【Grant-in-Aid for Scientific Research (S)】

One-chip near-infrared computational imaging using integrated photonics

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Project Information	Project Number : 23H05444 Project Period (FY) : 2023-2027 Keywords : Integrated photonics, computational imaging, optical phased array, wavefront measurement

Purpose and Background of the Research

●Outline of the Research

Integrated photonics is a technology that densely integrates numerous optical components on a compact semiconductor “chip” with a few millimeters in size. Following the recent expansion of silicon photonics and various other photonic foundry services, the integrated photonics has been extending its application from the conventional optical communications to diverse fields. Particularly, for the next-generation Internet of Things (IoT) society, there is a growing demand for compact and inexpensive sensing/imaging devices that leverage integrated photonics.

Among others, optical phased array is a promising device that emits phase-controlled lightwaves from an array of integrated optical antennas, enabling rapid synthesis/detection of optical wavefronts. However, conventional optical phased arrays are facing challenges in terms of scalability and spatial resolution, due to the difficulty in precisely controlling numerous optical phases within the chip.

On the other hand, computational imaging techniques that co-design the optical and signal processing systems have gained increasing attention as effective means to simplify optical systems and enhance the imaging performances. Particularly, in the near-infrared wavelength range, where low-cost and high-performance cameras are not available, computational imaging schemes that enable wavefront measurement using a single-pixel photodetector are attractive.

In this project, we aim to construct a new imaging method that combines the computational imaging techniques with the optical phased array devices and create compact and high-performance one-chip near-infrared imaging devices (Figure 1).

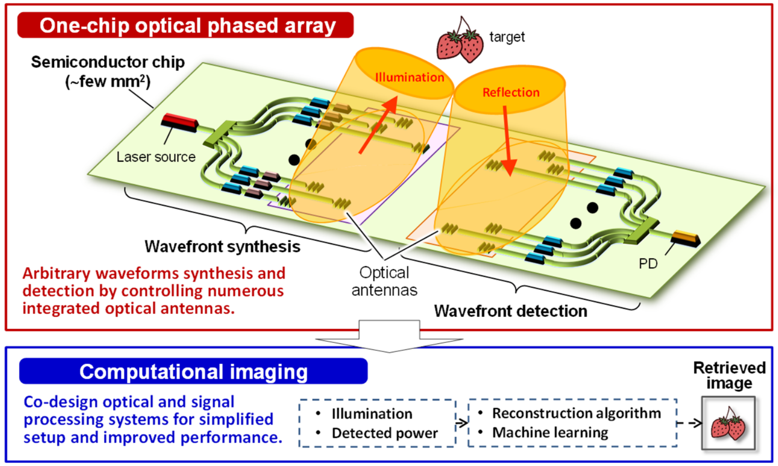

Figure 1. One-chip near-infrared imaging device, which will be developed in this project.

●Research Methods

First, by utilizing the non-redundant optical phased array developed in the previous research, we achieve high-resolution imaging with minimal number of phase controllers. In conventional optical phased arrays, the number of resolvable points scales linearly with the number of phase controllers. To obtain sufficient spatial resolution in practical applications, precise adjustment of thousands of phase controllers is thus required. In contrast, by applying the non-redundant array layout, we can increase the spatial resolution quadratically with the number of phase controllers (Figure 2). In this project, by adopting the non-redundant arrays in both the optical wavefront synthesis and detection sections, we achieve high-resolution imaging while limiting the number of phase controllers to a realistically controllable level.

Furthermore, in conventional optical-phased-array-based imaging, precise beam shaping and steering were required, which limited the scalability. Here, by integrating on-chip phase monitors (Figure 3), we compensate for the phase errors caused by fabrication deviations and environmental changes in real-time. Then, by applying advanced computational imaging techniques, we achieve robust and high-speed imaging.

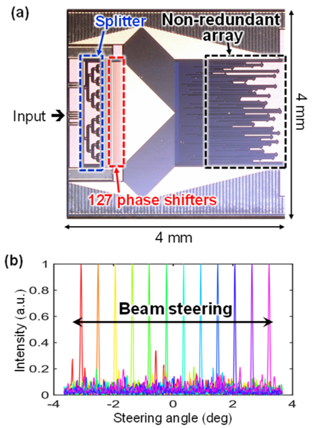

Figure 2. Non-redundant optical phased array

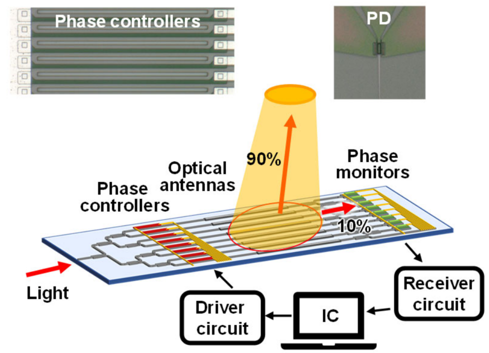

Figure 3. Optical phased array with on-chip phase monitors

Expected Research Achievements

While the optical phased arrays and computational imaging share a common goal of simplifying the optical imaging systems, they have been studied independently from different perspectives of device and algorithm. As a result, each approach faces its own challenges. It is therefore an interesting question to study whether the combination of two technologies would complement each other to solve these issues.

In this project, we address this unanswered question and explore “special computational imaging techniques suitable for optical phased arrays,” as well as “optical phased array designs optimized for computational imaging.” Through this research, we pioneer a new research field that combines integrated photonics and information science. We then aim to realize low-cost and high-performance one-chip near-infrared imaging devices that can be employed in the next-generation IoT society.

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