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

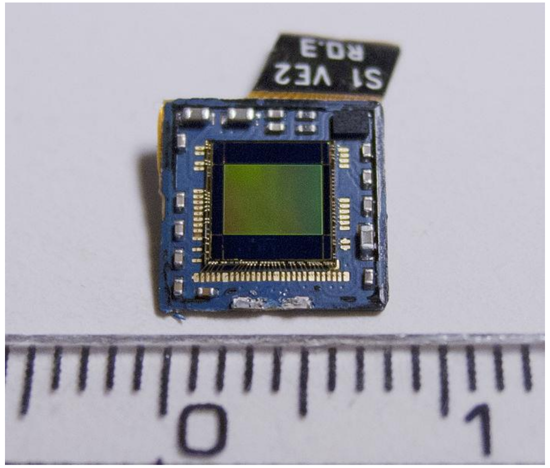
- This miniaturization requires smaller pixels and a redesign of traditional color filters

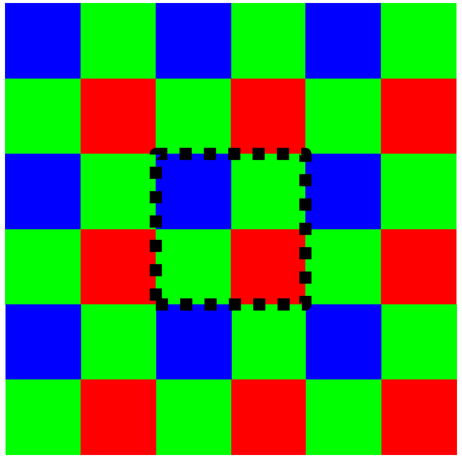
- Many color filters are based on traditional absorptive dyes:
  - More susceptible to cross-talk as pixel size decreases
  - Fade over time

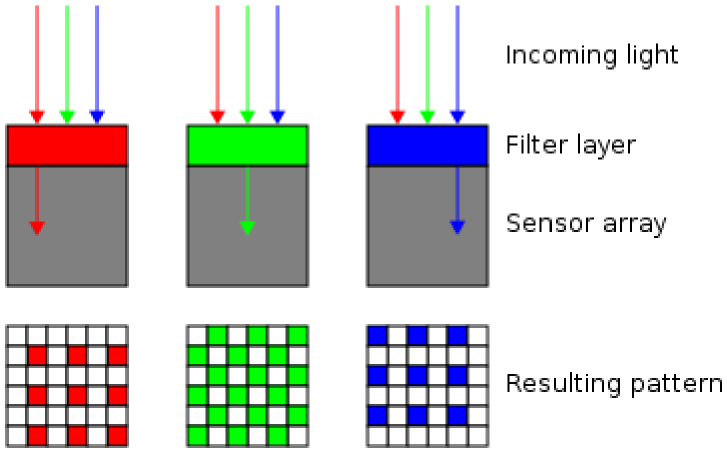
- Here we explore two alternative color filter types:
  - Plasmonic-based color filters built from thin metal films
  - Dielectric color filters built from dielectric materials

Color Filter Array

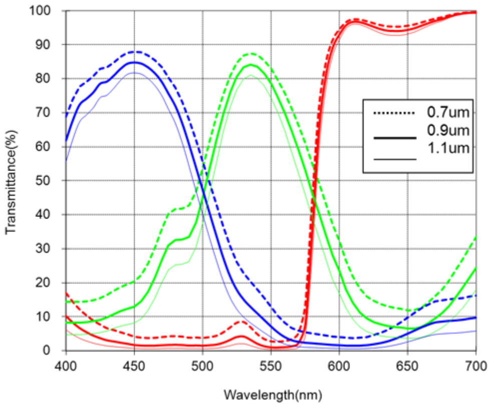
- Cameras utilize color filter arrays to accurately detect color
- There are many color filter arrangements:
  - The Bayer mosaic is shown below
  - It uses four sensors per pixel: 1 blue, 1 red, and 2 green
- The final color image is found via post-processing





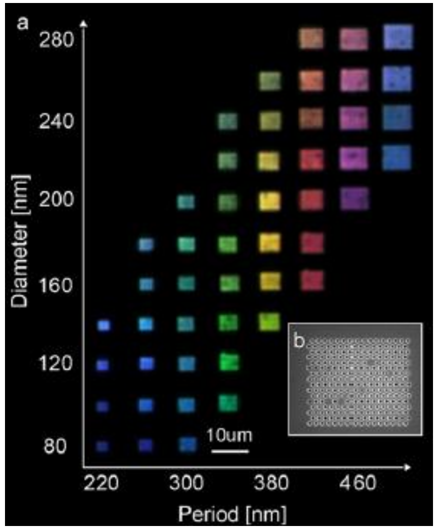


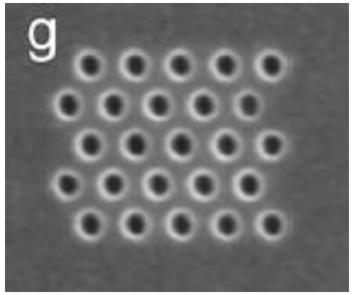
Types of Color Filters



Pigment/Dye Filters

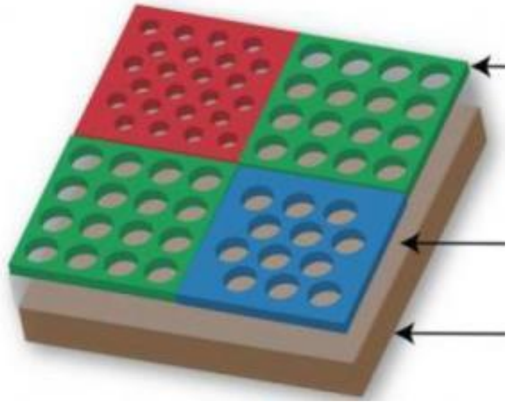
Fujifilm's COLOR MOSAIC (http://www.fujifilmusa.com)

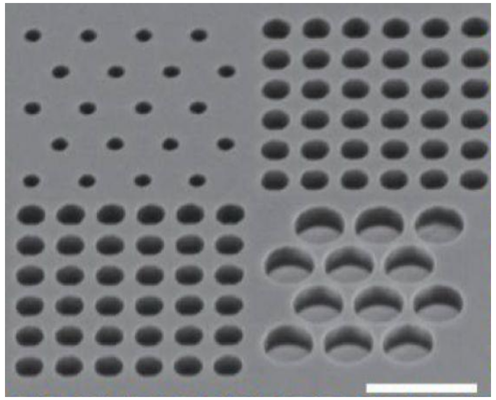




Plasmonic Filters

*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 Dieletric 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

- **Dielectic:** Potentially easy to fabricate, does not degrade and has high transmittance compared to plasmonic filters

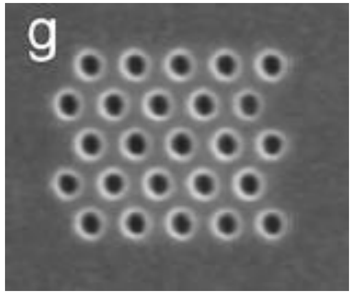
Plasmonic Color Filters

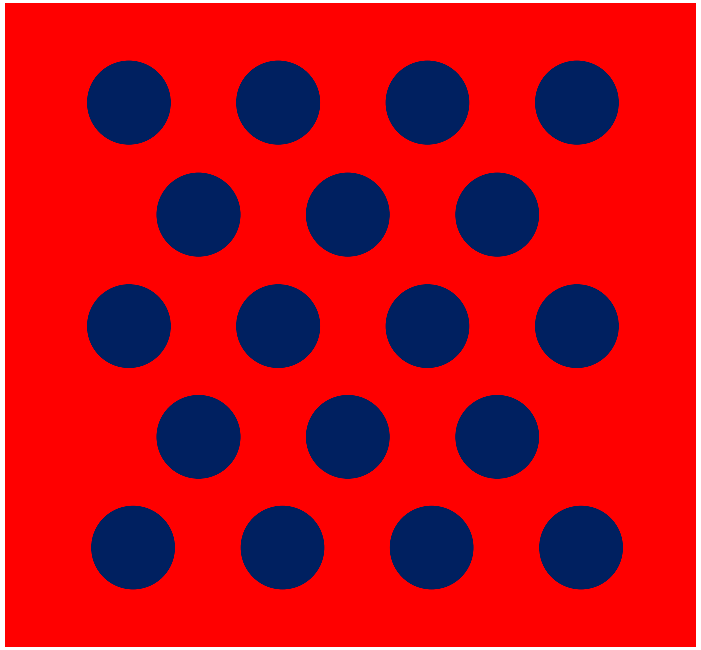
Structure Overview

- All gratings are hexagonal nano-hole arrays in a 150nm thick Al plate in a SiO_2 background

- Individually tuned transmissive gratings for Red, Green, and Blue:

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

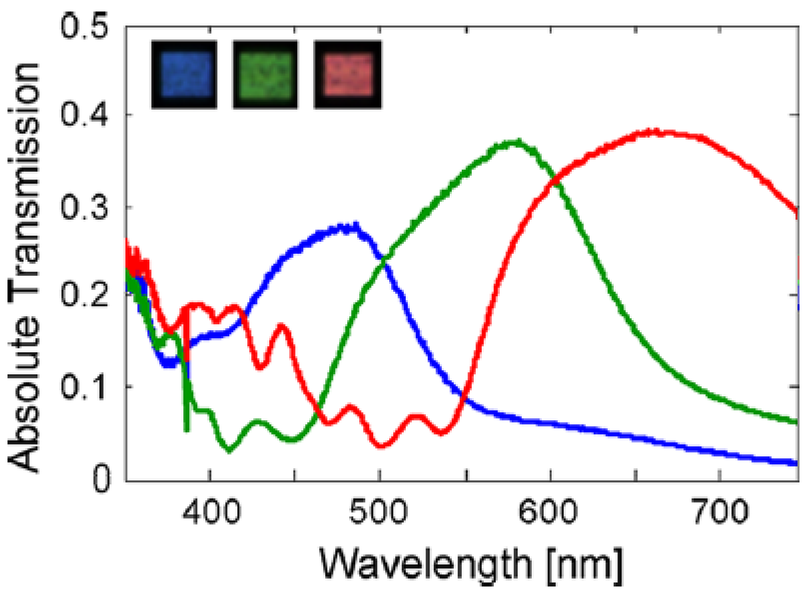


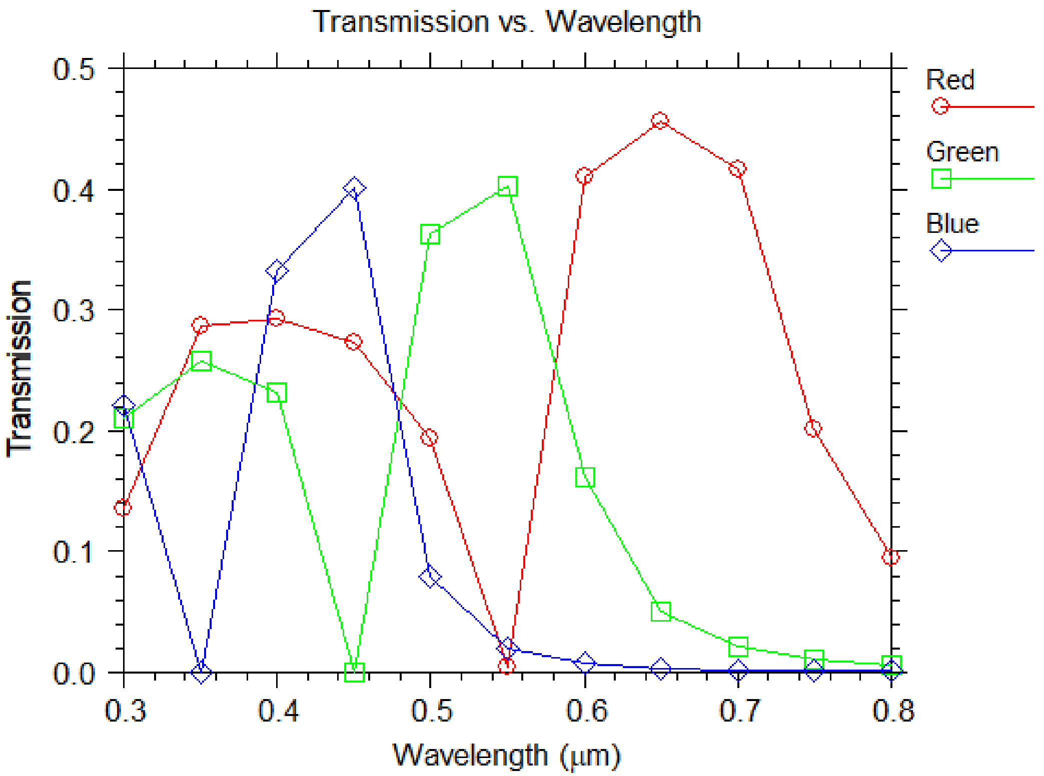


Yokogawa et al. 'Plasmonic Color Filters for CMOS Image Sensor Applications', Nano Letters ***12*** *(2012)*

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





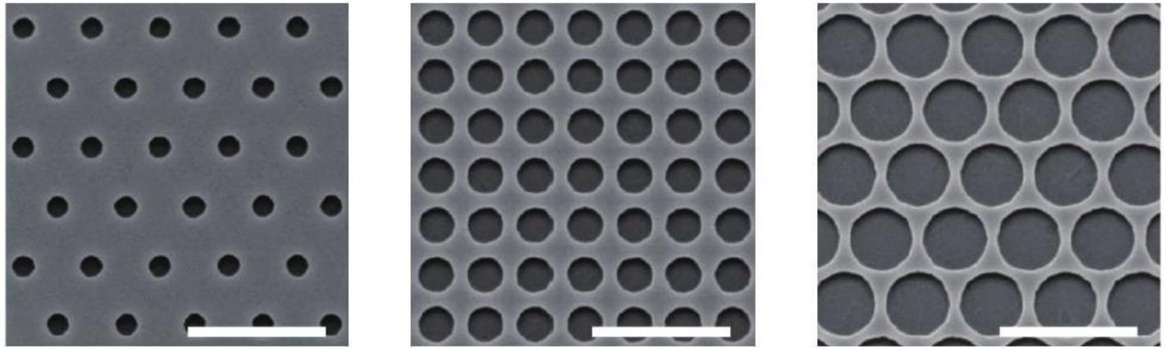
Dieletric Color Filters

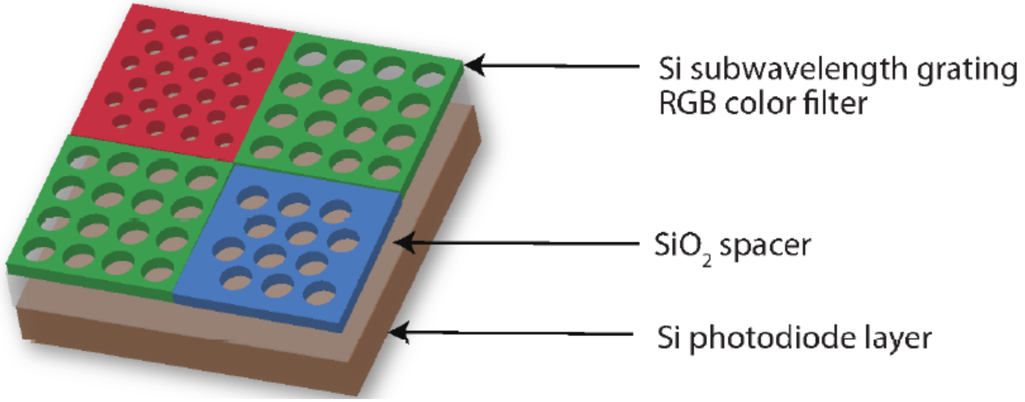
Structure Overview

- All gratings are air holes in a 80nm poly-Si slab on a 115nm SiO_2 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

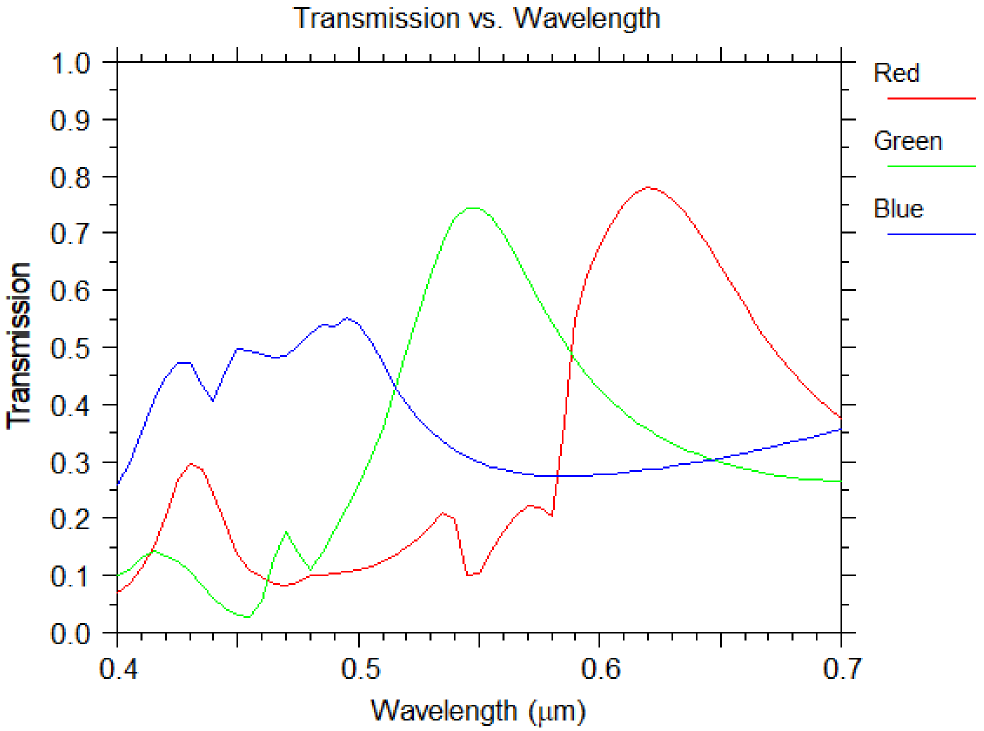




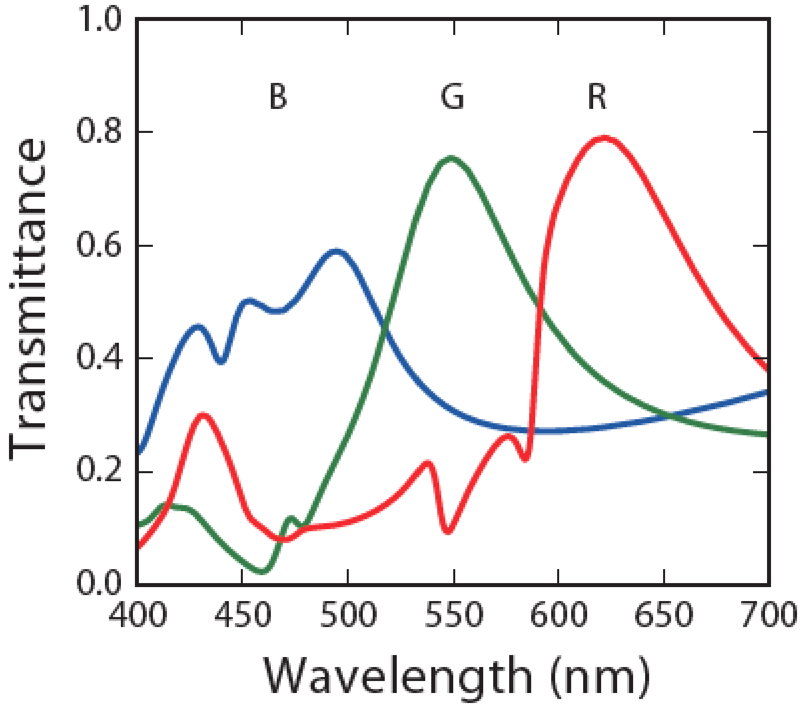
Horie et al, "Visible Wavelength Color Filters using Dieletric Subwavelength Gratings for Backside-illuminated CMPS Image Sensor Technologies', Nano Letters, 17 (2017)

Transmission Results

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



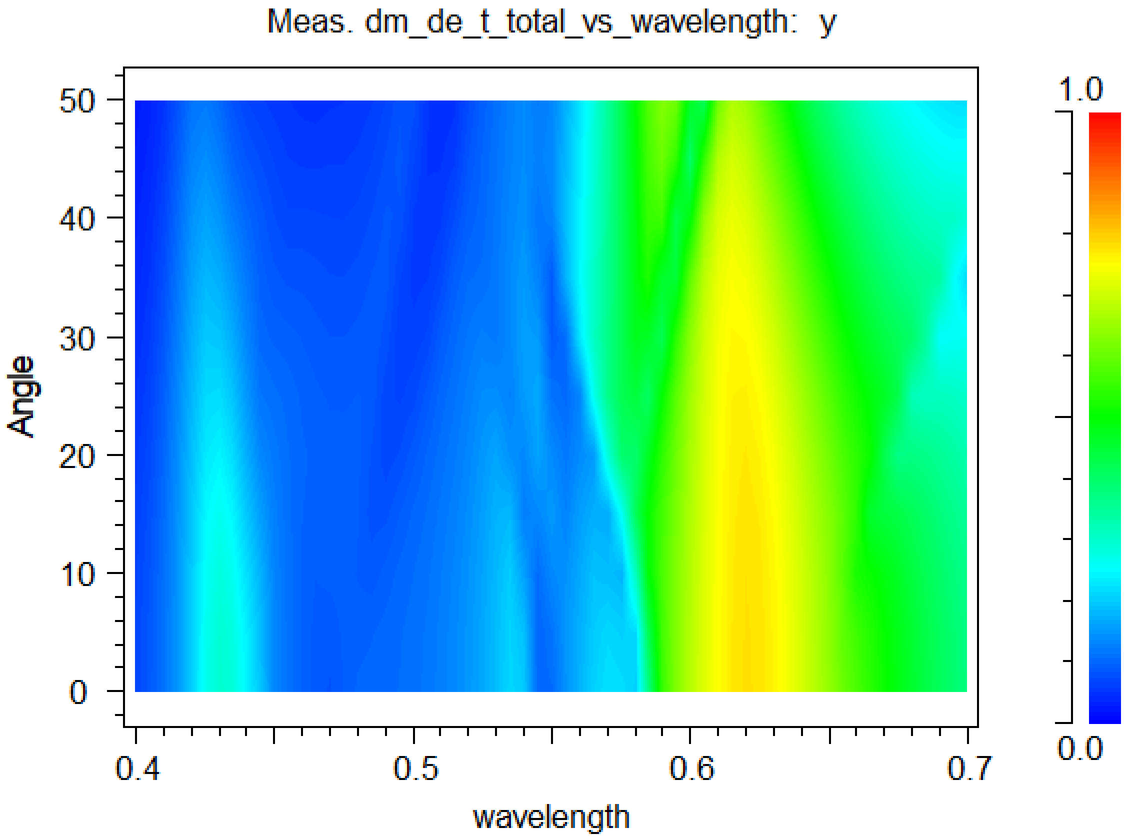
DiffractMOD Results



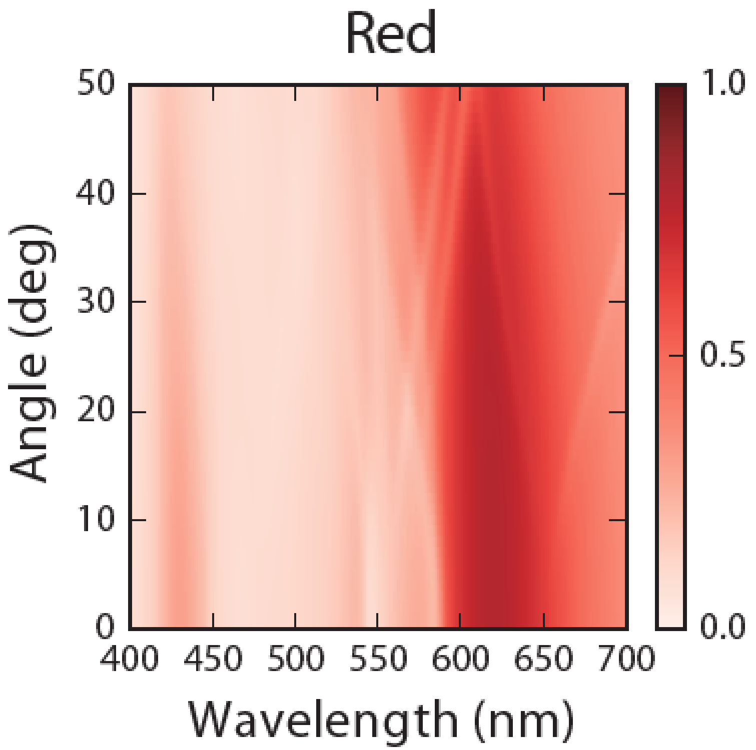
Reference

Angular Consistency

- The angular sensitivity results also agree with the reference



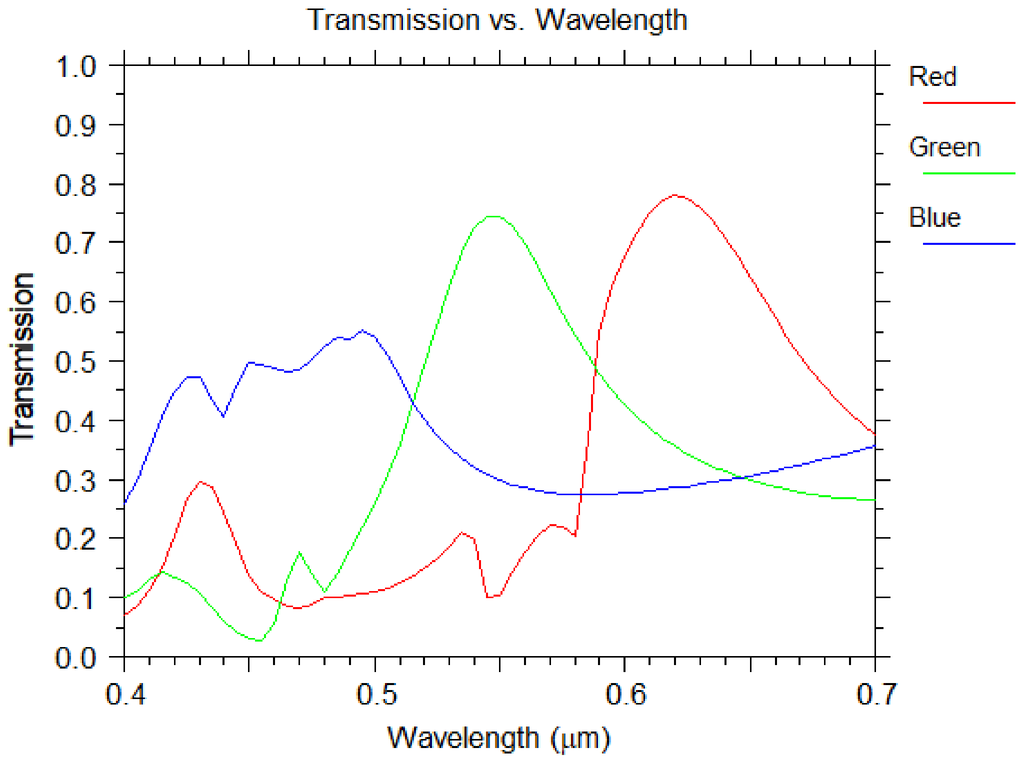
DiffractMOD Results



Reference

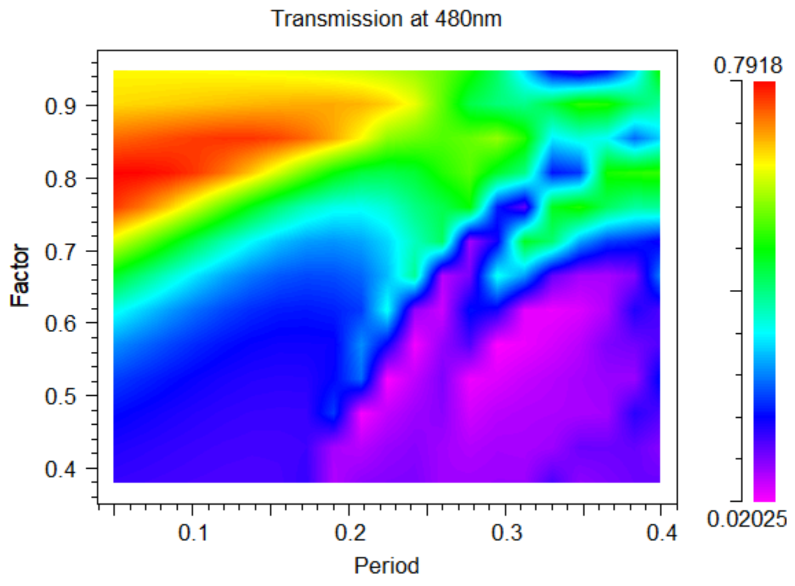
Looking for an Improved Blue Configuration

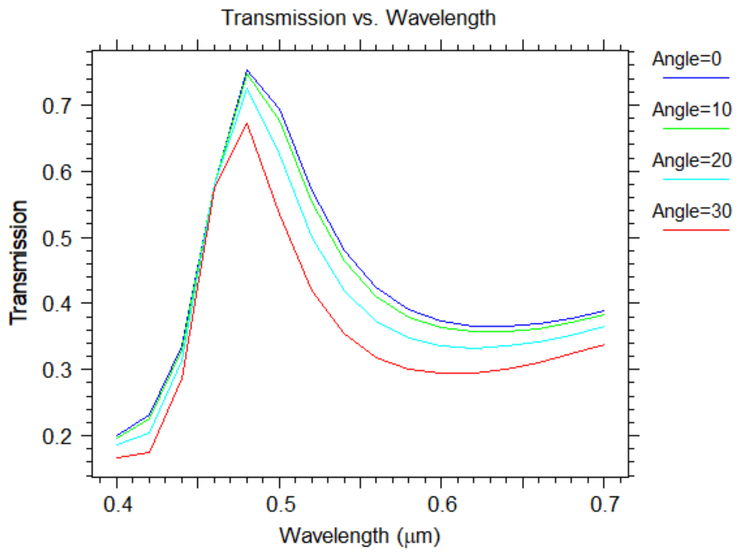
- The Red and Green configurations have ~75% transmission, Blue has only ~60%
- Possible reasons:
  - poly-Si is more absorptive at smaller wavelengths
  - Smaller wavelengths require smaller structures, introducing possible fabrication difficulties
- We can use MOST to explore the parameter space to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

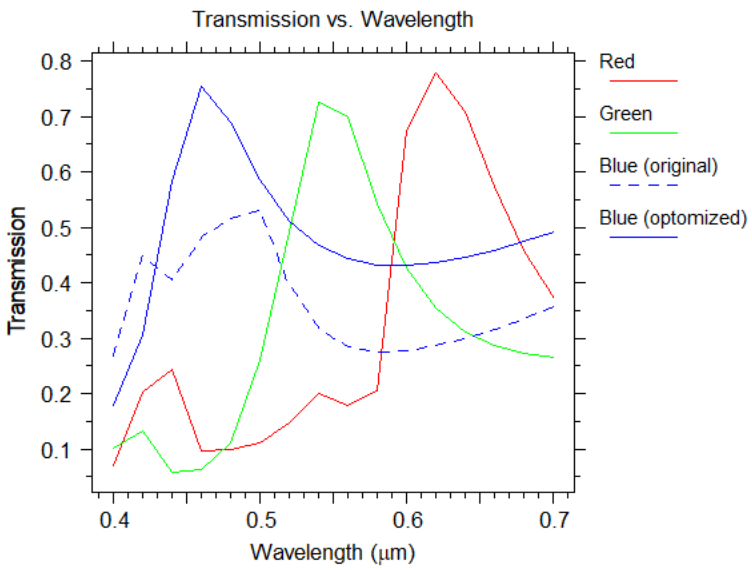


Looking for an Improved Blue Configuration

- Scan over `Period_custom` and `Factor` and measure transmission at ~450nm
- 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 (~480nm)



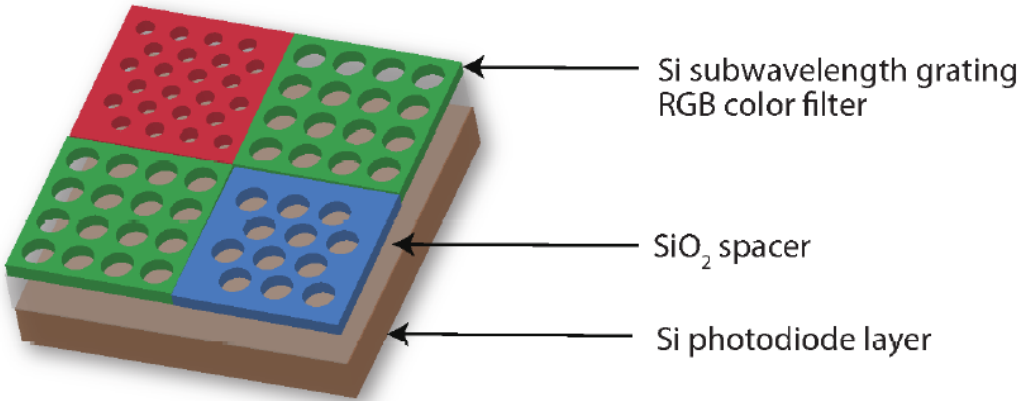


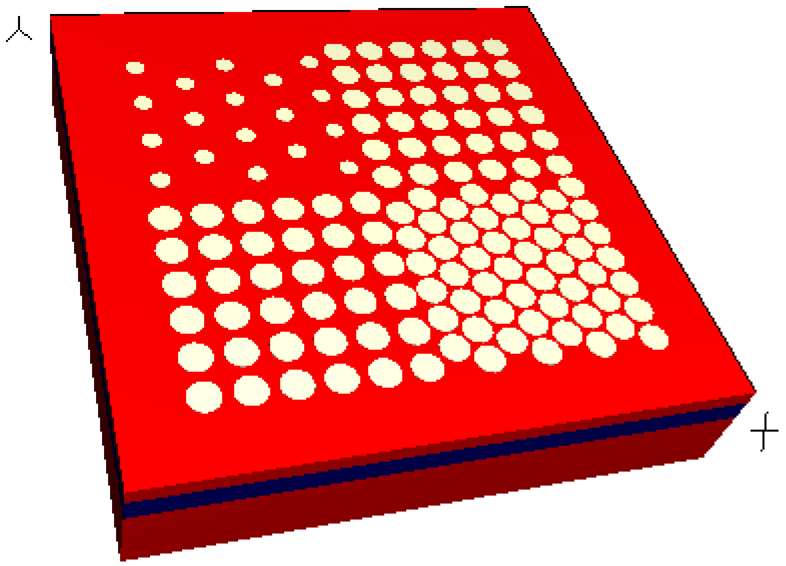


Studying 'Finite' Pixel

- 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 µm
  - Measure transmission through each subpixel
  - Use periodic boundary conditions to effectively consider an infinite 2x2 array of RGB subpixels



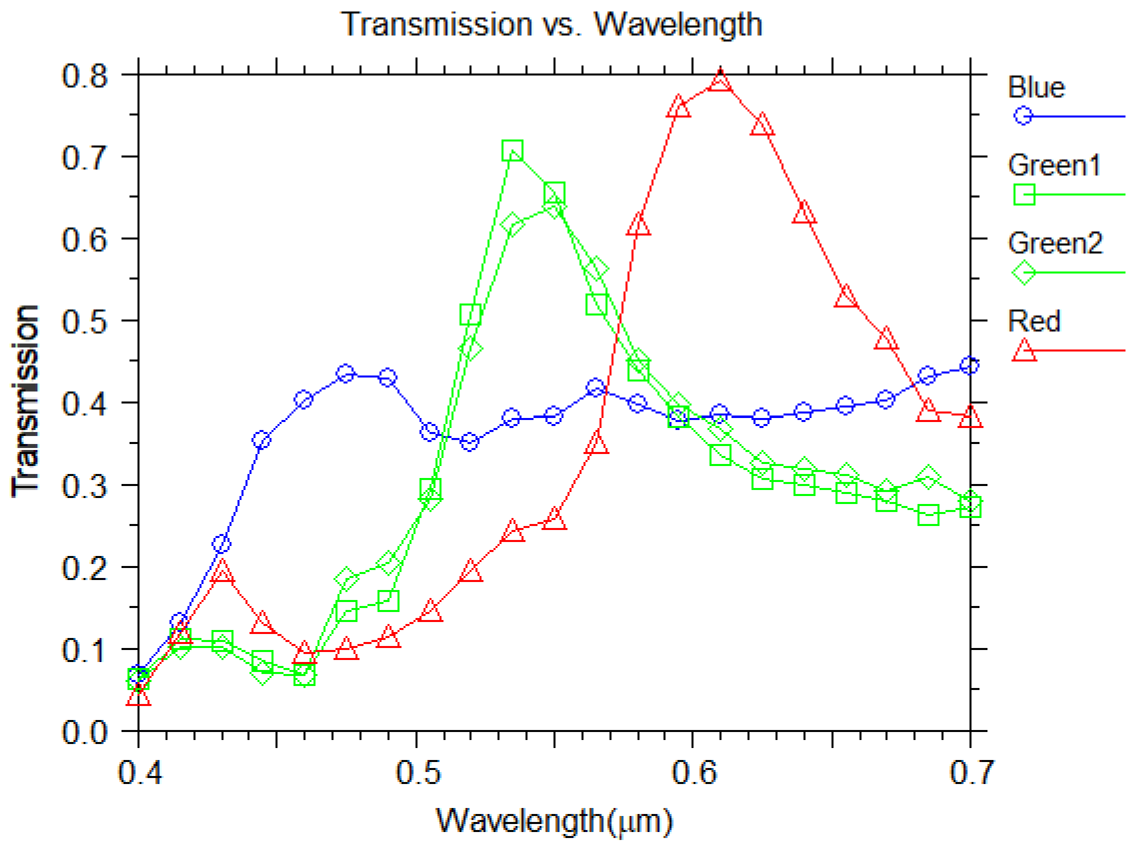


Studying ‘Finite’ Pixel

- 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