Monolithic Ultrabroadband Multispectral Color Filter Array

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Primary CNF Tools Used: ASML stepper, Oxford 100 ICP-RIE, YES EcoClean Asher, Oxford PECVD, JEOL 9500, Heidelberg Mask Writer-DWL2000, ABM Contact Aligner, Oxford Cobra ICP Etcher, Woollan RC2 Spectroscopic Ellipsometer, Logitech Orbis CMP, AJA Sputter System

Abstract:

We use a modified Fabry-Perot structure with selectively suppression and subwavelength structures in cavity to realize MSFAs that can cover the range from 450 - 910 nm.

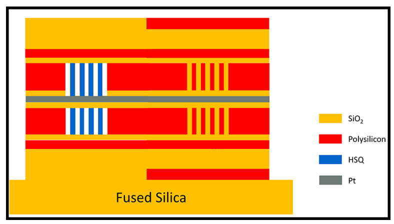

Figure 1: Schematic of the stack structure of the color filters.

Summary of Research:

Multispectral imaging (MSI) has found applications in various fields such as metrology, medical spectrum diagnoses, and industrial processes, offering scenes with multiple narrowband spectral channels. Conventional multispectral systems typically rely on dispersive elements like diffraction gratings or prisms, which limit further miniaturization and integration [1]. To overcome this limitation, snapshot multispectral imaging systems based on multispectral filter arrays (MSFAs) have been developed [2]. These systems enable the capture of a parallel array of images with different spectral channels in a single shot, eliminating the need for spatial or spectral scanning and allowing for highly compact and integrated designs. However, the design and fabrication of a monolithic broadband MSFA with narrow bandwidth and high color purity present significant challenges.

People have demonstrated integratable color filter arrays (CFAs) using various approaches such as plasmonic resonance [3], Mie resonance [4], and guided mode resonance [5]. Among these, CFAs based on Fabry-Perot (FP) resonators offer advantages such as polarization insensitivity, angle insensitivity, high transmission, and narrow full-width at half-maximum (FWHM), which are desirable for multispectral filter arrays (MSFAs). However, traditional thin film color filter arrays based on FP cavities often require multiple filter stacks, leading to fabrication challenges and limited spectral range [6]. Increasing the number of detection channels also necessitates additional lithography and etching steps, further complicating the fabrication process. To address these challenges, subwavelength grating structures have been introduced to modify the optical length of the cavity without altering the physical thickness. Nevertheless, in FP resonators, multiple resonances can impact color purity and the free spectral range (FSR). Furthermore, the spectral tuning range is restricted by the nanofabrication process, as the fill ratio of the subwavelength grating cannot be excessively high.

We present a CMOS compatible multispectral FP color filter arrays which have a large spectral range (450nm-910nm) with narrow FWHM (<40nm) based on selective suppression and a subwavelength grating (Figure 1). We demonstrate the broadband MSFAs based on modified FP structure with second order resonance which can cover the wavelength range from 630 nm to 960 nm [7]. One of the limitations of extending the color filters to shorter wavelength is the effective index range that can be obtained with polysilicon and silicon dioxide subwavelength structures. To extend the working wavelength range to cover visible spectra, we enlarge the effective index range by introducing air in the cavity. To cap air in the cavity, we need the air gaps in the cavity have a relatively small feature size and high aspect ratio such that we can cap as much as air in the cavity rather than fill it out with top deposition. To circumvent the high aspect ratio etch step, we directly use 11% HSQ as the cavity layer and expose the HSQ layer with hexagonal subwavelength grating or mesh structures. After development, we can have around 50 nm width and 170 nm depth air gaps without the need of high aspect ratio etching. We cap the air with top deposition based on the filling capability of deposition recipe. To enhance the transmission, we use one 35 nm layer as the reflection mirror. We combine the HSQ and air cavity design with the polysilicon and silicon dioxide cavity design such that we can cover the range from visible to NIR.

The main fabrication steps for our design are shown in Figure 2. We use polysilicon as the high index material in the DBRs. Polysilicon is deposited by plasma-enhanced chemical vapor deposition (PECVD) and anneal it at 700°C for two hours to make it crystalize. We use JEOL 9500 and negative resist hydrogen silsesquioxane (HSQ) to pattern the cavity and use inductively coupled plasma reactive ion etching with HBr to transfer the pattern from HSQ to polysilicon. We fill the gap by TEOS (Tetraethyl orthosilicate) SiO_2. After finishing the fabrication of long polysilicon and silicon dioxide cavity, we etched away the silicon dioxide for the area with HSQ and air cavity. The 11% HSQ is spun at 2000 rpm to have around 210 nm thickness. After exposure and development, we use PECVD to deposit silicon dioxide to cap the air gaps and use chemical mechanical polishing (CMP) to planarize the surface. We anneal our sample to make HSQ turn into silicon dioxide material. After testing, there is about 20% thickness decrease after annealing. However, there is no obvious lateral dimension change or structure deformation (Figure 3). Through the similar processes we can fabricate the top part of our design.

We present a broadband multispectral color filter arrays covering from 450 nm to 910 nm with transmissions over 40% and FWHM less than 40 nm (Figure 4). The simulation is based on Rigorous coupled-wave analysis (RCWA). To overcome the effective index range limitations, we lower the cavity effective index by mixing air with silicon dioxide. To alleviate the fabrication challenges, we use the e-beam resist HSQ as the cavity layer which is close to silicon dioxide after annealing. We show that the patterned HSQ will not have obvious deformation after annealing at 700°C which make it a good alternative for silicon dioxide when pattern relatively small features.

Conclusion and Future Steps:

We present a MSFAs design that can cover the wavelength range from 450 nm to 910 nm aligned with the detection range of most silicon CMOS imaging sensors. We demonstrate the potential of using HSQ directly as a part of nanostructure which can have relatively small feature size after development and have similar optical property as silicon dioxide after anneal. With the HSQ and air cavity, the effective index range is extended which enables monolithic MSFAs to cover a wavelength range from visible to NIR.

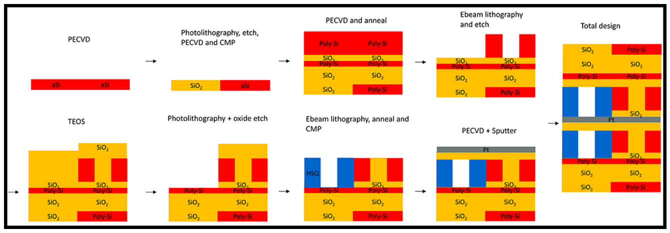

Figure 2: The main fabrication steps.

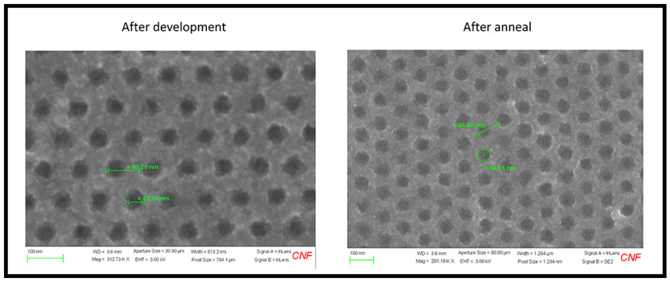

Figure 3: SEM images of patterned HSQ layers after development and anneal.

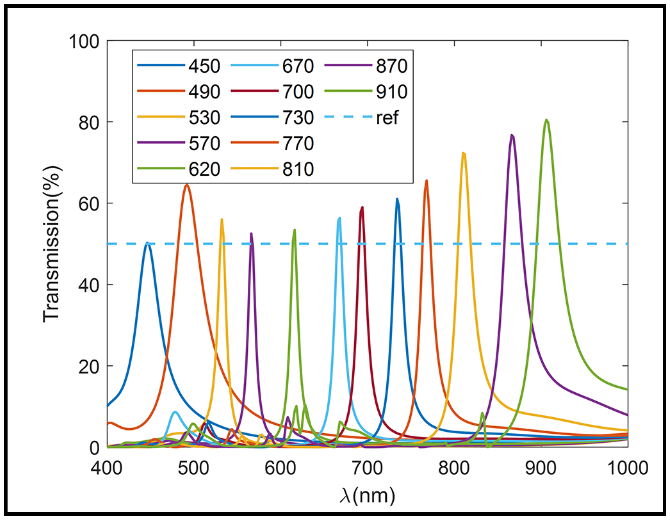

Figure 4: The relative transmission of different color filters based on simulation.

References:

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