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A CMOS on-chip image sensor with integrated LED array for optogenetics

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1. Introduction

Optogenetics is a methodology used in biosciences with which light-sensitivity is introduced onto biological cells [1-3]. Channelrhodopsin (ChR2) is one of the mostly used proteins for optogenetics. ChR2 is a light-activated anion channel protein. Neural cells with ChR2 can be activated by a light with wavelength of 470 nm.

Light emitting diode (LED) array is expected to be a two-dimensional light stimulator for optogenetics [4, 5]. To obtain light with wavelength of 470 nm, GaInN is suitable material for LED. X-Y matrix access scheme is used in the reported LED array devices.

In this work, we propose to implement a GaInN LED array on a CMOS on-chip image sensor. We use a multi-functional CMOS image sensor with on-chip current injection capability [6, 7] . Fig. 1 shows the concept of the CMOS on-chip image sensor with an integrated LED array.

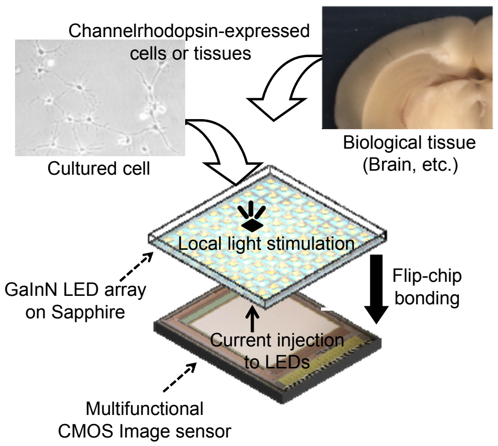


Fig. 1 Concept of the CMOS-based neural interface device with an integrated LED array.

In this report, we present the concept, structure and fabrication of the CMOS on-chip image sensor with LED array, including a design of the multifunctional CMOS image sensor. We also demonstrate the functionality of the localized light stimulation with the fabricated device.

2. Design and Fabrication of the CMOS On-chip Image Sensor with an Integrated LED Array

The proposed on-chip image sensor consists of two semiconductor chips that are bonded in face-to-face manner.

Layout of the multifunctional CMOS image sensor was shown as Fig. 2 (a). Table I shows specifications of the multifunctional CMOS image sensor chip. Based on a conventional CMOS image sensor equipped with 3-transistor active pixel sensor as light sensing circuitry, we implemented a capability of addressable current injection (and electric sensing) [6, 7]. The CMOS sensor was fabricated using 0.35 μm 2-poly, 4-metal standard CMOS technology. The size of the multifunctional pixel was 15 μm × 7.5 μm. A current injection electrode (pixel electrode) was formed with a top metal layer in each pixel. The pixel electrodes were exposed to establish connection to electrodes on the LED array wafer.

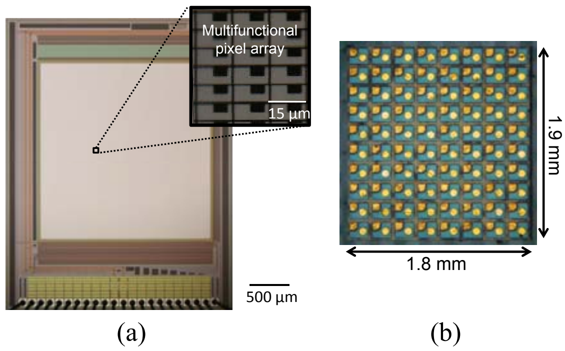


Fig. 2 Layouts of (a) multi-functional CMOS image sensor, and (b) GaInN LED array

Table I Specifications of the multifunctional CMOS image sensor

Technology	0.35 μm 2-poly 4-metal Standard CMOS
Chip size	2236 μm ×3171 μm
Array size	128×268
Pixel size	15 μm×7.5 μm
Pixel type	3-Transistor APS
Operation voltage	3.3 V

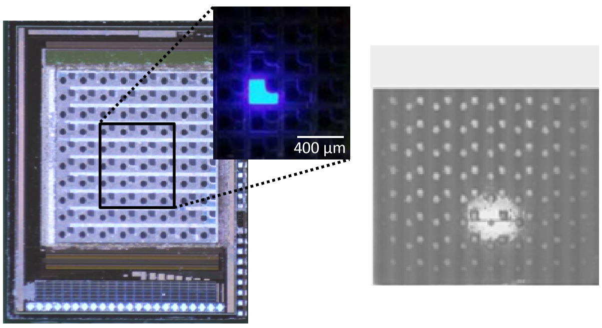
Two selectable columnar current injection circuits were implemented on the CMOS chip. We can use these columnar current injection lines to operate LEDs. In this chip, we used row selecting function (vertical scanner) of the light sensing function to select electrodes for current injection. Thus, to operate on-chip LED array, we set two columnar lines for current injection and activate external current sources synchronously to the row selection function of the chip.

Fig. 2(b) shows an outlook of the LED array wafer. The emission peak wavelength is typically 470 nm, which matches the sensitivity peak of ChR2. Size of single LED is approximately 190 μm × 230 μm, and the LED wafer was diced into 8 x 10 LED array. Since both the LED layer and sapphire substrate are transparent, we can perform on-chip optical imaging using the imaging function of the multi-functional CMOS image sensor.

We bonded the CMOS sensor chip and the GaInN LED chip using flip-chip bonding technique. We used anisotropic conducting paste (ACP) for the bonding and we have succeeded to directly bond the two wafers without gold bumps.

3. Functional Characterization of On-chip light stimulation capability

Fig. 3 shows images of LED operation taken (a) with an external microscope and (b) with the CMOS image sensor. We confirmed the addressable LED operation as shown in Fig. 3 (a). Furthermore, it was confirmed that the on-chip optical imaging is available during the LED operation, as shown in Fig. 3(b). This result suggests that that we can use the on-chip optical imaging function to monitor the operation of the LED array. This unique feature is quite advantageous for *in vivo* light stimulation.



(a) (b)

Fig. 3 Images of LED operation taken with (a) an external microscope and (b) the multifunctional CMOS image sensor

Typical emission light intensity of 7.5 μW was obtained. This value approximately corresponds to 200μW/cm^2. Referring values reported in the literatures, the present device is applicable to a part of neural stimulations in optogenetics. We have modified the current injection circuits in the multifunctional CMOS image sensor to be compatible with an operation voltage of 5 V. The result obtained with the new CMOS chip will be presented at the conference, too.

Not only single-site, but also multi-site stimulation is available with the present device. Since we implemented two columnar current injection lines that can be operated independently, we can perform simultaneous dual-site stimulation. Combining columnar addressing and current source for LED operation that are operated synchronously to the row (vertical) scanner, we can perform two-dimensional patterned light stimulation. Two LEDs in the same row can be operated simultaneously and LEDs in different rows will be operated sequentially. Simultaneous multiple LED operation is not available with previously reported LED array device with simple X-Y matrix addressing scheme [4, 5]. Therefore, we expect this feature will be one of the largest advantages of the CMOS-based neural stimulator.

4. Conclusions

A novel CMOS on-chip image sensor with an integrated LED array was proposed and demonstrated. We combined a multifunctional CMOS image sensor which is capable of on-chip addressable current injection and GaInN LED array formed on sapphire substrate. LEDs in the array were successfully operated using the addressable current injection function of the multifunctional CMOS image sensor. We have also demonstrated simultaneous dual-site stimulation, which is the key feature of the present device.

Acknowledgements

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