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Metallic Nano-Slit Array Lens for Spatial Resolution Improvement of *In-vivo* CMOS image sensor

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1. Introduction

Imaging of brain activities by implantable image sensors is a novel approach for elucidation. It is well known that brain activities can be imaged by functional magnetic imaging (fMRI) and positron emission tomography (PET) with low invasiveness[1, 2]. In contrast, the advantages of the implantable *in-vivo* image sensor are its high spatial and temporal resolution in a deep brain and the capability to observe the brain activities of a freely moving animal. To date, by using fluorescent measurement technique, the experiments of functional brain imaging have been performed successfully [3]. And, the implantable *in-vivo* complementary metal-oxide semiconductor (CMOS) image sensors have been applied to some fluorescent imaging [4-6].

One of the problems of implantable image sensors is its inherent difficulty to use lens optics. In order to reduce the invasiveness, the thickness of the sensor should be as low as possible. There is no space to put lens in front of the sensor. And, a lens made of high index material is required because the module is surrounded by fluid. One of the solutions is to use a light guide array plate, which has a narrow hole for each pixel of the image sensor and transmit only normal incident light [7]. This approach can reduce the thickness of the sensor module drastically. Its thickness must be more than tens of microns.

As a new approach, we propose to introduce the lens effect by a sub-micron thickness metallic nano-slit array. By the use of surface plasmons in the nano-slit, an ultra-thin lens is realized with a thickness of sub- micron [8-10]. By using a microlens located on each pixel, incident angle of light to the pixel is limited and image blur can be reduced. One of the differences of the nano-slit array lens with conventional lenses is its high dependence on the polarization and wavelength of the incident light. This characteristics is harmful in many cases. However, for fluorescent imaging, where lens effect is required at a specific wavelength, it is regarded as a benefit.

In this paper, we study the effect of metallic nano-slit lens on an implantable *in-vivo* CMOS image sensor. By electromagnetic simulation, it is shown that limitation of incident angle at a specific wavelength can be realized with an ultra-thin structure.

2. Structure of metallic nano-slit array for *in-vivo* image sensor

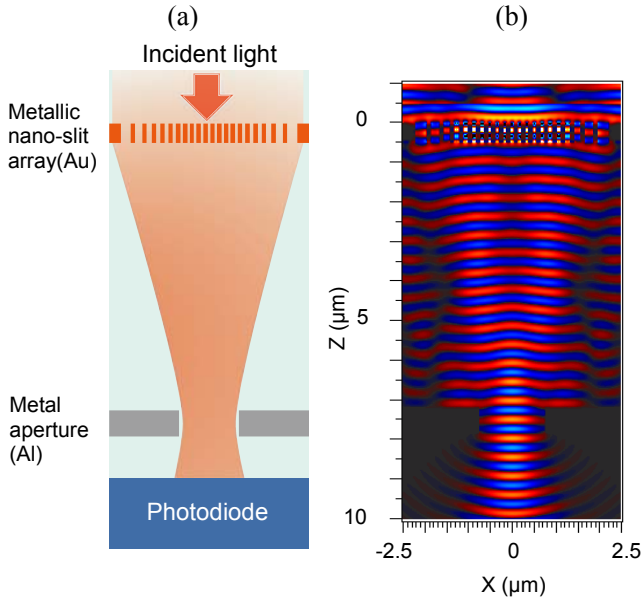

Fig. 1 (a) Schematic diagram of a metallic nano slit-array and a metal aperture. (b) Electric field distribution obtained by FDTD simulation.

Figure 1 (a) shows the proposed structure of the implantable image sensor with metallic nano-slit array. The incident light is focused on the aperture of the metal film and the transmitted light is received with a photodiode on the image sensor. As the incident angle increases, the transmittance decreases because the focused spot shifts to out of the aperture.

In a metal-insulator-metal nano structure, the phase of transmitted light depends on the slit width. The slit widths of the metallic nano-slit array lens increases as the distance between the slit and the center increases in order to focus the incident light at the specific point.

In this study, we assumed that the target fluorescent substance is a voltage sensitive dye, RH795, whose peak wavelengths of absorption and emission are 530 nm and 712 nm, respectively. The metallic nano-slit array is made of an Au film with a thickness of 480 nm. And, the lens width is 5 μm. A 1.5-μm wide aperture on Al film, which can be designed in a standard CMOS process, is placed 7.7 μm below the metallic lens. All the structures are sur-

rounded by SiO_2. The slit widths are from 60 nm to 250 nm.

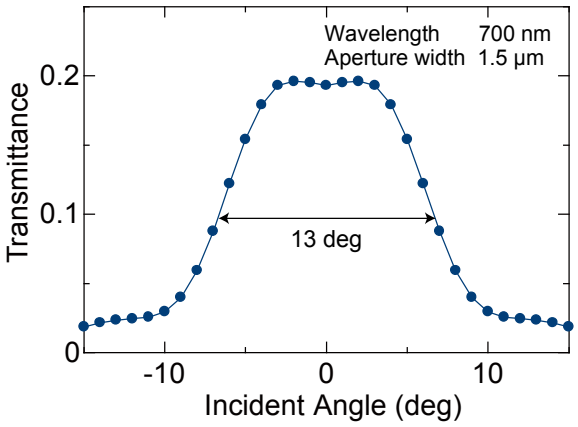

Fig. 2 Transmittance of the metallic nano-slit array and the aperture as a function of the incident light angle.

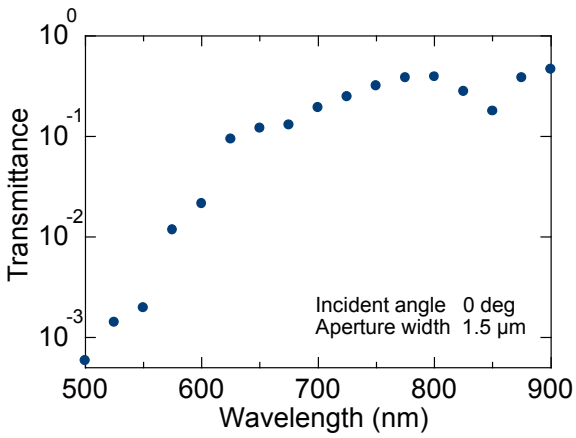

Fig. 3 Transmittance spectrum of the metallic nano-slit array and the aperture.

The spacing between the slits is 110 nm for each adjacent ones. This nano-slit array is designed with a focal length of approximately 7.5 μm.

3. Electromagnetic simulation by finite difference time domain method

The proposed structure is analyzed by a two-dimensional finite difference time domain (FDTD) method. Figure 1 (b) shows horizontal electric field when the vertical incident light with horizontal polarization at a wavelength of 700 nm is launched onto the metallic nano-slit array lens. The result shows that the incident light is focused and works as a lens.

Figure 2 shows the transmittance of the structure as a function of incident angle. The full width of half maximum (FWHM) is 13 deg. From this result, it is estimated that a spatial resolution of 5 μm is obtained at the approximately 40 μm away from the nano-slit array surface.

The transmittance spectrum is shown in Fig. 3. The incident light angle is assumed to be 0 deg. And, the width of the slit on Al layer is 1.5μm. As the wavelength decreases shorter than 600 nm, the transmittance also decreases drastically. At the excitation wavelength of the target fluorescent substance (530 nm), the transmittance is approximately 100 times lower than that at the emission wavelength (712 nm). This result shows that the Au nano-slit array also works as a long pass filter to filter out the unwanted excitation light in this case. When a fluorescent substance with shorter emission wavelength such as green fluorescent protein, the Au nano-slit array is not suitable and it should be made of Ag or Al. On the other hand, the transmittance is high even at 900 nm. This characteristic is not harmful for fluorescent imaging.

4. Conclusions

We proposed a metallic nano-slit array lens for implantable *in-vivo* CMOS image sensor. The electromagnetic fields were simulated by FDTD method. The results show that the incident angle is limited and the spatial resolution is improved by the structure. In addition, this structure has characteristics of a long pass filter. These characteristics are suitable for fluorescent imaging.

Acknowledgements

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