Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp1043-1044

Plasmonic filters integrated into back-illuminated CMOS image sensor for spectrometric applications

Yunki Lee[1], Bumsuk Kim[1], Dongmin Keum[1], Taehan Kim[1], Hyunseok Song[1], Changrok Moon[1] and Yongin Park[1]

[1] System LSI Division, Samsung Electronics Co., Ltd
Samsung-ro 1, Giheung-gu
Gyeogngi-do 17113, Korea
Phone: +82-10-3789-3973 E-mail: yunki97.lee@samsung.com

Abstract

Plasmonic filters which consist of periodic metal disc patterns were integrated into a back-illuminated CMOS image sensor with 1.0μm pixels. The metal layer used for the patterns is made of tungsten which is a common material for semiconductor process. The discs were formed by photo lithography and dry etching. The experimental ranges of disc size and pitch were 270~380nm and 400~550nm, respectively. It was verified that peak wavelength in inverse transmittance through the filters could be controlled simply by changing the size and pitch of the disc array. The experimental result revealed that the CMOS image sensor equipped with plasmonic filters could be used as a spectrometer for various applications.

1. Introduction

Recently, there is an increasing demand for sensors that can obtain more detailed spectrum information in the visible and near infrared regions for various special purposes. For example, a mobile spectrometer based on CMOS image sensor which has external color filters was commercialized.

Each pixel of normal color image sensors for cameras has on-chip organic color filter to get color information like red, green, or blue. The spectral characteristics of the color filter materials depend mainly on pigments or dye included in them. So, it is generally difficult to implement various spectral characteristics with organic on-chip filters. Also, it is quite natural that process would become complicated when there are more kinds of on-chip organic filters.

Many studies have been conducted on plasmonic color filter using metal films with periodic hole arrays [1-5]. It has been shown that the size and pitch of the holes can be adjusted to fine-tune the spectral properties. However, the transmittance through the subwavelength-sized holes is not so large though it is amplified by surface plasmon resonance (SPR) at peak wavelength position. This may limit the applications where low light performance is important because sacrifice of sensor sensitivity is inevitable.

On the other hand, good sensitivity can be achieved by forming metallic disc patterns instead of hole array. The periodic metal discs have spectral characteristics where light portion in specific wavelength range is reflected [6].

In this paper, we present a back-illuminated CMOS image sensor with 1.0μm pixels combined with plasmonic filters consisting of periodic tungsten discs. Spectral responses were measured according to the various sizes and pitches of the filter patterns. Analysis was done to check the feasibility of usage as a spectrometer.

2. Fabrication and measurement

Most of the optical filter fabrication methods based on surface plasmon resonance (SPR) were reported to have been using e-beam lithography or nano-imprint [7-8]. These methods have limited productivity compared to photo lithography, which is commonly used in semiconductor production. To ensure feasibility of the plasmonic filter fabricated by metal process compatible with mass production process, a commercial sensor was modified.

In the experiment, back-illuminated CMOS image sensors with 1.0μm-sized pixels were utilized. Figure 1 shows the structure of the reference chip used in the experiment. Various kinds of metallic disc patterns having different sizes and pitches were fabricated based on KrF photo lithography and etching process for general semiconductor fabrication. Among them, five different types of metallic disc arrays were inspected by scanning electron microscope, and the details are shown in Table 1. In addition, experiment of changing thickness of metallic structures and insulation film was carried out to confirm the impact of wavelength variation in the fabrication process. The metal thickness applied to the filters for experimental results in this paper is 200nm.

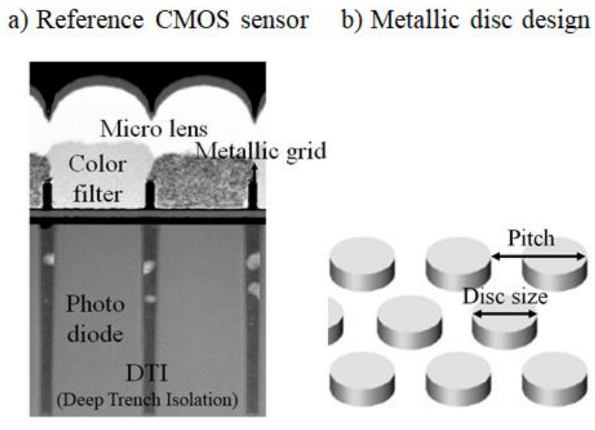
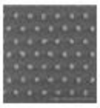
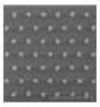
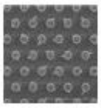
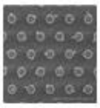


Fig. 1 Reference pixel structure which has 1.0μm sized pixels with DTI (Deep Trench Isolation) and metallic disc pattern design.

Table I Size and pitch of plasmonic filters

	Type1	Type2	Type3	Type4	Type5
Pitch (nm)	400	420	450	500	550
Disc size (nm)	270	278	290	360	380
SEM image					

The spectral response curves of sensors with no filters and those with the plasmonic filters were measured in the range of 400~1000nm using a monochromator. They were used to obtain transmittance through the plasmonic filters. To define the wavelength resolution of the optical filter, inverse transmittance of the filter was calculated at each wavelength. Then all the curves were normalized for comparison. Figure 2 shows the normalized inverse transmittance curves for the five types of the plasmonic filters. It can be seen that the peak wavelength gets larger as the pitch of the disc patterns increases. Figure 3 shows the peak wavelength according to change of the pitch of disc patterns. From this result, it is possible to distinguish specific wavelengths through metallic disc pattern design and general semiconductor process.

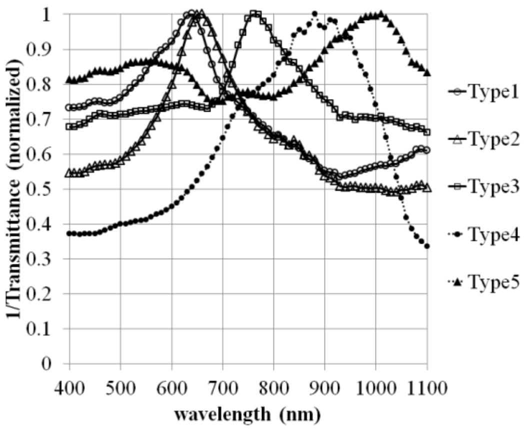
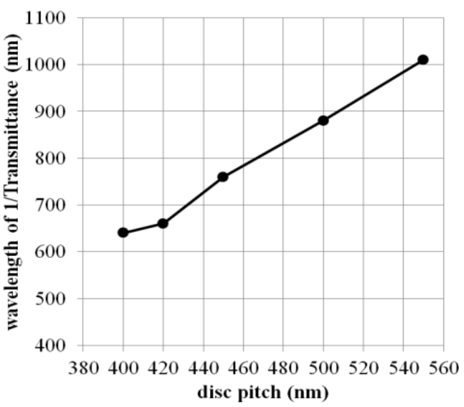


Fig. 2 Inverse transmittance curves for each type of plasmonic filters. The peaks are normalized for comparison.

Fig. 3 Peak wavelength of inverse transmittance curves according to the disc pitch of plasmonic filter.



3. Conclusions

Plasmonic filters made up of tungsten were integrated into commercial back-illuminated CMOS image sensors with 1.0μm pixels. The filters were designed as periodic disc arrays, and they were fabricated using standard KrF photo lithography. The reciprocal curves of transmittance through the plasmonic filters show that design of the disc patterns allows wavelength of light to be resolved with good resolution. The experimental result increases the possibility that CMOS image sensor equipped with plasmonic filters can be used as a spectrometer for various purposes.

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