Wavelength Identification Sensor Using MOS Photo-Transistor Array Based on Metal Slit Diffraction

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Abstract

We present a wavelength identification technique using MOS photo-transistor array based on a metal slit. Intensity profile caused by the single slit diffraction corresponds to wavelength of incident light. Photo-transistor array with 128 photo-transistors in 520nm pixel pitch underneath the single metal slit detect intensity profile and wavelength is identified using the intensity profile. We have fabricated this wavelength identification sensor using monolithic 0.15 μm CMOS-SOI process without further post-process. We demonstrate less than 10 % wavelength identification error for 475nm-795nm light with 520nm metal slit.

Keywords:diffraction, intensity profile, photo-transistor array, CMOS image sensor, wavelength identification.

1 Introduction

VLSI process technology has achieved metal line spaces narrower than the visible light wavelength, which can generate the possibility of treating light properties on a sensor using monolithic CMOS process without further post-process such as color filter and so on. Light has various properties, and it is used by not only illumination or display, but information tag [1] or communication. Therefore, it is very important to obtain light properties. For example, wavelength identification can be applicable to the information tag systems and others. It has, however, not been achieved the light wavelength identification using image sensors without further post-process such as color filters. In this paper, we introduce a wavelength identification technique for projected light based on monolithic CMOS process.

Figure 1 shows a concept of the wavelength identification. A narrow single slit is formed by the top most metal layer above photo-transistor array. Intensity profile is generated by the single slit in cases the wavelength of incident light is equal or longer than the slit width, as shown Fig. 1(a). Intensity profile is detected by the photo-transistor array with 128 photo-transistors underneath the single slit, and using the measured photocurrent, wavelength is estimated. We have fabricated the wavelength identification sensor using 0.15 μm CMOS-SOI process with 5 metal layers without further post-process.

Figure 2 shows the intensity profile simulated based

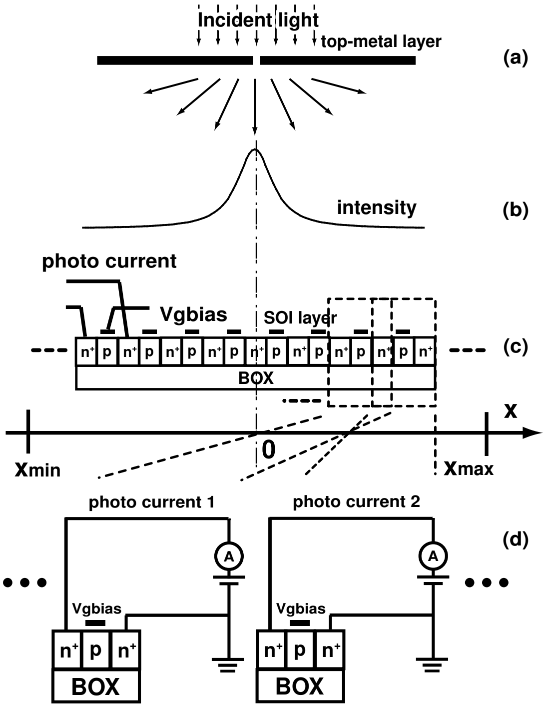

Figure 1: Concept of wavelength identification: (a)Incident light is exposed to a single slit, (b) Intensity profile is generated based on Fresnel diffraction, (c) Photo-transistor array underneath the single slit detects photo-current distribution with gate bias voltage as shown in (d).

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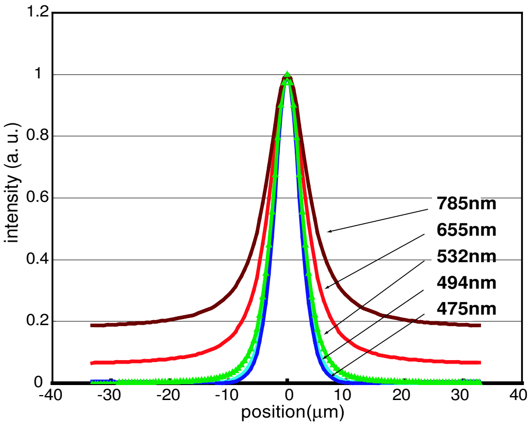

Figure 2: Intensity profile obtained by simulation based on Fresnel diffraction.

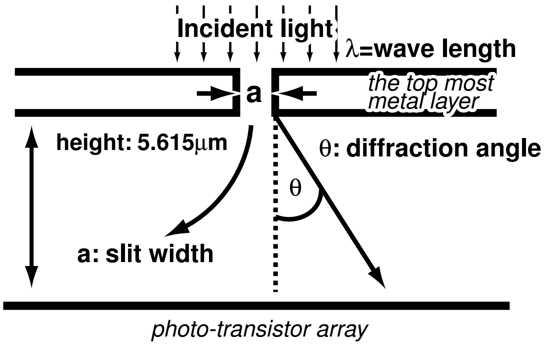

Figure 3: Fresnel diffraction diagram.

on the Fresnel diffraction expressed by equation(1).

$$\begin{aligned} I(\theta) &= I_0(0)\cdot(\frac{sin\beta}{\beta})^2(\frac{\sin\alpha}{m\alpha})^2 \qquad (1) \\ \alpha &= \frac{\pi d\sin\theta}{\lambda} \\ \beta &= \frac{\pi a\sin\theta}{\lambda} \end{aligned}$$

Note that, m, a, d, θ, λ, correspond to number of slits, slit width, distance between slits, diffraction angle, light wavelength, respectively, as shown in Fig.3. I_0 corresponds the peak intensity at $\theta = 0$. In this case, slit number is 1, the slit width is set to 520nm, height of slit from photo-transistor array is set to 5.615 μm, and intensity is normalized by the peak intensity $I_0(0)$.

2 Wavelength Identifier Configuration

CMOS APSs by SOI process have been presented [2][3]. PIN photo diodes have high optical absorption and high-sensitivity, as is the same as bulk CMOS APSs with PIN photo diodes. SOI technology has an advantages for CMOS active pixel image sensors(APS) that can avoid cross talks of photo-current through substrate, which enables finer pixel pitch image sensors. It is, however, difficult for the lateral PIN photo diodes to make fine pitch. The precision of the wavelength identification in this paper depends on pixel pitches as well as slit height from the pixel array. Vertical photo-transistor array has advantage on making finer pitch pixel array, as adjacent photo-transistors can share their sources and drains. Photo-current is generated at the depletion region between source and drain. Photo-transistors achieve the highest sensitivity in a case of sub-threshold operating condition, because of smaller drain bias current compared with the case of liner region operation. Figure 1(c) and (d) illustrate nMOS based photo-transistor array. Photo-current for a photo-transistor is read out between the source and the drain terminals with a Gate bias voltage Vgbias and Drain bias voltage Vdbias to control the operation of the photo-transistor as in the sub-threshold region. We formed 128 photo-transistors with 520nm pitch, which is far smaller than the state of the art fine pixel pitch CMOS APSs. Fig. 4 shows the fabricated chip microhotograph.

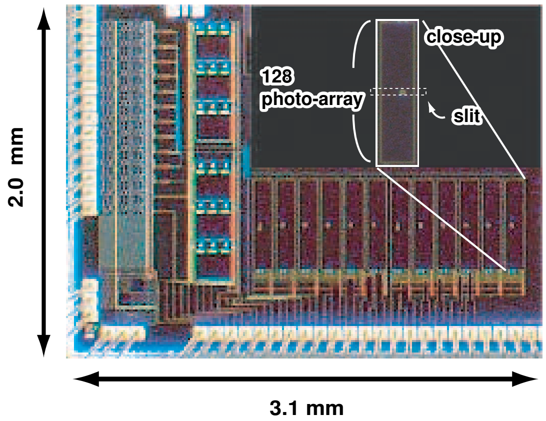

Figure 4: Chip Microphotograph.

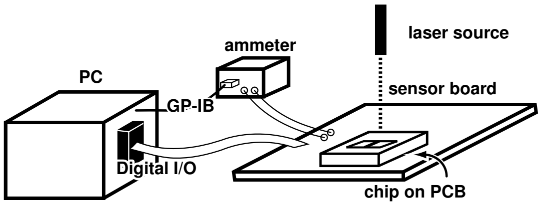

Figure 5: Measurement setup.

3 Measurement and Evaluations

The fabricated chip has been measured using a test PCB controlled from a PC through a digital IO board, as illustrated in Fig. 5. Photo-current is measured by an ammeter controlled by the PC through GP-IB interface. We employed 5 lasers, whose wavelengths are 475nm(10mW), 494nm(2mW), 532nm(1mW), 655nm(300mW, 1% ND filter), 785nm(80mW).

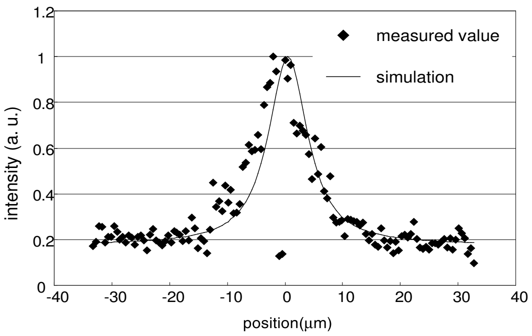

Figure 6: Measurement intensity profile in a case of 785nm laser exposure.

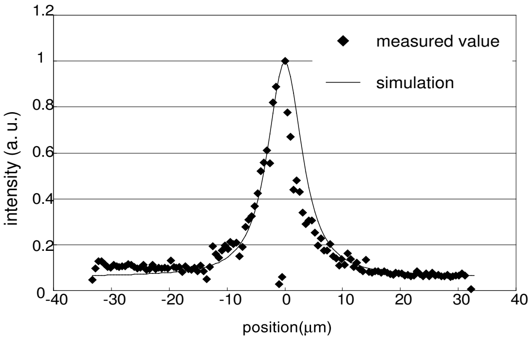

Figure 7: Measurement intensity profile in a case of 655nm laser exposure.

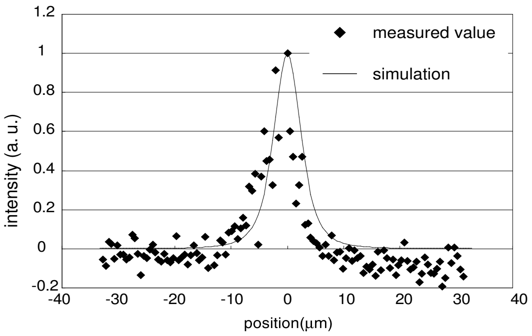

Figure 8: Measurement intensity profile in a case of 532nm laser exposure.

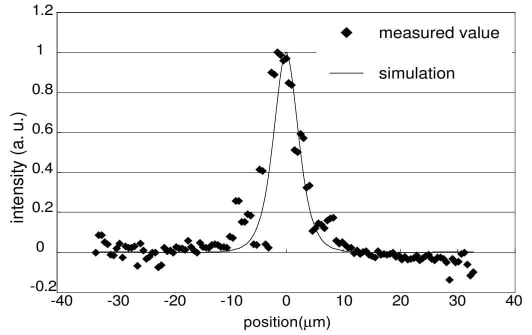

Figure 9: Measurement intensity profile in a case of 494nm laser exposure.

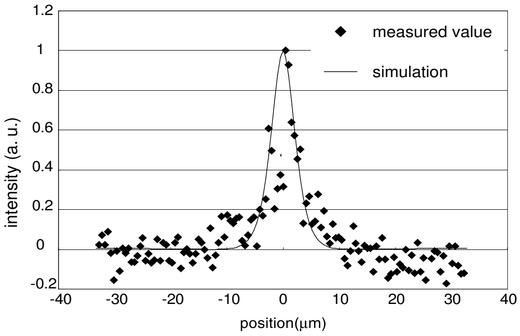

Figure 10: Measurement intensity profile in a case of 475nm laser exposure.

Figures 6, 7, 8, 9, and 10 show obtained intensity profiles for lasers of 475nm, 494nm, 532nm, 655nm, and 785nm respectively. The horizontal axes correspond to the pixel position, where the vertical axes correspond to the light intensity obtained from the measured photo-current. Note that the light intensity profiles are normalized by the peak intensity. The dark currents of photo-transistors are subtracted from the measured photo-currents. Dashed-lines in figures correspond to the simulated intensity profiles.

We have evaluated the measurement results in term of wavelength identification accuracy. We employed the sum of the absolute difference(SAD) between the measured intensity profiles and the simulated intensity profiles as described in equation (2).

$$SAD(\lambda) = sum(|Im(x) - Is(x, \lambda)|) \tag{2}$$

Here, $Im(x)$ is measured intensity at a position of x and $Is(x, \lambda)$ is simulated intensity at a position of x assuming the exposed wavelength of λ note that x_{min} and x_{max} corresponds to left-most pixel and right-most pixel, as shown in Fig. 1(c).

We identify the exposed wavelength where the $SAD(\lambda)$ becomes minimum. Figure 11 shows the SAD according to the wavelength. We evaluated the wavelength identifications based on errors of identification from equation (3). The identification errors well corresponding to the peak current of the measurement which is determined by the laser intensity and the sensitivity of the photo-transistor.

$$error = \frac{SAD(\lambda_{exposed}) - SAD(\lambda_{estimated})}{SAD(\lambda_{exposed})} \tag{3}$$

Table 1 summarizes the wavelength identification results with the identification errors. The identification errors well correspond to the peak photo current of the measurement which is determined by the laser intensity and the sensitivity of the photo-transistor.

Table 1: Exposed wavelength and Estimated wavelength result.

Exposed wavelength[nm]	Exposure Power[mW]	Peak Photo Current[μA]	Estimated Wavelength	error[%]
785nm	70 mW	11 μ A	795 nm	1.36 %
655nm	300 mW(1% ND filter)	10 μ A	654 nm	0.002%
532nm	1 mW	0.68 μ A	482 nm	3.34 %
494nm	10 mW	5.8 μ A	548nm	9.29 %
475nm	10 mW	0.95 μ A	503nm	2.41 %

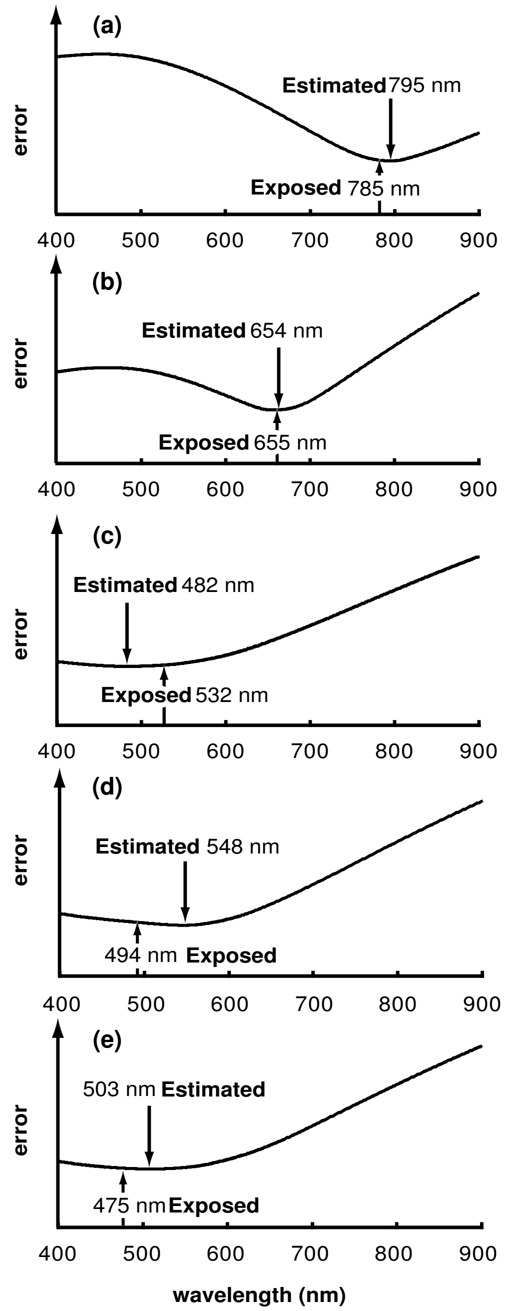

Figure 11: SAD according to the wavelength: (a) 785nm laser exposure, (b)655nm laser exposure, (c)532nm laser exposure, (d)494nm laser exposure, and (e) 475nm laser exposure.

4 Conclusions

We presented a wavelength identification technique using MOS photo-transistor array based on metal slit diffraction. We fabricated the fine pixel pitch of 520nm in 0.15 μm SOI-CMOS process, with a 520nm width metal slit at 5.615μm above the photo transistors. Measurement results indicate that the exposed wavelength can be identificated within 10 %error at the range of 475nm to 795nm wavelength.

5 Acknowledgment

The VLSI chip in this study has been fabricated in the chip fabrication program of VLSI Design and Education Center(VDEC), University of Tokyo in collaboration with OKI Electric Industry. The VLSI chip measurements in this study are partially carried out with lasers through the courtesy of Prof. Ohtsu of the University of Tokyo.

6 References

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