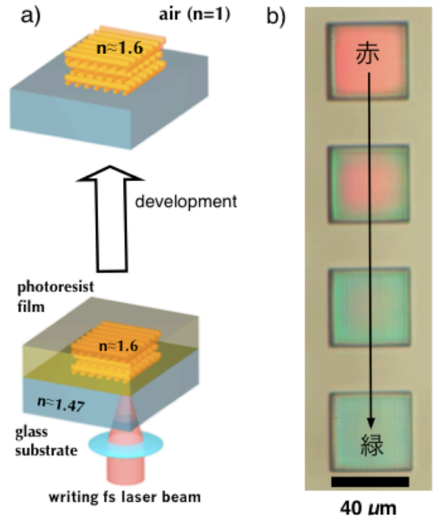

Fig. 2. Fabrication of 3D photonic crystals by DLW technique in photoresist (a), realization of controllable structural color in photonic crystals fabricated by DLW (b).

spectral shift of the PBG region.

We have developed a concept of PhC based IR sensor illustrated in Fig. 1. This concept is based on IR sensitivity of a natural PhC structure – blue wing of *Morpho* butterfly – observed and reported previously in the literature (Nature Photonics 6, 195 (2012)). The proposed PhC structure should be built from a material that has strong IR absorption, and a high coefficient of thermal expansion (CTE). External IR radiation absorbed by the PhC, may induce thermal expansion of the PhC lattice, and lead to the corresponding spectral shift of the PBG reflectance peak. Thus monitoring the change of PhC reflectance sat visible wavelengths allows one to detect IR radiation.

The first step towards realization of this new principle is to fabricate a PhCs structure exhibiting structural color and strong optical reflectance at visible wavelengths. This was achieved using Direct Laser Write (DLW) method in photoresist illustrated in Fig. 2(a). DLW allows rapid prototyping of 3D PhC structures with various lattice geometries and parameters by exploiting two-photon photopolymerization induced in the focal spot of tightly focused femtosecond laser beam, and scanning of the focal spot to draw complex 3D PhC structures. This method is highly suitable for tailoring of 3D photonic crystals, and will be used to realize the structures required for this study. Using this approach we have prepared PhC samples with 3D woodpile architecture. High reliability and resolution of the fabrication technique allowed us to realize structural color in the fabricated structures as illustrated in Fig. 2(b). Woodpile PhC structures had a lateral lattice period of 0.9µm, a footprint size of (40x40) μm^2 and consisted of 30 layers. Optical reflectance images shown in the figure illustrate bright structural color, and its controllable variation from red to green when PhC lattice parameters are varied during the fabrication. Next steps of our study will involve search of thermal and IR sensitivity of the structural color.

(3-2) Ripple effects and further developments

Exchange of scientific expertise between the participants was very helpful for coordination of experimental and theoretical work towards the goal of this project. Also, it has contributed to strengthening of domestic and international collaboration at Research Institute of Electronics (RIE) of Shizuoka University. In addition, participants of the workshop (Prof. K. Staliunas, Prof. S. Juodkazis, and Dr. M. Malinauskas) also attended the 2014 International Workshop on Advanced Nanovision

Science organized by RIE on January 20-21, 2014, where they contributed oral presentations.

Another important ripple effect of this collaboration was decision by all participants to collaborate in preparation of joint application for a larger international project partially overlapping with the topic of the present project. Enhancement of optical absorption in photonic crystals is a new way to boost sensitivity of IR detectors. Consequently, the participants decided to work on grant proposal tentatively entitled “Stopped light in photonic crystals for substantial enhancement of the efficiency of infrared detectors” for funding by NATO Science for Peace and Security Programme. Work on this proposal is currently in progress, and will likely be also joined by additional researchers from RIE and Shizuoka University.

In conclusion, the joint work of all participants and the mini-workshop conducted within the present project has broadened existing domestic and international research collaborations at RIE, and opened new venues for future collaborations.

[4] Achievements

Journal article:

(1) V. Mizeikis et al., “Realization of Structural Color by Direct Laser Write Technique in Photoresist” JLMN-Journal of Laser Micro/Nanoengineering **9**, 42-45 (2014).

Conference presentation:

(2) S. Juodkazis, “Femtosecond laser fabrication: from curiosity to industrial applications” Saulius Juodkazis, 2014 International Workshop on Advanced Nanovision Science, Jan. 20-21, Hamamatsu Campus, Shizuoka University (2014).

(3) M. Malinauskas, “Ultrafast laser 3D micro/nano-fabrication of polymers - applications in microoptics and biomedicine”, 2014 International Workshop on Advanced Nanovision Science, Jan. 20-21, Hamamatsu Campus, Shizuoka University (2014).

(4) K. Staliunas “Beam focusing by flat mirrors” (Invited talk), 2014 International Workshop on Advanced Nanovision Science, Jan. 20-21, Hamamatsu Campus, Shizuoka University (2014).

Travelling report

Name:	Prof. Saulius Juodkazis
Affiliation:	Centre of Microphotonics, Swinburne University of Technology, Melbourne, Australia
Period of time:	2014.01.20-01.30
Destination:	Shizuoka University, Japan
Purpose:	To carry out a joint research, plan the future collaboration, participate and report previously obtained results. To attend Cooperative Research Workshop " Development of Infrared Sensors Based on 3D Photonic crystals" and 2014 International Workshop on Advanced Nanovision Science.
Name of receiver:	Prof. Vygantas Mizeikis

Name:	Dr. Mangirdas Malinauskas
Affiliation:	Vilnius University, Department of Quantum Electronics
Period of time:	2014.01.19-01.25
Destination:	Shizuoka University, Japan
Purpose:	To carry out a joint research, plan the future collaboration, participate and report previously obtained results. To attend Cooperative Research Workshop "Development of Infrared Sensors Based on 3D Photonic crystals" and 2014 International Workshop on Advanced Nanovision Science.
Name of receiver:	Prof. Vygantas Mizeikis

Name:	Prof. Junko Morikawa
Affiliation:	Tokyo Institute of Technology
Period of time:	2014.01.23
Destination:	Shizuoka University, Japan
Purpose:	To plan the future collaboration, participate and report previously obtained results. To attend 2014 To attend Cooperative Research Workshop "Development of Infrared Sensors Based on 3D Photonic crystals"
Name of receiver:	Prof. Vygantas Mizeikis