MERIT Long-term Overseas Dispatch Report

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Dispatch Destination

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Dispatch Period

June 10, 2024 – June 29, 2024, August 3, 2024 – August 10, 2024

Introduction

Our laboratory focuses on deepening the understanding of optical properties through experimental work, covering a wide range of research themes. My research falls under the field of metamaterials, which involves controlling light propagation characteristics using small structures on the order of the wavelength of light. Professor Svirko, who hosted me during my dispatch, also works in the field of metamaterials, and our laboratory collaborates with him. I believe that mastering not only physical theories and optical experiments but also the techniques for micro-fabrication of samples is crucial for advancing metamaterials research. This opportunity allowed me to learn about chemical vapor deposition (CVD) technology unique to the University of Eastern Finland, which enables uniform deposition of special carbon films on substrates at nanometer thickness. I went to Joensuu, Finland, to use this CVD technology and fabricate THz wideband perfect absorbers, a joint research theme between our laboratory and the University of Eastern Finland.

Climate

June in Finland is considered summer, but it was reported that snow fell until mid-May. Although the days were warm, the evenings had a cool, gentle breeze reminiscent of early spring in Japan. Notably, the phenomenon of the midnight sun was remarkable, with the sky remaining bright, with only a slight dimming from midnight for about two hours. Conversely, by October, the polar night begins, where days are characterized by continuous darkness. The cost of living is higher than that in other European countries, with dining out costing approximately 3 to 5 times more than that in Japan.

Background of the Research

Terahertz (THz) waves are located in the electromagnetic spectrum between 100 GHz and 10 THz, bridging the gap between infrared and microwave regions. This wavelength range holds promise for various technological applications, particularly in non-destructive testing and sub-millimeter wave astronomy, with potential applications in next-generation high-speed wireless communication technologies. Utilizing THz waves requires specialized optical elements, and one of the challenges is the significant loss due to Fresnel reflections.

Advantages of THz Band Metamaterial Anti-Reflection Structures

The THz band metamaterial anti-reflection structures consist of fine pyramid-like structures on the order of the wavelength. These structures have a spatial occupancy ratio that varies continuously with respect to the surrounding medium, allowing the effective refractive index to vary continuously over a broad frequency range. This reduces Fresnel reflections and achieves high transmissivity. This technology is particularly crucial for high-sensitivity THz wave measurements and astronomy. My laboratory, Konishi Lab, has developed technology to fabricate metamaterial anti-reflection structures for the THz band using laser processing, and is conducting research on design optimization and astronomical applications.

Objective of the Research

Application of Pyrolyzed Carbon (PyC) Thin Films

The fabrication of efficient absorbers using thin film structures is well-known, and Pyrolyzed Carbon (PyC) is particularly promising for broad-band absorption in the THz region. The University of Eastern Finland has been advancing both theoretical and experimental research on PyC. In this research, we aimed to create a device that achieves complete absorption of incident light over a previously unattainable broad band by combining PyC thin films with metamaterial structures. Preliminary simulations confirmed that depositing a uniform PyC thin film on the metamaterial surface could achieve an absorption rate of over 99.8% between 1 THz and 10 THz, and the required film thickness was determined.

Outcomes of the Research Activities

During the international dispatch, PyC deposition was performed on the metamaterial structures fabricated by Konishi Lab using the CVD equipment at the University of Eastern Finland. After deposition, optical responses were measured using local measurement systems to confirm changes in absorption performance. Currently, more advanced measurements of broad-band absorption performance are being conducted in collaboration with the Center for Physical Sciences and Technology (FTMC) in Lithuania.

Presentation at International Conference

From August 3 for one week, I participated in the international conference "Nanocarbon Photonics and Optoelectronics 2024" held in Kuopio, Finland, where I presented our research through a poster session. This conference provided valuable insights and ideas related to nanophotonics research involving carbon and my own research theme. In particular, discussions with researchers from FTMC enabled detailed information exchange regarding additional measurement conditions and sample management for future verification.

Summary

Through this research activity, we successfully fabricated a wide-band perfect absorber by combining metamaterial structures with PyC thin films. Furthermore, presenting at the international conference facilitated interaction with other researchers and the acquisition of new insights. Moving forward, I aim to explore further applications and contribute to the advancement of THz wave technology.

Acknowledgments

I would like to express my gratitude to my supervisor, Professor Konishi, for providing me with this opportunity. I would also like to thank Professor Svirko for his generous support and the members of Professor Georgy's group for their cooperation in the experiments. Lastly, I would like to thank MERIT for organizing this event.

Center: Prof. Svirko
Right: Thermal CVD oven.

Riko National Park, where Professor Georgy Fedorov (center of photo) took me on holiday. Although it was summer, it was very cool and the scenery was