A custom CMOS imager for wavelength-multiplexed indoor optical LANs

Tomoya Miyawaki, Keiichiro Kagawa, Itsuki Nagahata, Masahiro Nunoshita, and Jun Ohta
Graduate School of Materials Science, Nara Institute of Science and Technology,
8916-5 Takayama, Ikoma, Nara 630-0101 JAPAN
Phone: +81-743-72-6054, Fax: +81-743-72-6052, E-mail: kagawa@ms.naist.jp

ABSTRACT

We are developing a custom CMOS imager to realize a compact and high-data-rate indoor optical wireless LAN module. The CMOS imager has a function of fast optical data acquisition, and we can obtain the positions of the communication nodes from the imager. The function of concurrent multi-point data acquisition of the imager enables us to utilize a wavelength-division-multiplexing (WDM) technique to increase the data rate of the downlink. We have fabricated a 64x64-pixel custom CMOS imager prototype with capability of 4-channel concurrent data acquisition, and constructed a prototype system of WDM indoor optical wireless LAN for proof-of-concept. Image acquisition and the experiments of wavelength-multiplexed free-space optical data transmission by use of the prototype imager are shown.

I. INTRODUCTION

Free-space optical communications (FSOC) including indoor optical wireless local area networks (LANs) [1,2] are an promising technology to realize ultra-fast wireless communications. CMOS imagers can be a candidate of the photoreceiver for the FSOC due to its high functionalities. For example, a custom CMOS imager for the application of communication between unmanned tiny airplanes has been developed[3]. In this paper, we present a custom CMOS imager to realize a compact, high-speed, and intelligent wavelength-division-multiplexing (WDM) indoor optical wireless LAN system. We have already reported custom CMOS imagers for indoor optical wireless LANs [3,4]. We have introduced a WDM function to our imager to increase the total communication bandwidth in proportion to the number of the multiplexed wavelengths. The features of our imager are concurrent data acquisition and crosstalk reduction of the demultiplxed light spots as well as position detection of the communication nodes and the hub from the captured images. Figure 1 depicts our WDM indoor optical wireless LAN system. The functional mode is determined at each pixel among an image capture mode for position detection of the communication counterparts with high photo-sensitivity and a photoreceiver mode for receiving the high-speed optical communication data. The custom CMOS imagers are used at both hub and nodes. The sensor can receive multiple optical data up to four in our prototype imager. With the function, the hub concurrently receives the data from the multiple nodes, and the nodes receive a bundle of the wavelength-multiplexed optical data from the hub at the same time. The wavelength band will be 850 nm. Figure 2 shows a configuration of our system, in which gratings are utilized as a multiplexer and a demultiplexer, and movable MEMS (micro-electro-mechanical systems) mirrors coupled with scan lenses are used for steering the communication light beams.

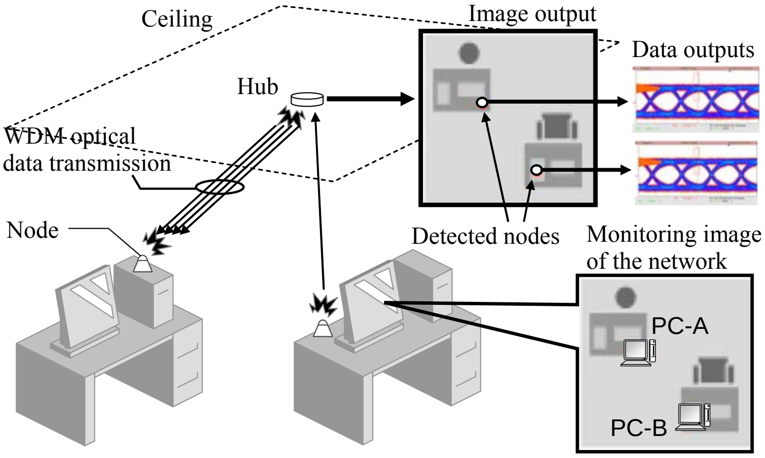


Fig. 1. Wavelength-division-multiplexed indoor optical wireless LAN.

II. SENSOR ARCHITECTURE

Figures 3 and 4 show a block diagram and a pixel schematic of our imager. The features of the pixel structure are simple configuration without in-pixel amplifier, and a function of photo-currents summation of optical communication data among the neighboring pixels to fully utilize the incident optical power. The pixel has vertical signal lines, Vsig<i-1> and Vsig<i>, in its both sides. They are shared among the neighboring columns. In the communication mode, the photocurrent is put out to one of the Vsig lines, which is controlled by the in-pixel latch memories, toward the transimpendace amplifier (TIA) at each column. When both of the in-pixel memories are LOW, the pixel works in the image capture mode, and the photodiode voltage is read through the PMOS source follower to the Vaps<i> signal line. Figure 5 shows a simplified schematic of the photoreceiver circuit of our imager. To alleviate the common-mode noises, the photocurrents from the pixels surrounding the signal pixels are read out through Vref<i> line to realize differential signaling. At most four pairs of Vsig and Vref are selected by the analog multiplexer, and are amplified by the limiter after the cross-talk reduction circuit. The demultiplxed optical signals at the receiver possibly have inter-channel interferences when the pitch of the resolved spots is as large as or smaller than the pixel size or the pitch of the wavelengths is not same as the designed one. The cross-talk reduction circuit is composed of Gilbert-cells to perform a matrix operation, which calculates a product of a matrix with 4x4 elements and four input signals from the analog multiplexer in an analog domain. The matrix elements are applied from outside the imager.

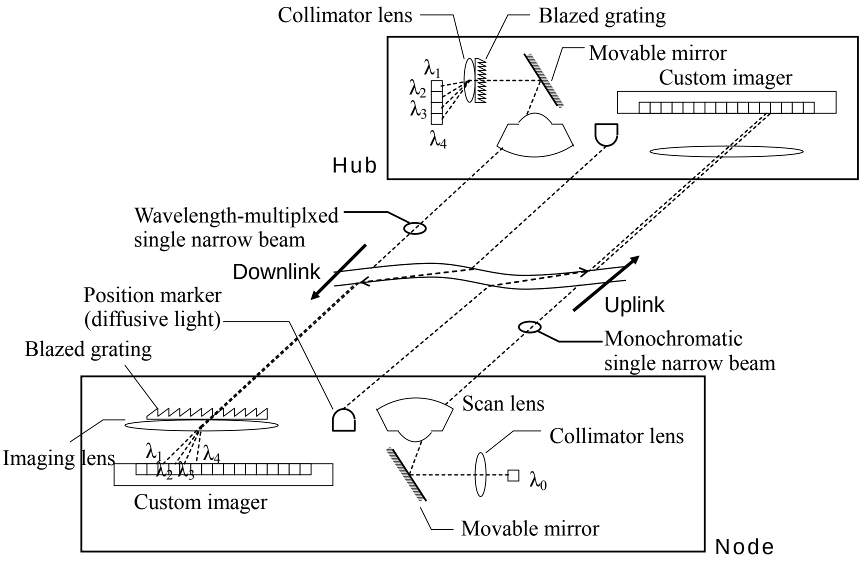


Fig. 2. Configuration of the communication modules.

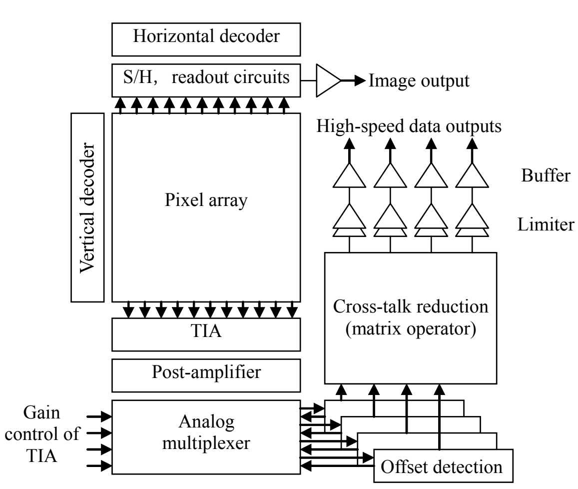


Fig. 3. Block diagram of the imager.

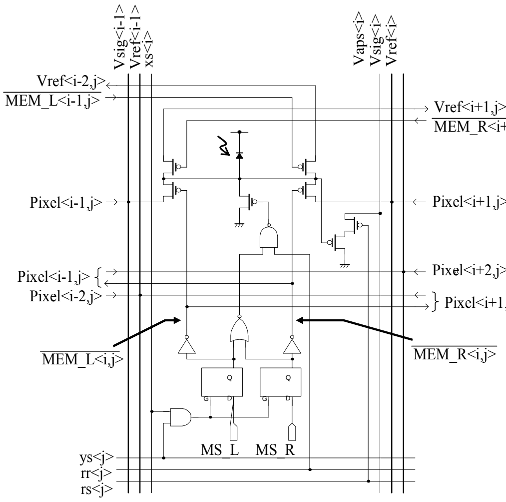


Fig. 4. Pixel schematic.

III. EXPERIMENTAL RESULTS

Figure 6 and Table 1 show the photomircrography and the specifications of our prototype sensor to demonstrate WDM free-space optical data transmission. Figure 7 shows the experimental setup. Three light beams with wavelengths of 676, 785, and 897 nm were multiplexed into a single beam by dichroic mirrors, and deflected by a motorized mirror toward the receiver. After free-space propagation over distance of 1.65 m, the beam is demultiplexed to the multiple spots aligned with 400 μm interval by use of the grating and a visible-infrared video lens at the receiver. Figure 8(a) shows a captured image of a scene of our laboratory to verify the functionality of image acquisition. After the positions of the demultiplexed light spots were detected from the captured images as shown in Fig. 8(b), the output waveforms from our custom CMOS imager were successfully acquired. Fig. 9 shows an eye diagram of a single channel and results of concurrent data acquisition. The waveform for wavelength of 898 nm was not obtained due to low sensitivity of the photodiode for that wavelength. Although the aimed data rate was 100 Mbps for non return to zero signals, the measured data rate was about 20 Mbps. That is why the parasitic capacitances of the bus line in the pixel array and the analog multiplexer were not considered properly in design.

IV. CONCLUSIONS

We have presented a custom CMOS imager for WDM indoor optical wireless LANs, and demonstrated the preliminary WDM optical data transmission and concurrent data acquisition by use of the prototype imager. The data rate will be improved by use of a finer CMOS technology and with proper circuit modeling.

REFERENCES

1. J. R. Barry: *Wireless Infrared Communication* (Kluwer Academic Publishers, 1994).
2. D. C. O'Brien *et al.*: IEEE J. Selected Topics in Quantum Electron. **11** (2005) 173.
3. B. S. Leibowitz, IEEE J. Solid-State Circuits **40**, 9 (2005) 1948.
4. K. Kagawa *et al.*: IEICE Trans. Comm. **E86-B** (2003) 1498.
5. K.Kagawa *et al.*: in Proceedings of 2003 Workshop on CCD&AIS (2003).

Table 1 Specifications of the fabricated imager.

Technology	0.35-μm CMOS (silicide process) 2-poly, 3-metal
Chip size	9.8 mm sq.
Pixel count	64 x 64
Pixel size	100 μm sq.
Photodiode structure	Nwell/ Pdiff
Fill factor without μ-lens	16%
Photoamplifier	RGC (TIA)/ Cherry-Hooper amp. (post amp and gain stage)
Total transimpedance gain	2.5 kΩ – 2.5 MΩ (simulation)
Data rate	20 Mbps NRZ/ ch
Number of channels	4

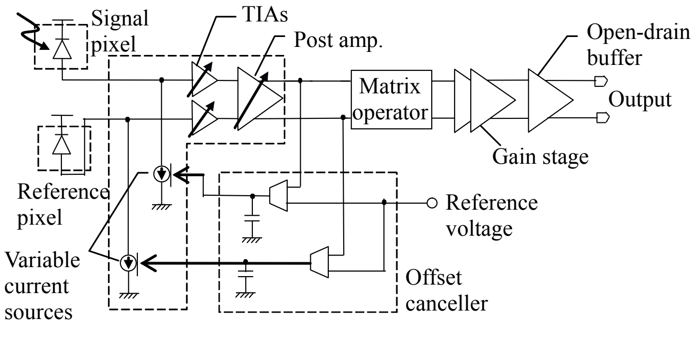


Fig. 5. Simplified schematic of the photoreceiver circuits.

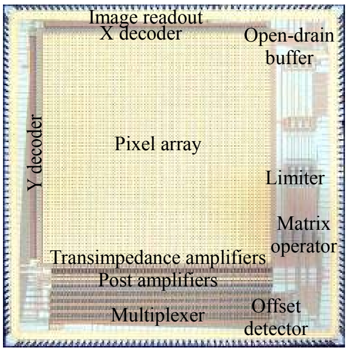


Fig. 6. Photomicrography of the fabricated imager.

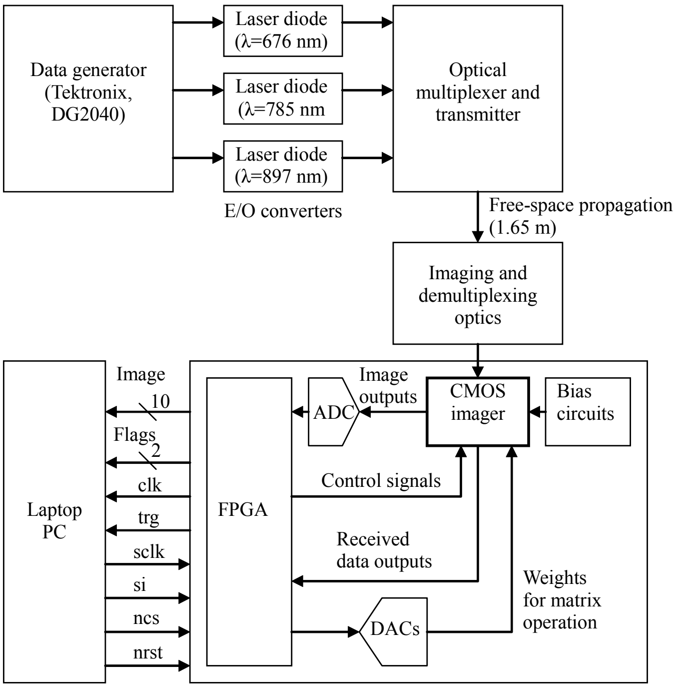
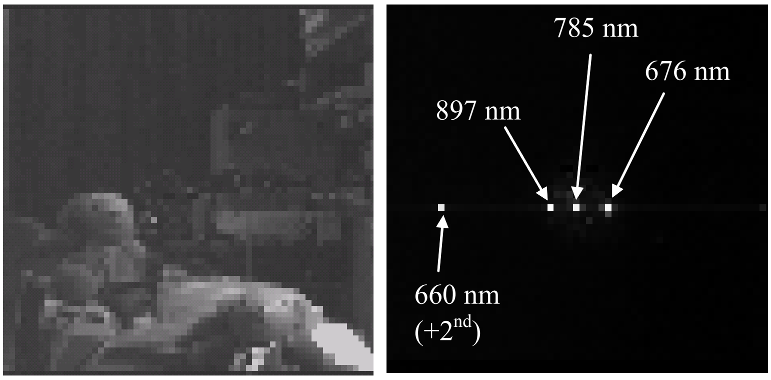
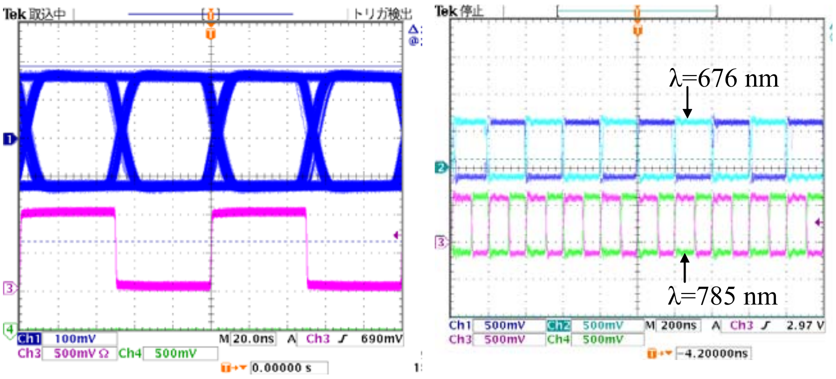


Fig. 7. Block diagram of the demonstration system.



(a) (b)

Fig. 8. Captured images of (a) a scene of our laboratory and (b) the demultiplexed light spots.



(a) (b)

Fig. 9. Received waveforms after limiting: (a) eye pattern of a single channel for 20-Mbps NRZ pseudo-random sequence and (b) concurrent acquisition of two channels