Monolithic Multispectral Color Filter Array

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

Abstract:

We introduce subwavelength grating and selective suppression to a Fabry-Perot cavity. We demonstrate a miniaturized monolithic broadband multispectral color filter with more than 40% transmission and less 30 nm full width at half maximum (FWHM).

Summary of Research:

A CMOS compatible multispectral color filter array with miniatured size is desired for the application in displays, image sensors and multispectral imaging. Many conventional multispectral imaging systems consist of a dispersive element (prism or grating) to separate the wavelengths, which makes the system challenging to further miniaturize [1]. Many transmissive color filters based on surface plasmon resonance and dielectric metasurfaces have been demonstrated to have high spatial resolution and small pixels. However, due to large FWHM (>50nm), low transmission (<40%) and high angular sensitivity, it is challenging to apply them to multispectral imaging.

People propose to combine multiple thin-film color filters based on Fabry-Perot (FP) resonators for high-quality MSFA [2]. Compared to a color filter based on diffraction, an FP resonator is polarization insensitive and relatively angular insensitive. It also has a high transmission and a narrow FWHM. The transmission peaks are tuned by changing the thickness of the cavity with lithography and etching. Due to the increasing steps of fabrication, it is challenging to have many detection channels. To overcome this challenge, people propose to introduce a 2D subwavelength grating structure inside the resonance cavity to manipulate the optical path length and control the transmission peak [3]. However, due to the properties of FP resonators, there will be multiple resonance peaks which constrain the free spectral range (FSR). Also, due to the limitation of fabrication, the fill ratio of the subwavelength grating structure cannot be too high which would result in a small spectral tuning range.

We demonstrate a broadband multispectral FP color filter array based on two-dimensional subwavelength gratings and selective suppression [4], which can cover from red to near-infrared (630nm-960nm) with narrow bandwidths (<30nm). Our thin-film color filter stack consists of two DBR mirrors and a cavity with two layers of subwavelength gratings sandwiching a thin metal layer (Figure 1). To achieve a large tuning range, we apply a combination of mesh and grating structures (Figure 2) and use the second-order resonance of the FP resonator with selective suppression. We change the effective index of the cavity to tune the location of the transmission peak. Instead of using the first-order transmission peak, we choose the second-order transmission peak for its smaller reflection phase. Also, the second-order transmission peak has a narrower linewidth compared to the first-order transmission peak due to a larger optical path length in the cavity, which makes the FWHM of our filters smaller than 30 nm. By inserting a metal layer in the middle of the cavity, the odd-order transmission peaks will be largely suppressed, which allows the second-order resonance to have a comparable FSR with the first-order resonance.

There are mainly six steps for the fabrication of our color filter array (Figure 1). We use polysilicon as the high index material for both DBR and cavity. Polysilicon

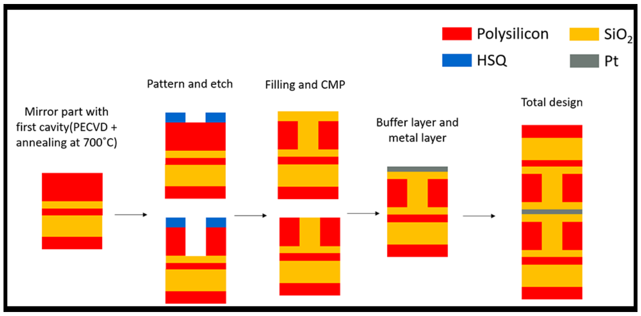

Figure 1: Schematic of the stack structure of the color filter and the main fabrication steps.

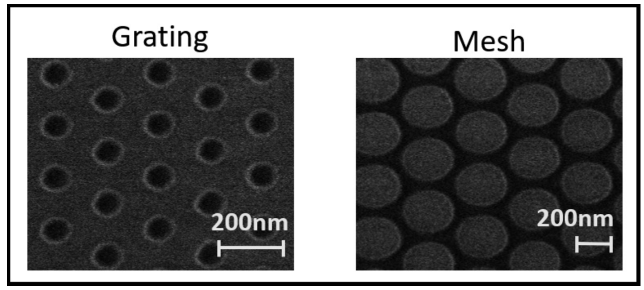

Figure 2: SEM of the mesh and grating structure. The dark part is the HSQ after e-beam lithography and developing. The gray part is polysilicon underneath the HSQ.

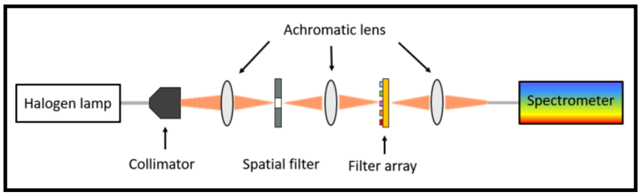

Figure 3: Schematic of the measurement setup.

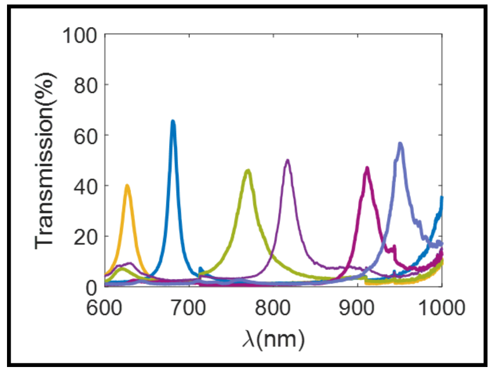

Figure 4: The relative transmission of different color filters based on measurement.

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 atomic layer deposition (ALD) with SiO_2 and polish the surface with chemical mechanical polishing (CMP).

We demonstrate a multispectral color filter array covering from 630 nm to 960 nm with transmissions over 40% and FWHM less than 30 nm. We use a halogen lamp (HL-2000-LL) to generate a broadband light source that covers 400-1700 nm (Figure 3). A collimator and an achromatic lens are used to focus the light on the filter which is 50 µm × 50 µm. We deposit 100 nm Pt above the sample and open a 40 µm × 40 µm aperture on the filter. A blank fused silica wafer with the same apertures is used as the reference. The transmitted light is collected and focused on the spectrometer (Ocean Insight FLAME-S-VIS-NIR-ES). The relative transmission is acquired by comparing the transmission of filters with the reference wafer. From the measurement (Figure 4), the filter array can cover the spectrum from 630 nm to 960 nm with transmission above 40%. The FWHM of all measured transmission peaks is smaller than 30 nm. The transmission and FWHM can be improved by refining the fabrication process to decrease the asymmetry between the two cavities.

Conclusions and Future Steps:

We show that using the sub-wavelength grating, broadband and narrow linewidth color filter array with the same layer structure can be created, which enables monolithic integration of filter banks with imaging sensors. This design can be transferred to visible or infrared wavelength by changing the high index material and optimizing the thickness and lattice structure. This has the promise of a monolithic broadband multispectral color filter array and paves the way for one-shot multi-spectral imaging.

References:

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