

8K Video Data Transmission through Optical Phased Array Packaged by Direct Optical Wire Bonding

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Abstract— We have proposed and demonstrated high-speed optical wireless transmission system using 2D beam steerable optical phased array (OPA), achieving 8K video data transmission through free-space range of 3m for the first time. OPA was designed based on transmission power budget from the proposed system, having 64 phase tunable channels and 2 μ m pitch grating radiators array with n-i-n heater at each radiator for 2D beam steering. The manufactured OPA had beam divergence angle of 0.7°/0.9° and beam steering range of 46.0°/10.2° each in transversal/longitudinal direction. Eye-diagram for 32Gbps data transmission was measured for several receiving points with different phases and radiator heating power, each showing identical shape. We also managed to send 8K video data using OPA, verifying the potential for OPA uses in commercialized optical wireless communication (OWC) systems. For integrating OPA into a module, direct optical wire (DOW) bonding was applied for optical packaging.

Keywords— Optical phased array (OPA), Optical wireless communication (OWC), Direct optical wire (DOW), Optical packaging, Silicon photonics

I. INTRODUCTION

Optical wireless communication (OWC) technologies have received numerous interests due to the exploding data and Internet of Things (IoT) along with the limitation of RF communication. RF communication such as WiFi can only transmit data up to 150Mbps and various techniques with complex modulations are required for 1Gbps communication speed. In this era of 5G communication, millimeter wave (mm-wave) and multi-input multi-output (MIMO) technologies are mainly used to fill the shortage of RF communication. However, the maximum speed of both technologies does not exceed 6Gbps which still lack of 5G and 6G communication's need. According to 6G and later generations demand of large bandwidth, OWC with fundamentally different carrier frequency from RF communications are essential.

Optical bands used for wireless communications can be classified in to infrared (IR), visible light (VL) and ultraviolet (UV). Communications using UV has great advantages of non-line of sight (NLOS) communication and noise free from solar radiation. But due to its harmfulness on human, UV is difficult to apply to general imposing applications. In the case of visible

light communication (VLC), illumination and communication are operated simultaneously but limitations for communication distance and outdoor applications remain. IR can be considered to be the most suitable region for commercializing high speed OWC due to its capability of long range, low power consumption and high data rate. To date, 850nm and 1550nm wavelengths were generally used. 850nm communication was preferred due to the low price of 850nm source and availability. As the 1550nm laser price has decreased, 1550nm communication has gained interest appealed to eye safety. 1550nm is mainly absorbed by cornea, having higher output power regulation by two orders of magnitude from 850nm. OWC using 1550nm wavelength will enable long range and high-speed communication between optical network units (ONU) and devices.

Directivity of optical radiation is the key for OWC to have long range and high data rate. Steering optical beams are essential in optical wireless technologies and has been carried out with lens, mirrors, microelectromechanical system (MEMS) and optical phased array (OPA). Using lens and mirrors were the initial technique for steering beam but has bulky system and low steering speed. MEMS has a compact and efficient system, but still has problems with power consumption, speed limitation due to physical movement. However, OPA is an emerging technology for beam steering since it uses phase control of branched beam without physical movement and can be manufactured on a compact silicon chip.

OPA has been studied a lot in recent years as it is regarded as the core device of LiDAR and OWC [1-2]. In the most advanced OPA study, LiDAR of 200m and data transmission of 10Gbps using receiver OPA was demonstrated. Many studies showed that OPA can be applied as a transceiver in OWC with various communication methods and increasing the demonstrated data rate. We have been conducting research in accordance with the OPA research flow, and has developed 2D beam steering OPA. In this study, we aim to propose and demonstrate a wireless transmission system using 2D beam steering OPA. We also verify the performance degradation when transmission using OPA for the first time in the world. Using the proposed system, we have succeeded in wireless

transmission of 32 Gbps at free-space range of 3m and confirmed that 2D beam steering OPA can transmit tens of Gbps data without degrading performance.

The polymer optical wire bond structures have been regarded as a key solution to realize passively aligned interface paving the way to mass-producible optical interconnection. The two-photon polymerization method has been widely investigated to perform the top-down fabrication of the optical wire bond structures with feature size below the diffraction limit of the laser wavelength. Its direct-write lithography allows to print highly efficient free form microstructures for optical links, hybrid integration and pluggable structures. As an alternative way, a bottom-up fabrication of the optical wire bond structure has been reported with open-air solidification of polymer solution within nanoscale meniscus pulled out from glass micropipette. Since the meniscus-guided method involves only physical actions under open-air condition, it was readily extended to provide direct optical wire (DOW) bonding for laser-to-fiber interconnection [3-5]. DOW technology can be used for packaging OPA chip into a module.

II. DATA TRANSMISSION USING OPTICAL PHASED ARRAY

The architecture shown in Fig. 1 conceptually describes the optical wireless data transmission through an optical beam-steering module. It can be used for transmitting high-speed data in the field of drone, VR device and UHD TV. OPA chip based optical module has very low power consumption and very small in size. The module can be integrated to commercial interfaces, such as DP, USB, HDMI ports.



Figure 1. Architecture of optical wireless data transmission through an optical beam steering module based on optical phased array and applications.

A. Optical Phased Array Module

Figure 2 describes the optical beam-steering module based on OPA. The module is applied to the HDMI interface with an electro-optic converter. The electric signal is converted into optical signal and transmitted through the OPA chip. Modulated light is coupled into the OPA chip. The coupling is generally made by fiber coupling which is an active method resulting in high-cost and low efficiency. The packaging of laser diode (LD) or fiber is done by the DOW bonding.

Optical Phased Array Module

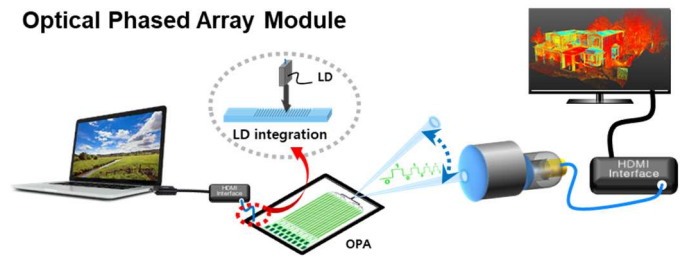


Figure 2. Structure of beam steering module with an OPA chip integrated with laser diode.

B. Fabrication

The designed OPA consists of an input grating coupler, multi-mode interferometer (MMI) power splitters, electro-optic (EO) phase shifters, phase feeding lines and tunable grating radiators. The input grating was designed for coupling 1550nm fiber-tailed light source. Array scale was determined with 128 through FDTD simulation to satisfy the transversal beam divergence smaller than 1° determined in the architecture design. Also, to achieve this divergence in the longitudinal direction, the grating radiators was designed with a etch depth of $10\ \mu\text{m}$ and a length of $100\ \mu\text{m}$, considering manufacturing tolerance. 7 stages of 1×2 MMI power splitters were used to equally distribute the optical powers to 128 channels. The phase shifters were designed with the electro-optic p-i-n junction structure to attain high-speed operation with low power consumption. Phase feeding lines between the phase shifters and the radiators were designed with a pan in structure, similarly with the pan-out structure of the power splitter, to provide equal path length for each channel in order to eliminate the time dispersion caused by path difference. The rating radiator array was designed with a uniform pitch of $2\ \mu\text{m}$ which can provide a transversal beam steering range over 45° with a zeroth-order single beam. The thermo-optic tunable grating radiators was applied for longitudinal beam steering employing the n-i-n heaters. Longitudinal beam steering range of 10.2° was achieved using the tunable grating radiators. Figure 3 shows the photograph of a fabricated OPA chip.

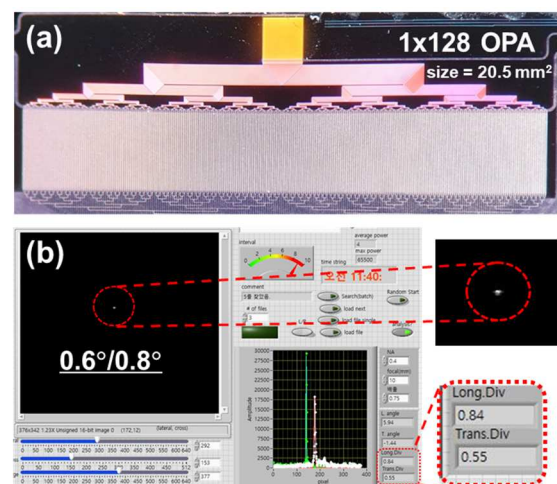


Figure 3. Photograph of (a) fabricated OPA chip with 128 channels having equal path lengths and (b) measured beam divergence angle.

C. Data Transmission Experiment

Figure 4 shows the experimental setup and results of data transmission through the OPA chip. 32 Gbps PRBS data and 8K video data was transmitted through OPA chip with different modulation method. Optical signal of 32 Gbps data was generated from a pulse pattern generator and 8K video data was generated by converting the HDMI video data source. Both signals were transmitted through OPA by an optical switch and was successfully transmitted at 3 meters.

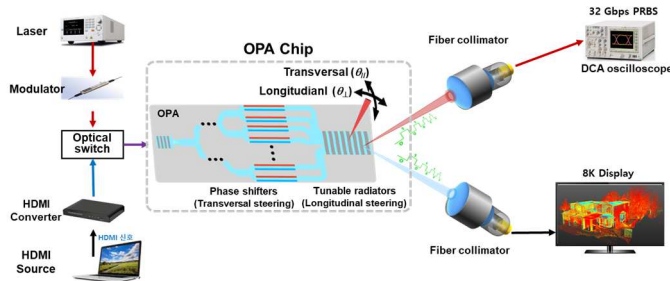


Figure 4. Experimental setup and results of optical wireless data transmission through OPA chip.

III. PACKAGING USING DIRECT OPTICAL WIRE BONDING

A. Direct Optical Wire Bonding

Figure 5 shows the architecture of optical interconnection using DOW bonding for photonic ICs. Optical components are pick-and-placed on designed optical bench with alignment precision of 10 μm . The polymer wire is directly formed by controlling the glass micropipette filled with polymer solution. The micropipette is initially moved to nearly touch the optical interface for creating meniscus outside its opening. As the meniscus is stretched by pulling the micropipette, the polymer solution within the meniscus is rapidly open-air polymerized and subsequently solidified into a desired wire shape. This directly grown polymer wire is curved in the micropipette direction forming DOW bonding at the in/out interface of photonic chips. Since the DOW bonding utilizes only physical actions of micropipette, it offers one-stop procedure for landing and wiring processes analogous to electrical wire bonding. We can readily adjust the properties of DOW such as refractive index, wire diameter and surface adhesion by controlling the polymer material and concentration of the polymer solution.

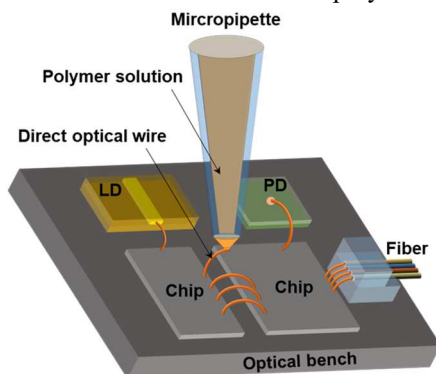


Figure 5. Architecture of interconnecting photonic circuits using direct optical wire bonding technology.

B. Fabrication

Figure 6 shows the SEM image of DOW bonding for grating-to-grating interconnection with 300 μm distance. DOW structure was measured with a radius length near 150 μm , performing a very precise fabrication to the targeted lengths. DOW bonding was fabricated in an array with 50 μm pitch, equal to the grating-to-grating array for convenient measurement. The polymer stud formed with the optimized parameters by simulation is imaged as Fig. 6(c), having the exact lengths. The open-air polymerization method for fabricating DOW can accurately control the polymer wire radius. Thermal stability of DOW bonding was tested with repeated heat apply up to 200 $^{\circ}\text{C}$, but there was no structural damage and performance degradation.

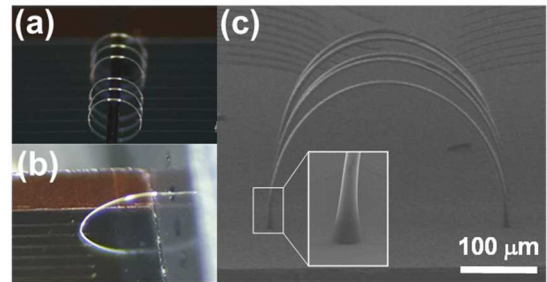


Figure 6. Optical microscope image of DOW bonding between (a) chip-to-chip and (b) chip-to-fiber. (c) SEM image of DOW bonding between chip-to-chip.

C. Experiment

Figure 7 shows the simulated and measured insertion loss of DOW link between grating couplers. The distance between grating couplers were varied from 50 μm to 150 μm . For both lengths the simulated and measured results had almost equal insertion loss and tendency. Fiber coupling between grating couplers was also measured as a reference. DOW link had lower insertion loss and larger bandwidth.

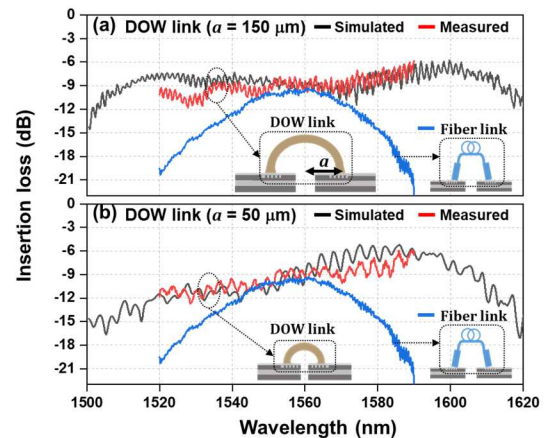


Figure 7. Simulated and measured insertion loss of DOW link between the grating couplers with horizontal radius of (a) 150 μm and (b) 50 μm . Fiber link between grating couplers is also measured as a reference.

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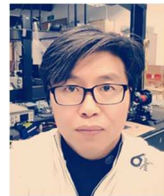
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