

Design of Sub-Wavelength Color Filters

Design and Simulation with the RSoft Tools



Outline

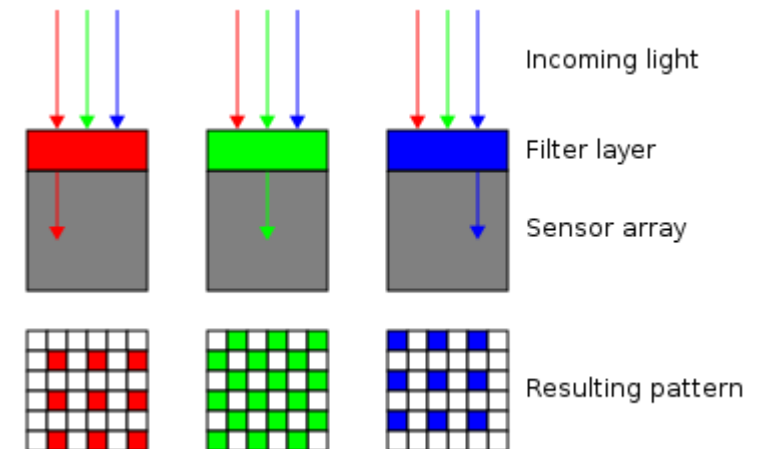
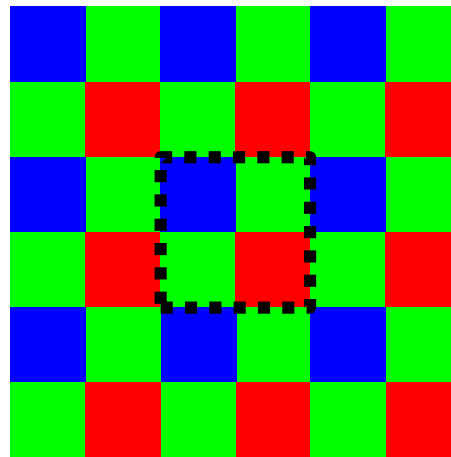
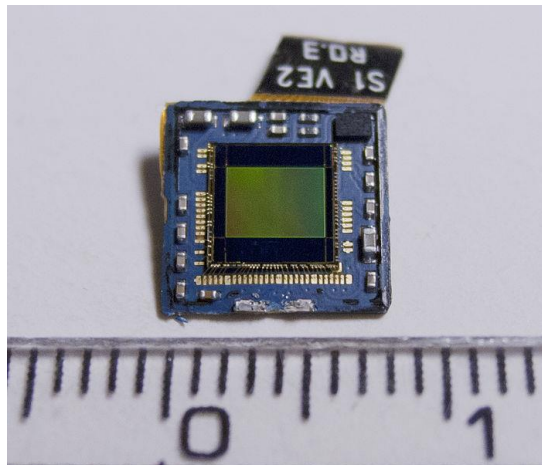
- Introduction
- Plasmonic color filters
- Dielectric color filters
- Related Topics
- Conclusion

Introduction

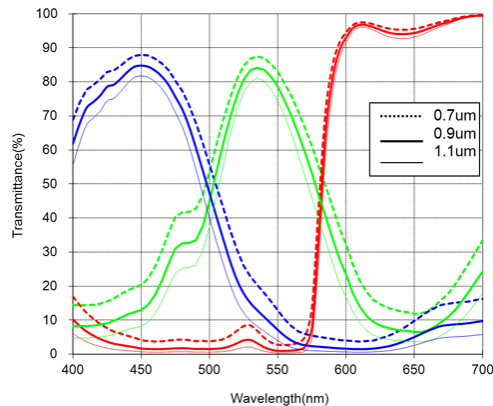
- Cameras are becoming smaller to meet the need for increased resolution and smaller form factors
- This miniaturization requires smaller pixels and a redesign of traditional color filters
- Many color filters are based on traditional absorptive dyes:
 - More susceptible to cross-talk as pixel size decreases
 - Fade over time
- Here we explore two alternative color filter types:
 - Plasmonic-based color filters built from thin metal films
 - Dielectric color filters built from dielectric materials

Color Filter Array

- Cameras utilize color filter arrays to accurately detect color
- There are many color filter arrangements:
 - The Bayer mosaic is shown below
 - It uses four sensors per pixel: 1 blue, 1 red, and 2 green
- The final color image is found via post-processing

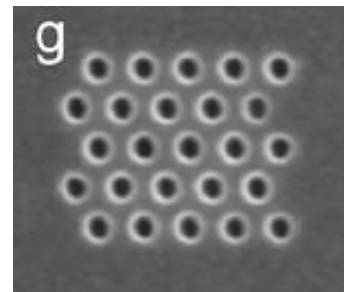
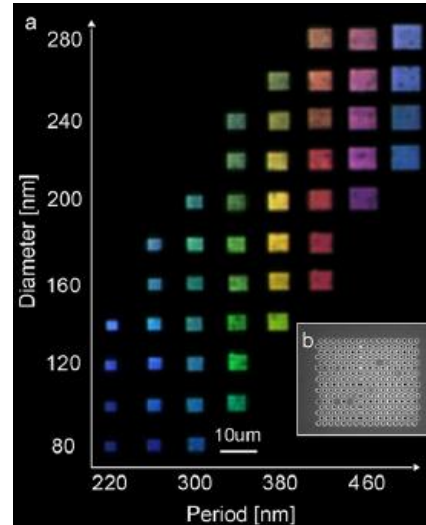


Types of Color Filters



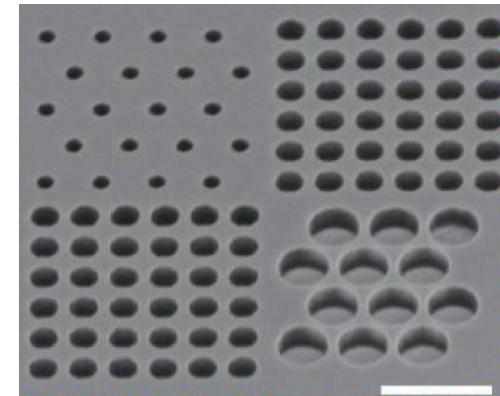
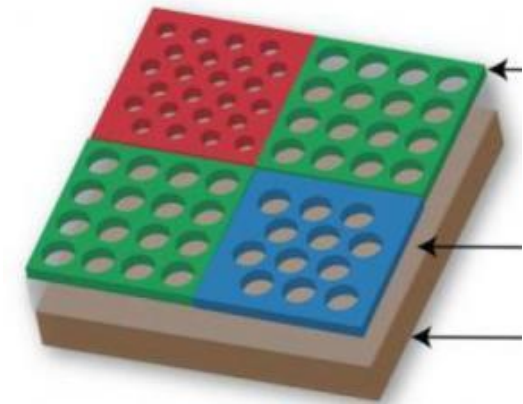
Pigment/Dye Filters

Fujifilm's COLOR MOSAIC
(<http://www.fujifilmusa.com>)



Plasmonic Filters

Yokogawa et al. 'Plasmonic Color Filters for CMOS Image Sensor Applications', *Nano Letters*, **12** (2012)



Dielectric Filters

Horie et al, "Visible Wavelength Color Filters using Dielectric Subwavelength Gratings for Backside-illuminated CMPS Image Sensor Technologies", *Nano Letters*, **17** (2017)

Types of Color Filters

- **Pigment/Dye:** Well known and widely used, but small pixels more susceptible to cross-talk and slowly fade with UV exposure
- **Plasmonic:** Very sensitive (both good and bad), potentially easier to fabricate, and do not degrade, but have low transmittance
- **Dielectric:** Potentially easy to fabricate, does not degrade and has high transmittance compared to plasmonic filters

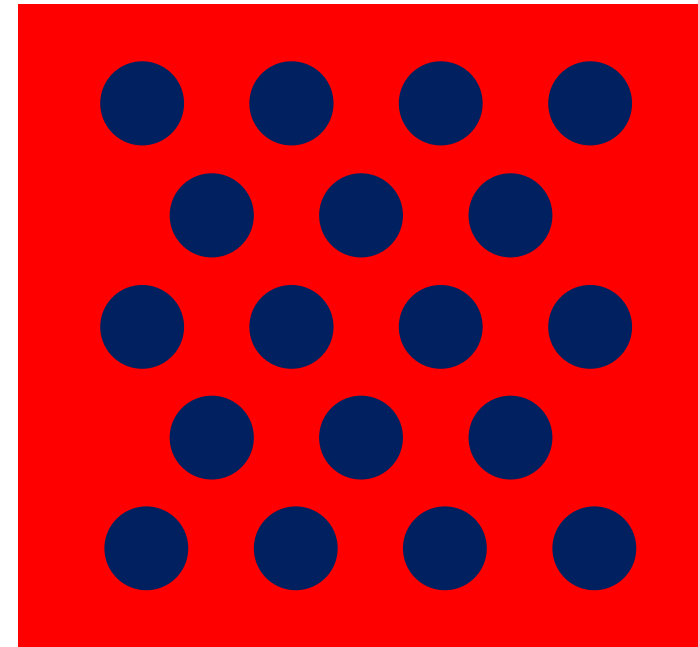
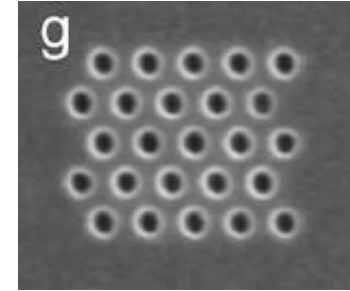
Plasmonic Color Filters



Structure Overview

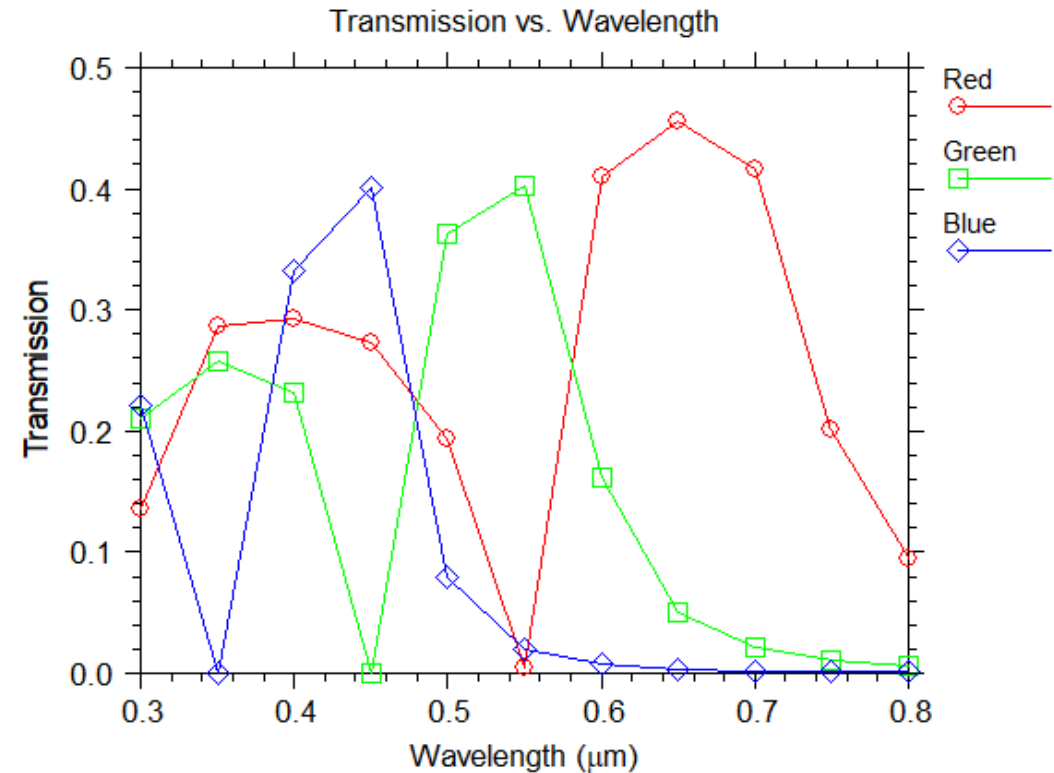
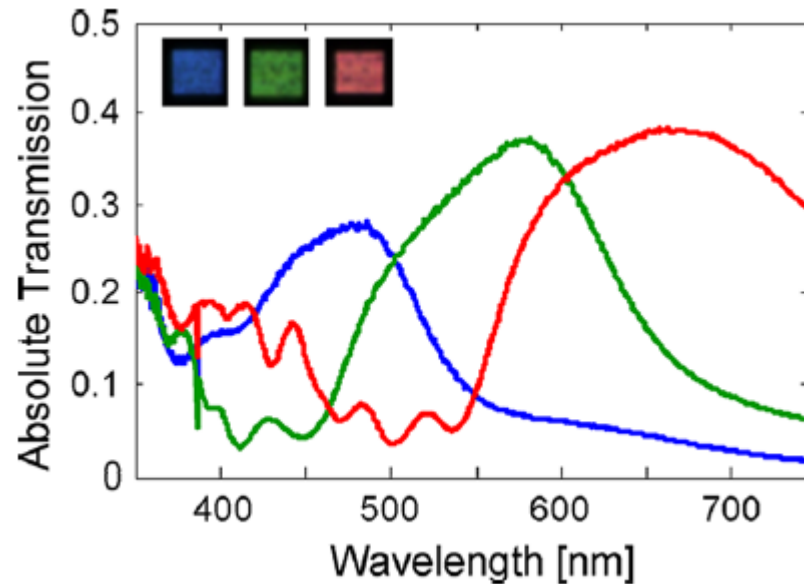
- All gratings are hexagonal nano-hole arrays in a 150nm thick Al plate in a SiO₂ background
- Individually tuned transmissive gratings for Red, Green, and Blue:

Color	Period	Radius
Red	420nm	120nm
Green	340nm	90nm
Blue	260nm	70nm



Results

- The results calculated by FullWAVE FDTD agrees well with the reference, with the exception of an additional resonance at shorter wavelengths which contributes to cross-talk
 - Reference did not give exact geometry
 - Resonances are sensitive to geometry

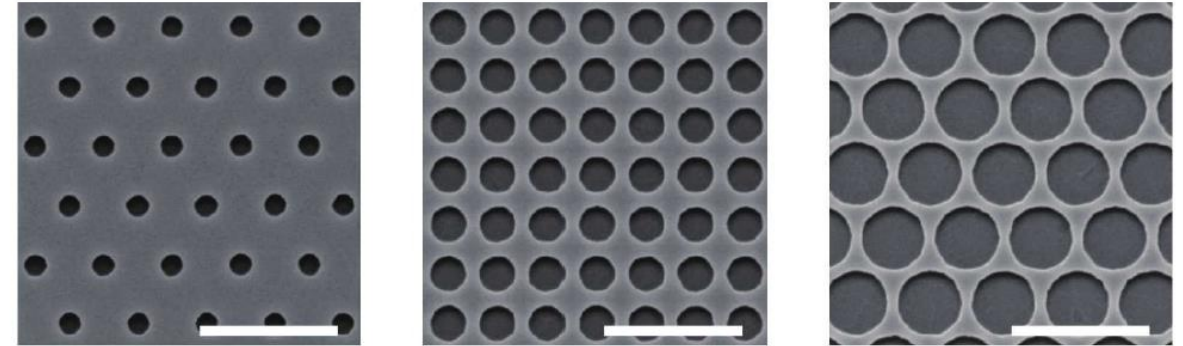


Dielectric Color Filters

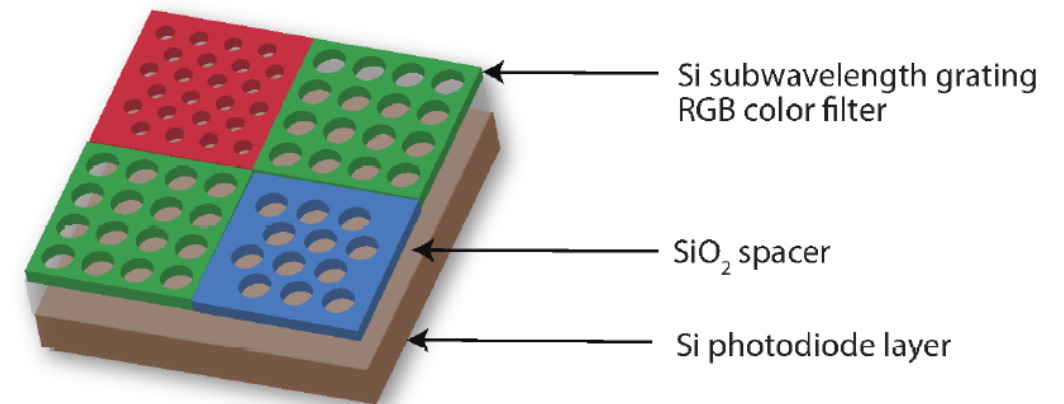


Structure Overview

- All gratings are air holes in a 80nm poly-Si slab on a 115nm SiO₂ spacer
- Individually tuned transmissive gratings for Red, Green, and Blue:

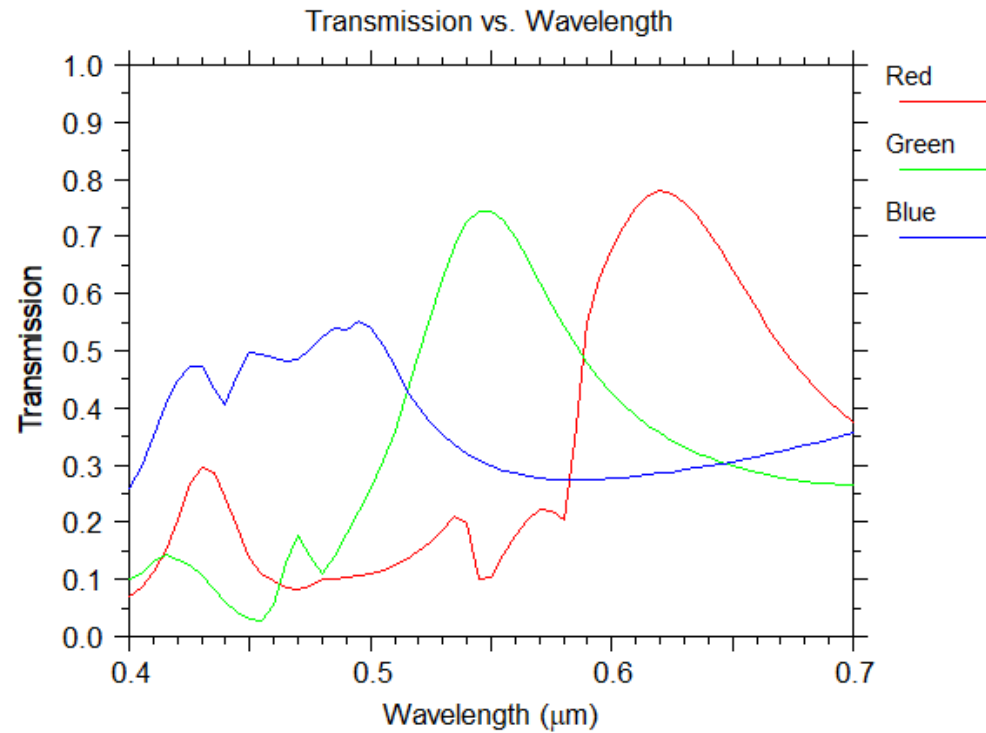


Color	Period	Diameter	Lattice
Red	250nm	90nm	Hexagonal
Green	180nm	140nm	Square
Blue	270nm	240nm	Hexagonal

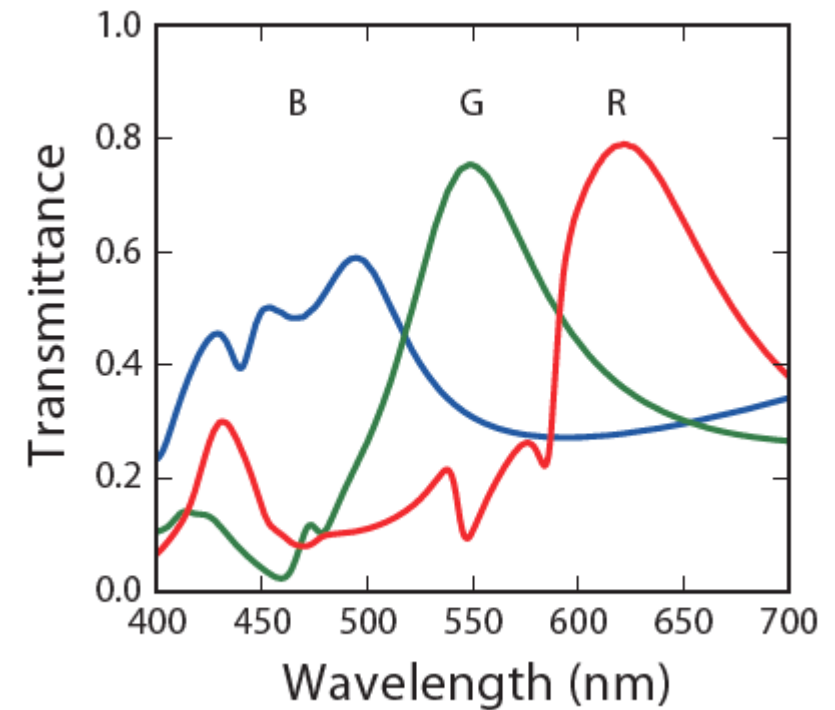


Transmission Results

- The results calculated by DiffractMOD agree very well with the reference



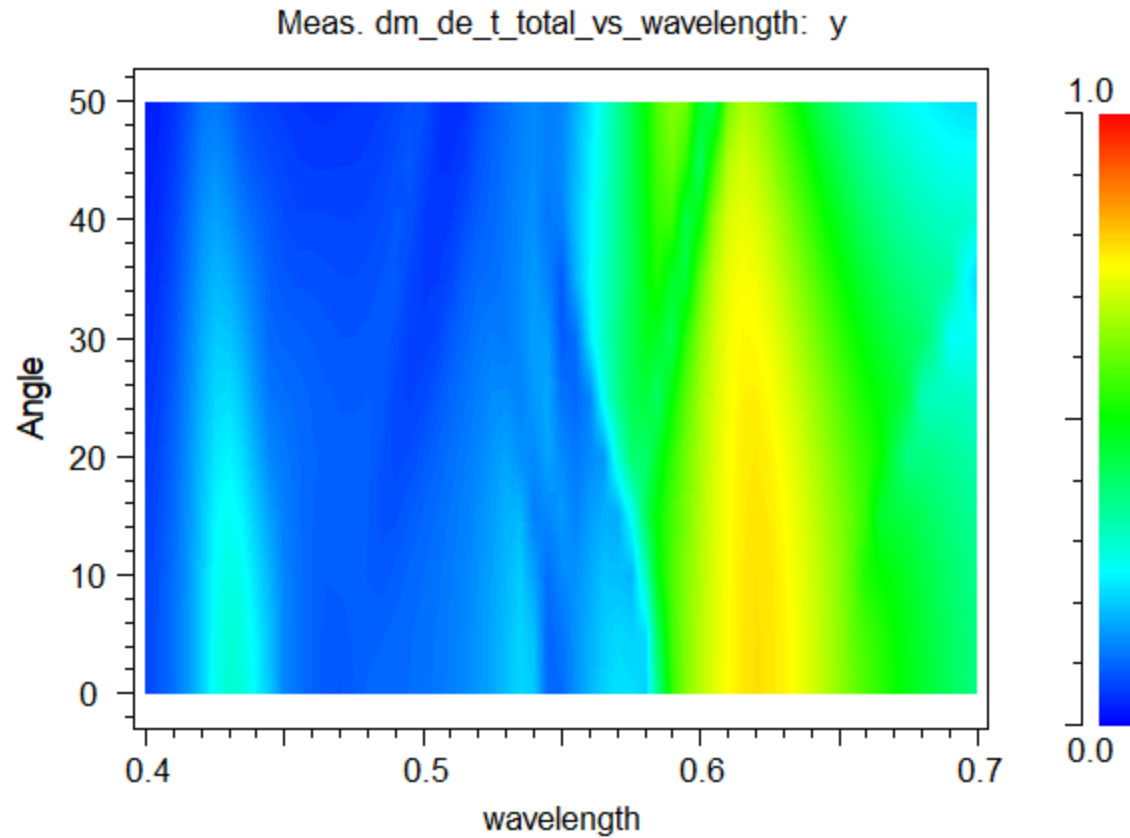
DiffractMOD Results



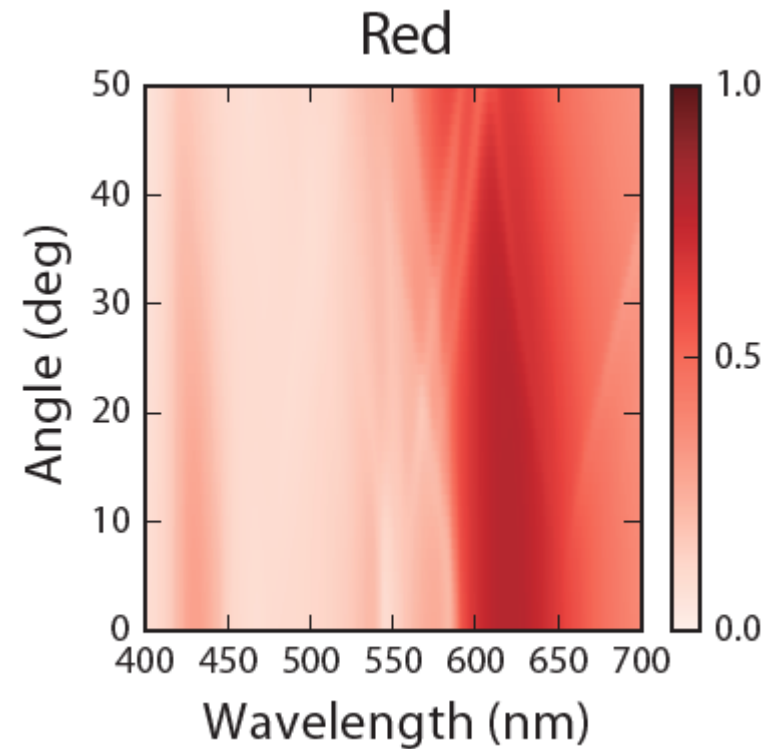
Reference

Angular Consistency

- The angular sensitivity results also agree with the reference



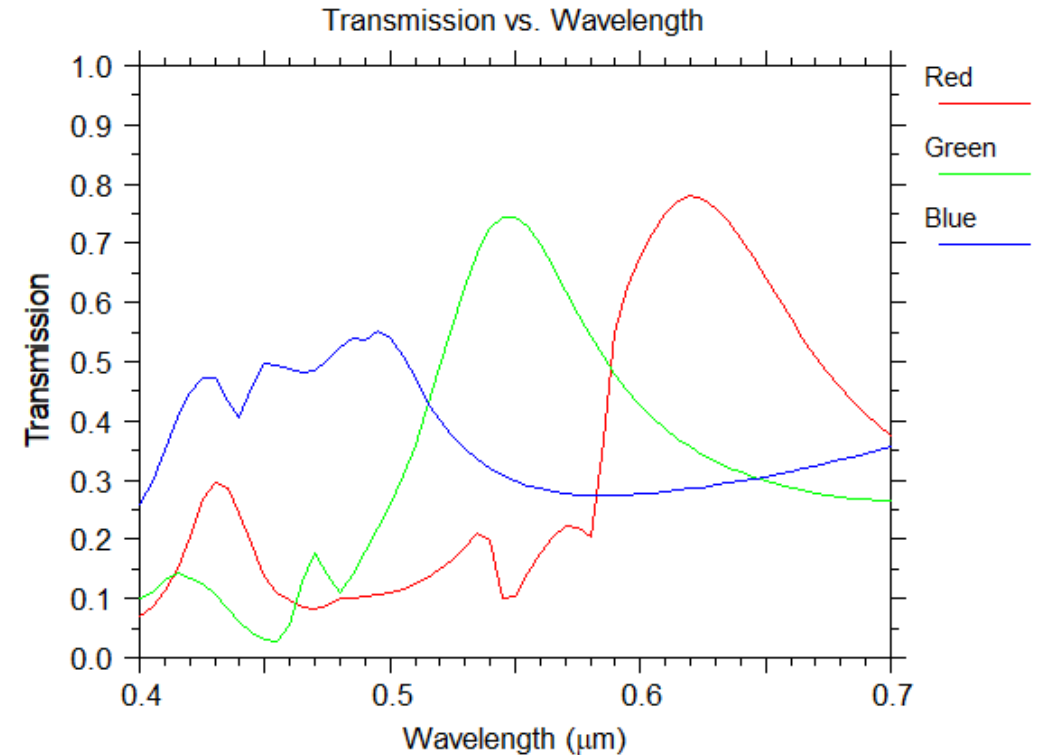
DiffractMOD Results



Reference

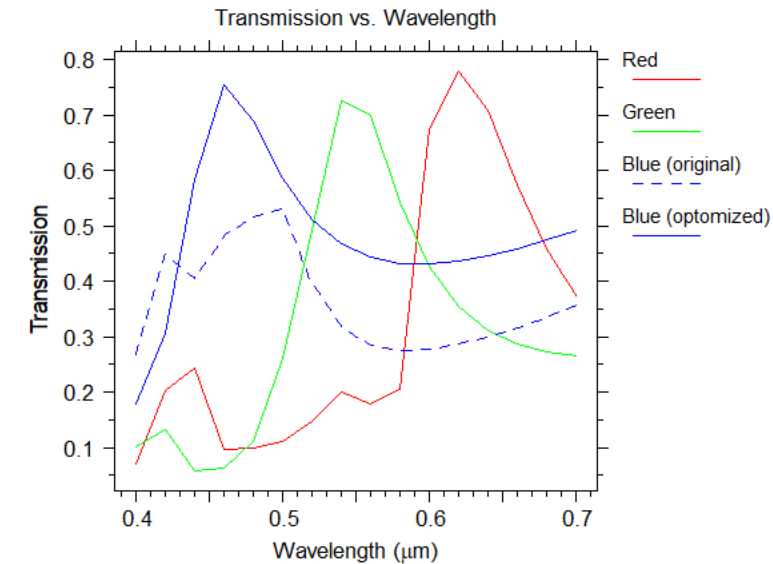
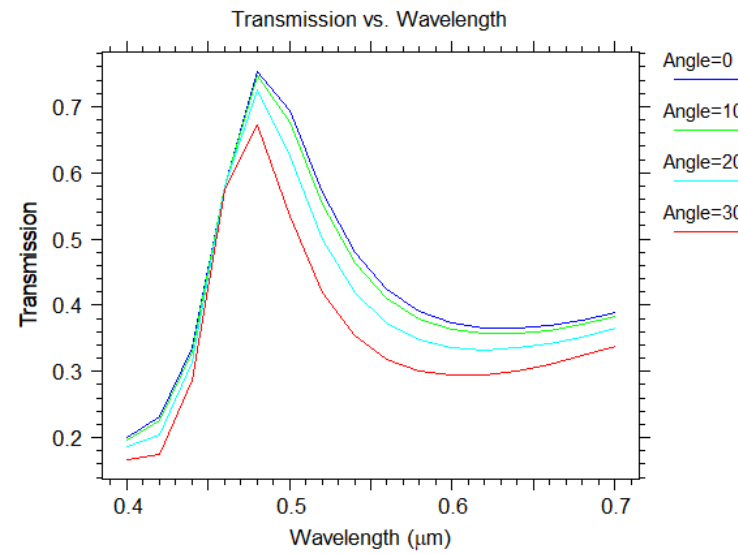
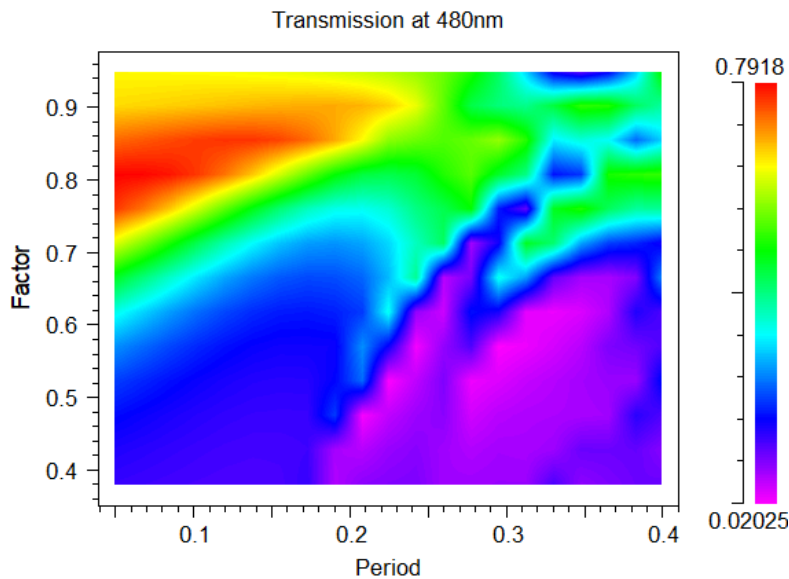
Looking for an Improved Blue Configuration

- The Red and Green configurations have ~75% transmission, Blue has only ~60%
- Possible reasons:
 - poly-Si is more absorptive at smaller wavelengths
 - Smaller wavelengths require smaller structures, introducing possible fabrication difficulties
- We can use MOST to explore the parameter space to see if we can improve the performance of the Blue configuration



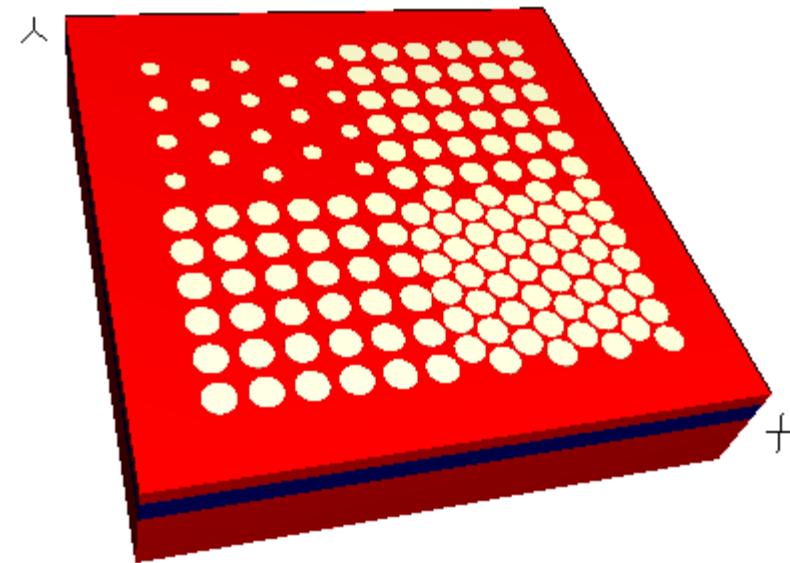
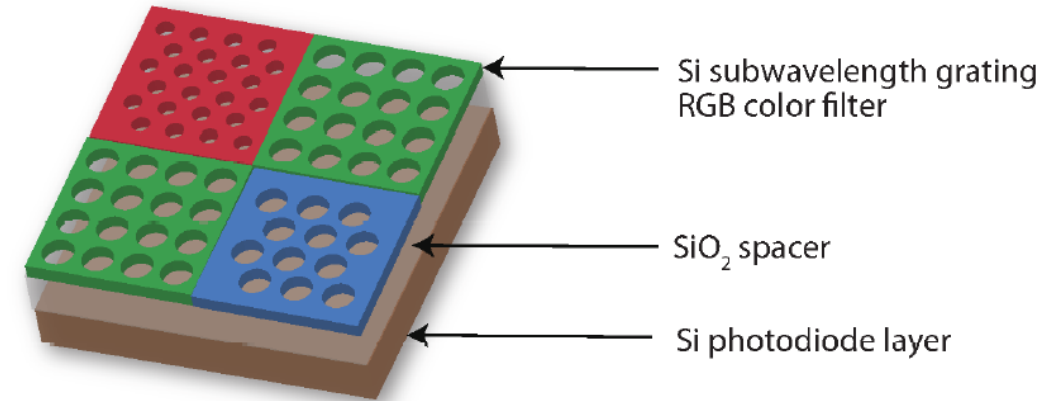
Looking for an Improved Blue Configuration

- Scan over `Period_custom` and `Factor` and measure transmission at $\sim 450\text{nm}$
- Calculate spectra at optimal point `Period_custom` = 150nm, `Factor` = 0.9
- Retains angular insensitivity but has higher cross-talk
 - Cross-talk can be reduced if slightly higher ‘blue’ wavelength is used ($\sim 480\text{nm}$)



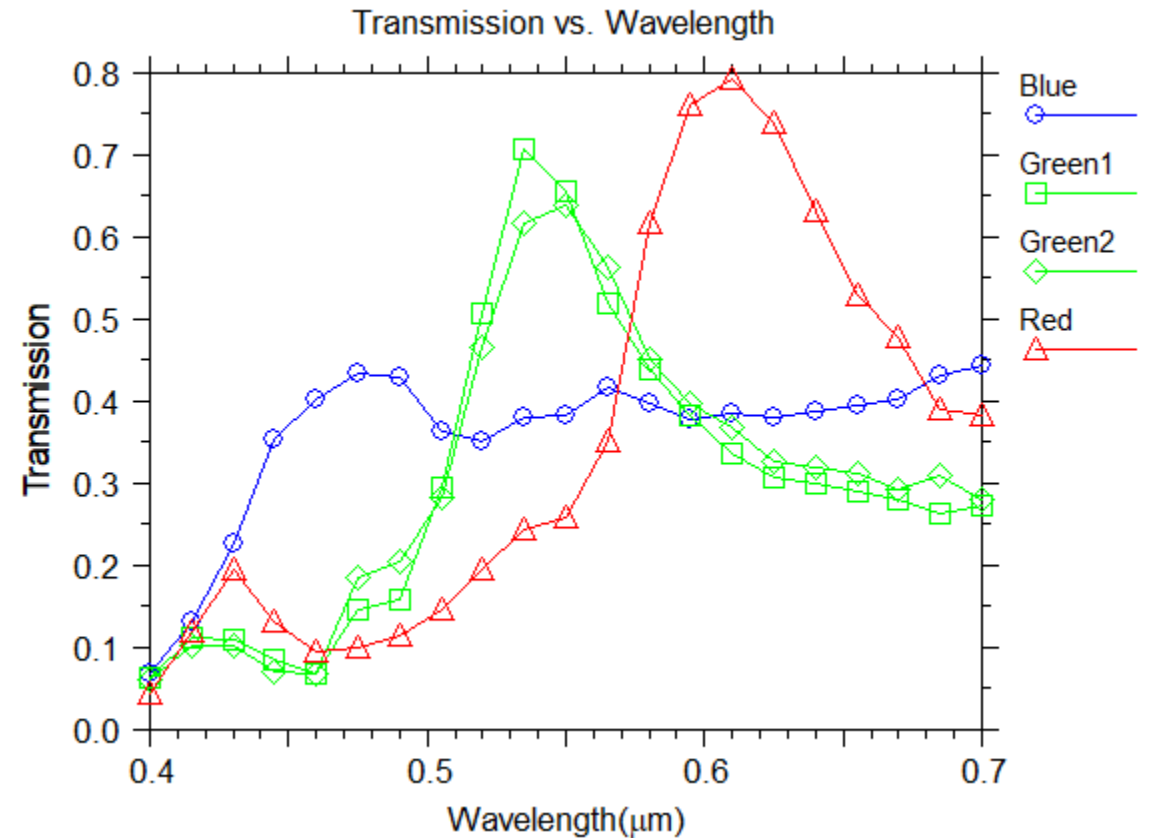
Studying 'Finite' Pixel

- So far, we have studied infinite structures but in reality, the pixel size is finite
- We can use FullWAVE to study a single pixel
 - Used new 'optimized' blue sub-pixel
 - Sub-pixel pitch of $1.05\ \mu\text{m}$
 - Measure transmission through each subpixel
 - Use periodic boundary conditions to effectively consider an infinite 2×2 array of RGB subpixels



Studying 'Finite' Pixel

- Normalized results are similar to ideal infinite simulation, with some expected differences
- Peak transmission is lower, most likely due to edge effects and finite size of pixels
- Blue peak is lower and has high cross-talk
 - Blue pixel should be optimized for finite size, not infinite size



Conclusion

- Miniaturization of cameras requires smaller pixels and redesigned color filters
- Color filters based on traditional absorptive dyes are susceptible to cross-talk as pixel size decreases and can fade over time
- Plasmonic color filters are promising but suffer from high loss
- Dielectric color filters are a good alternative and can fit into existing processes