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High performance aluminum plasmonic filters integrated into back-illuminated CMOS image sensor for spectrometric applications

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Abstract

Plasmonic filters which consist of periodic metal disc patterns were integrated into a back-illuminated CMOS image sensor with 0.8µm pixels. The tungsten metal layer for disc patterns was replaced with aluminum which is also a common material for semiconductor process. To detect target wavelength precisely, aluminum disc pattern (100~380nm) and pitch size (400~550nm) were investigated by simulation. Peak wavelength in inverse transmittance is controlled by changing disc size and pitch of the disc array and the range of peak is wider and peak is more intense when using aluminum than tungsten. Also, the ratio of intermediate layer (IMD) to disc thickness plays a key role in increasing performance of filter. CMOS image sensor equipped with plasmonic filters could be used as a spectrometer for various applications.

1. Introduction

Over the decade, various types of bio and medical sensors are widely used and require more accurate and handy scanning technology with more detailed spectrum analysis in the visible and near infrared regions. For example, medical diagnosis kit monitoring our body status such as oxygen saturation level in human blood cell could be application of using sensors for spectrum analysis. For more powerful and useful sensor, mobile spectrometers based on CMOS image sensor with customized external color filters are suggested for spectrum analysis.

Mobile CMOS image sensors absorb all range of incident light source and utilize 400-700nm range by red, blue and green color filter arrays. Purpose of the normal camera sensors is to represent original image to output screen without any loss of information or image distortion. However, diagnosis system reading oxygen saturation (ratio of oxy-hemoglobin and oxy- and de-oxy-hemoglobin), for example, depends on accuracy since intense peaks of Hb and HbO_2 spectrum are near-by and inaccurate results lead to severe health problem. More detailed recognition requires extended number of different color filters materials consists of pigments or dye. With small pixel sized image sensor, it is difficult to implement various color filters on chip and it is also not distinguish peaks with adjacent color.

For this purpose, plasmonic color filters using metal films with periodic hole arrays [1-5] have been studied and geometric parameter such as size and pitch of the holes are evaluated for spectral properties. Since metal arrays for amplifying surface plasmon resonance (SPR) occupy surface area on pixel and block incident light source, metal array should be well-designed not to sacrifice sensor sensitivity severely. Losing transmittance signal at peak wavelength weaken resolution of spectrum and performance of filter.

The most required key technology of in-chip spectrometer is if the sensor can distinguish different peaks in narrow range for more precise results. This can be implemented by well-designed plasmonic filters on small (<1.0um) pixels and input signal is reconstructed by software algorithm. For separation of spectrum at short wavelength, aluminum was chosen for the next plasmonic filter. With same structure and scheme, aluminum with high reflectivity is expected as a powerful low-wavelength filter.

In this paper, we present a back-illuminated CMOS image sensor with 0.8µm pixels combined with plasmonic filters consisting of periodic Aluminum discs. Spectral responses were simulated according to the various sizes and pitches of the filter patterns..

2. Fabrication and simulation

E-beam lithography or nano-imprint fabrication methods were suggested for most of the optical filter using surface plasmon resonance (SPR) [6-7]. However, these lab-scale fabrication methods are not suitable for mass production compared to photo lithography in semiconductor production and chip size is also limited due to number of filtering material needed to separate spectrum. For commercial use, plasmonic filters with metal films were fabricated on modified CIS sensors.

In the experiment, back-illuminated CMOS image sensors with plasmonic filters were developed. Previously, tungsten metallic disc patterns with different sizes and pitches were fabricated using general KrF photo lithography and etching process on modified CIS reference chip and insulation film was carried out [8].

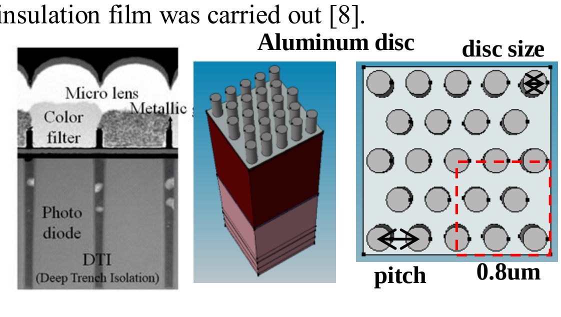

Fig. 1 Reference pixel structure and simulation with DTI (Deep Trench Isolation) and metallic disc pattern design

The spectral response of sensors with aluminum plasmonic filters and tungsten plasmonic filters were compared by simulation, based on experimental evaluation in the range of 400~1000nm using a monochromator. Inverse transmittance was used to observe the wavelength resolution of the optical filter, and all curves are normalized for comparison. Figure 2 shows the normalized inverse transmittance curves with aluminum and tungsten plasmonic filters and aluminum filter has much sharper curve near max value guaranteeing detection and separation of spectrum more clearly.

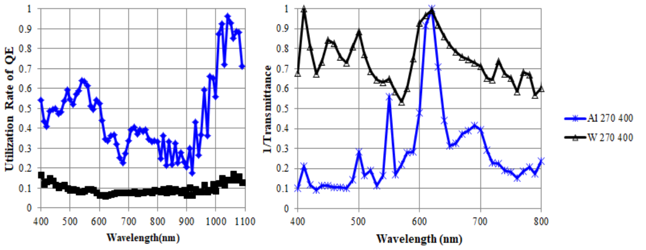

Fig. 2 (Left) Filtering ability of tungsten and aluminum and (Right) inverse transmittance curves for each type of plasmonic filters. The peaks are normalized for comparison.

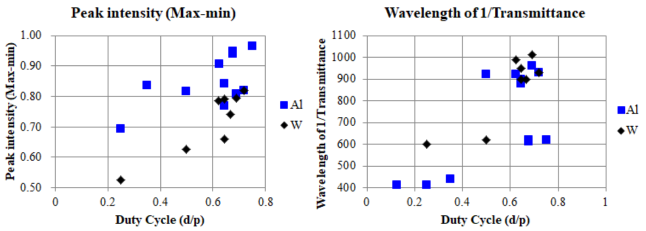

Fig. 3 (Left) Peak intensity of aluminum vs. tungsten and (Right) peak wavelength of inverse transmittance curves with duty cycle (d/p).

For more optimized spectrum analysis, effect of geometry was also examined. Figure 3 (left) shows that peak intensity gets larger as ratio of disc size to pitch distance (duty cycle, d/p). Peak wavelength of inverse transmittance was also investigated for both aluminum and tungsten and only aluminum can detect target peak under 600nm in Figure 3 (right). The peak wavelength gets more clearly separated as the ratio of intermediate layer (IMD) to disc thickness increases (Figure 4 and 5 (Right)). Peak wavelength of inverse transmittance also varies with IMD/Disc thickness (Figure 5(Left)). Based on this simulation, with the change of the pitch of disc patterns, the ratio of IMD to aluminum disc thickness, we can distinguish specific wavelengths through aluminum metallic disc pattern by designing metal/photo/etch process in general semiconductor process.

Type	Type1	Type2	Type3	Type4	Type5
D (nm)	270	270	270	270	270
P (nm)	400	400	400	400	400
Ratio of IMD /Disc Thickness	0.13	0.25	0.64	1.27	1.82

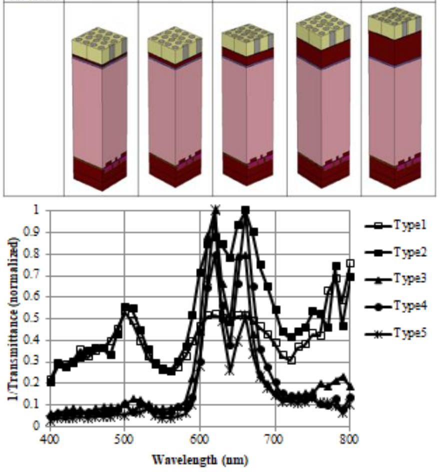

Fig. 4 (Top) Geometry of intermediate layer (IMD) and disc thickness and (Bottom) inverse transmittance with different IMD/disc ratio.

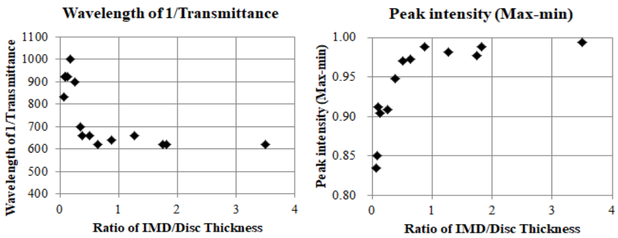

Fig. 5 Peak wavelength of inverse transmittance curves and peak intensity with IMD/disc thickness of plasmonic filter.

3. Conclusions

High performance aluminum plasmonic filters were integrated into back-illuminated CMOS image sensors with 0.8um pixels. Various process factors for periodic disc arrays are designed and suggested based on commercial standard KrF photo lithography. Transmittance through the plasmonic filters indicates aluminum utilizes wider range of wavelength with more intense peak of QE, therefore more applications are expected. We can produce customized CMOS image sensor equipped with plasmonic filters as a spectrometer for various purposes.

References

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