Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp399-400

H-4-05(Late News)

An implantable needle shape image sensor with an on-chip thinned LED

Kiyotaka Sasagawa[1], Takahiro Yamaguchi[1], Makito Haruta[1], Yoshinori Sunaga[1], Yasumi Ohta[1], Hironari Takehara[1], Hiroaki Takehara[1], Toshihiko Noda[1], Takashi Tokuda[1] and Jun Ohta[1]

[1] Graduate School of Material Science, Nara Institute of Science and Technology
8916-5 Takayama, Ikoma, Nara 630-0192, Japan
Phone: +81-743-72-6054, E-mail: sasagawa@ms.naist.jp

Abstract

We developed a thin implantable CMOS imaging device using a small CMOS image sensor and an on-chip thinned blue LED. The image sensor was specially designed and has a needle shape. The thinned LED was fabricated by removing a sapphire substrate by laser lift off technique. The total thickness is approximately 0.18 mm. Fluorescence imaging by the device is demonstrated.

1. Introduction

Fluorescence imaging is one of the most important methods for observation of cell activity. Various kinds of activities can be visualized by using fluorescent dyes or proteins. To observe inside a tissue, three dimensional imaging techniques such as confocal or two-photon microscopy have been developed. However, it is still difficult to observe deep brain regions. An imaging system using a GRIN lens is one of the solutions. Deep brain can be observed with the device. However, it has some invasiveness [1].

We have proposed and developed a low-invasiveness needle type imaging device based on a custom designed CMOS image sensor (Fig. 1(a)) [2-4]. In our previous work, we fabricated a device and succeeded in imaging of deep brain activities [5]. However, large part of the thickness was the flexible circuit board. In this work, we fabricated a very thin needle type image sensor device for green fluorescence imaging (Fig. 1(b)). A thinned blue LED was directly mounted on a sensor chip and the flexible circuit board has been removed.

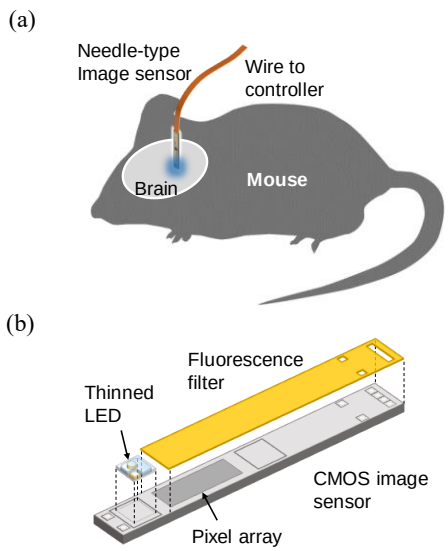

Fig. 1. (a) Concept of an implantable image sensor. (b) Schematic of the needle type image sensor device with a thinned LED.

2. Device fabrication

Thinned LED

Thinned LEDs were fabricated by using laser lift-off (LLO) technique [6, 7]. We used GaN based blue LEDs on sapphire substrates (ES-CEBHM12A, Epistar). The chip size is 280 μm × 305 μm. The peak emission wavelength is 470 nm. For LLO process, UV laser pulses at a wavelength of 266 nm, which is fourth harmonic wave of a Nd-YAG laser, have irradiated from the backside of the substrate. Figure 2 shows a micrograph of the thinned LED after LLO process. The thickness is approximately 8 μm.

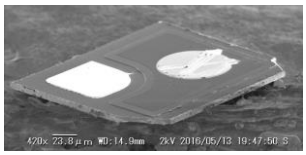

Fig. 2. SEM micrograph of a thinned LED.

Needle type CMOS image sensor

A CMOS image sensor was designed in our laboratory and fabricated by a foundry (AMS). The technology is 0.35um 2-poly 4-metal standard CMOS process.

The pixels are based on conventional 3-Tr active pixel sensor architecture. The size and number of the pixels are 7.5 μm × 7.5 μm and 42 × 160, respectively. The chip has a space for mounting a LED where the metal layers and a top protective layer were avoided. The width and length of the circuit area are 0.45 mm × 3.9 mm, respectively. The thickness was reduced to 0.16 mm by lapping and polishing.

Assemble process

Thinned LEDs are very fragile and it is difficult to pick up by a tweezer. LEDs are adhered to a silicone membrane before the LLO process [7]. The membrane was also used as a supporting substrate. To remove unwanted light to the image sensor chip substrate, an Al film was placed on the space for LED. A thinned LED is aligned to the space by using manual stages. The LED was bonded on the chip with UV-curable adhesive (NOA63, Norland) and the supporting substrate was

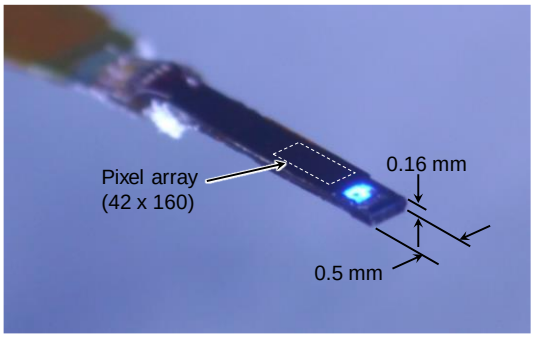

Fig. 3. Micrograph of the needle type imaging device with an on-chip thinned LED.

removed after curing.

The pads on the LED and the chip were connected by W-deposition of a focused ion beam system or wire bonding. The sidewalls of the LED were covered by blue filter resist to decrease stray light.

A yellow dye (VALIFAST YELLOW 3150, Orient chemical) doped transparent epoxy resin (GA, Cannon chemicals) film, which was applied on a fluorine polymer as a release layer, is transferred on the pixel array of the chip. This film is used as an emission filter for green fluorescence. The epoxy resin was also used as adhesive between the chip and the filter.

The pads on the chip were connected to a flexible printed circuit board by wire-bonding and coated with a parylene film for waterproofing. A micrograph of the fabricated device is shown in Fig. 3. The total thickness of the device is approximately 0.18 mm

3. Results and discussion

Performance of an on-chip thinned LED

Figure 4(a) shows the emission spectra of a bare LED and an on-chip thinned LEDs. The spectrum after LLO process was slightly blue shifted. It suggests heat spreading through the silicon chip although further investigation is required.

Figure 4(b) shows the light emission distribution from an on-chip LED in the air. The light is emitted almost omnidirectionally. However, light to horizontal directions from the LED has been reduced slightly by the coating to the sidewalls.

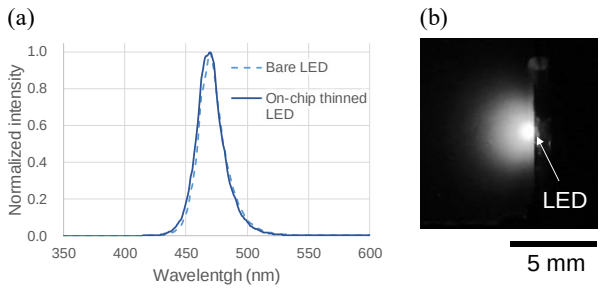

Fig. 4. (a) Emission spectra of bare and on-chip thinned LEDs. (b) Light distribution from an on-chip LED.

Fluorescence imaging

As a demonstration of fluorescence imaging, yellow fluorescent beads were spread on the sensor and observed. The imaging result is shown in Figure 5. The fluorescent beads were successfully observed by the sensor. Here, the Al layer on the backside of the LED as an optical shield is important. By using the device without the shield. It was difficult to observe the beads due to saturation of the pixel array. This was because the light emitted from the back side of the LED is absorbed by the silicon substrate. The photo-carriers are generated in the substrate and some of them were detected by the pixels.

In Figure 5, the LED was placed on the right side of the image. The image has some offset that is not rejected by the emission filter. This is because light emitted from the blue LED includes not green components that is not effectively rejected by the yellow filter. It can be improved by introducing an excitation filter for the LED [8].

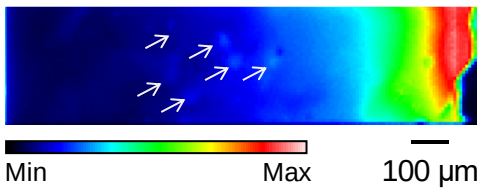

Fig. 5. Fluorescence image of fluorescence beads spread on the chip. The arrows indicate the beads.

4. Conclusion

We developed a needle-type CMOS imaging device with an on-chip thinned LED. The sensor has an emission filter on the pixel array and fluorescence imaging in water was demonstrated. The thickness of the chip is 0.18 mm. This value can be reduced further because the most part of the device thickness is the silicon substrate (0.16 mm). The small cross-section of the proposed device structure enables *in-vivo* imaging with low invasiveness.

Acknowledgments

This research was partially supported by Grant-in-Aid for Scientific Research (26249051 and 15K01289) from the Japan Society for the Promotion of Science (JSPS) and VLSI Design and Education Center (VDEC), The University of Tokyo, in collaboration with Cadence Corporation and Mentor Graphics Corporation.

References

[1] K. K. Ghosh *et al.*, Nat. Methods **8** (2011) 871.
[2] J. Ohta *et al.*, Sensors (Basel) **9** (2009) 9073.
[3] T. Kobayashi *et al.*, Sci. Rep. **6** (2016) 21247.
[4] M. Haruta *et al.*, Jpn. J. Appl. Phys. **53** (2014) 04EL05.
[5] H. Takehara *et al.*, Biomed. Opt. Express **6** (2015) 1553.
[6] M. K. Kelly *et al.*, Appl. Phys. Lett. **69** (1996) 1749.
[7] T.-I. Kim *et al.*, Science **340** (2013) 211.
[8] Y. Sunage *et al.*, Jpn. J. Appl. Phys. **55** (2016) 03DF02.