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Nano-patterned visible wavelength filter integrated with an image sensor exploiting a 90-nm CMOS process

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Abstract

A highly efficient visible wavelength filter enabling a homogeneous integration with an image sensor was proposed and manufactured by employing a standard 90-nm CMOS process. A one dimensional subwavelength Al grating overlaid with an oxide film was built on top of an image sensor to serve as a low-pass wavelength filter; a microlens was then formed atop the filter to achieve beam focusing. The structural parameters for the filter were: a grating pitch of 300 nm, a grating height of 170 nm, and a 150-nm thick oxide overlay. The overall transmission was observed to reach up to 80% in the visible band with a decent roll-off near ~700 nm. Finally, the discrepancy between the observed and calculated result was accounted for by appropriately modeling the implemented metallic grating structure, accompanying an undercut sidewall.
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Keywords: Optical filters; Subwavelength structures; Diffraction gratings; Metals; Detectors

1. Introduction

Visible wavelength filters, in conjunction with a complementary metal–oxide–semiconductor (CMOS) image sensor (CIS), have been extensively studied in various applications including digital cameras and other types of sensors [1]. For cell-phone cameras, they especially play the important role of enhancing the image quality by suppressing the unwanted infrared light delivered by the sun, while passing the visible light efficiently [2]. Previously, the filters were mainly implemented by making the best of a dielectric multi-film structure with an alternately varying index of refraction or a spin-cast dye film. There has been also an approach based on a SiO_2/TiO_2 photonic crystal structure with a defect layer inserted in the middle, offering a high transmission yet requiring a precision film-thickness control [3]. Meanwhile, a subwavelength patterned grating in silicon or metal has been manufactured individually in a quartz substrate, attracting a vast amount of attention as a visible filter in light of the simple structure and the ultra-small thickness [4]. However, the homogeneous integration of the visible filter with the image sensor through a single CMOS process is definitely preferred over the hybrid integration, in order to accomplish significant benefits, including a high compatibility, a low cost, an ease in mass production, and a flexible integration with signal processing circuits and other optical devices.

In this paper, we attempted to construct a visible wavelength filter incorporating a one-dimensional (1D) subwavelength patterned Al grating, integrating homogeneously into a CMOS image sensor. A standard 90-nm CMOS process was utilized for producing both the

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filter and the image sensor simultaneously, thereby improving the transmission efficiency of the filter as well as the resolution of the sensor in a cost effective manner. The practical structure of the fabricated grating was elaborately modeled to identify the discrepancy between the measured and the theoretical performance.

2. Proposed device and its design

The primary aim of this work is to create a visible filter in conjunction with a CIS, where the entire visible band covering the red, green and blue is allowed to pass. The schematic configuration of the proposed visible filter combined with a CIS is sketched in Fig. 1. The CIS consists of an array of photodetectors and the corresponding driving/reading circuits. A 1D Al grating is created on a bottom oxide layer atop the CIS, and it is overlaid with a top oxide layer; a microlens is formed over the top oxide to achieve beam focusing. The structural parameters associated with the device are denoted: Λ for the grating pitch, H_a for the grating thickness, W for the grating width, and H_o for the height of the top oxide layer. The transfer characteristics of such a grating may be mostly dependent upon the parameters, like the metal thickness, the duty ratio, and the surrounding overlay. The dispersion data of the Al metal was derived from the Lorentz–Drude model, while the oxide was assumed to have a constant refractive index of 1.5, with a negligibly small optical loss [6]. It is to be noted that we have taken advantage of an overlay on top of the Al grating for substantially enhancing the transmission in the visible band. Thanks to it, the top surface of the filter could be naturally

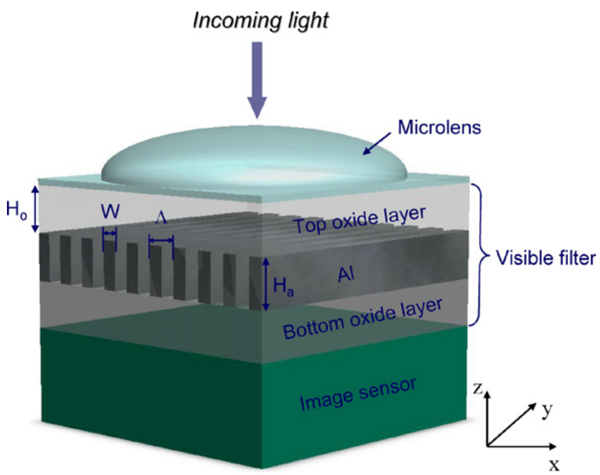

Fig. 1. Configuration of the proposed visible filter incorporating subwavelength patterned metal gratings, which are integrated with a CMOS image sensor.

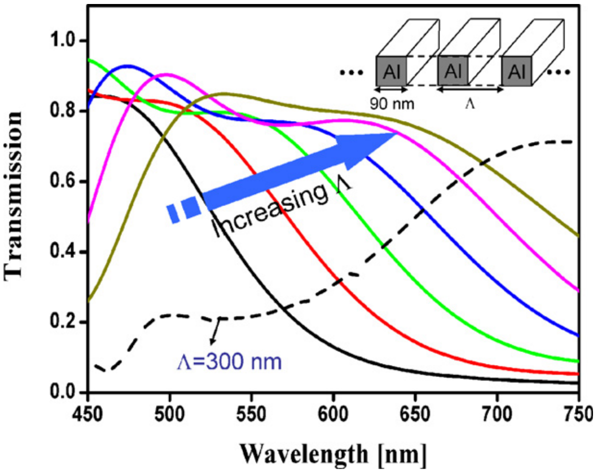

Fig. 2. Calculated spectral response for the proposed visible filters, when the grating period varies from 260 to 360 nm with a step size of 20 nm.

planarized to facilitate the formation of a microlens array, which is widely used to elevate the sensitivity of the CIS by virtue of the beam focusing.

The calculated spectral responses for the device designed in this work are shown in Fig. 2, where the grating pitch is primarily varied from 260 nm to 360 nm with a step size of 20 nm to control the roll-off characteristics and to maximize the transmission, while the grating width was fixed at a minimum feature size of 90 nm [5]. As indicated in Fig. 2, for the transverse electric (TE) polarization (solid curve), the cutoff wavelength moved to longer wavelength with increasing Λ. Meanwhile, for the transverse magnetic (TM) polarization (dashed curve) the spectrum exhibits no roll-off characteristics, which is due to the fact that a filter based on a 1D metallic subwavelength grating is known to act as a low-pass wavelength filter only for the TE polarization, where the electric field is aligned in the direction of the grating [5]. We have focused on a few promising candidates with Λ = 260, 280, 300 nm, in light of an affordable transmission in the visible domain. The other structural parameters were: W = 90 nm, H_a = 170 nm, and H_o = 150 nm. The available overall transmission efficiency in the visible band was about 85%, and the transmission in the NIR band was sufficiently suppressed. It is remarked finally that the transmission was increased by ~70% with the help of the overlay made of an oxide film. This may result from the fact that the difference in the surface plasmon waves on the top and bottom side of the metallic grating is minimized to help boost the light transmission [7].

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