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


Dielectric Filters

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 SiO$_2$ background

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

<table>
<thead>
<tr>
<th>Color</th>
<th>Period</th>
<th>Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>420nm</td>
<td>120nm</td>
</tr>
<tr>
<td>Green</td>
<td>340nm</td>
<td>90nm</td>
</tr>
<tr>
<td>Blue</td>
<td>260nm</td>
<td>70nm</td>
</tr>
</tbody>
</table>

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 SiO$_2$ spacer

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

<table>
<thead>
<tr>
<th>Color</th>
<th>Period</th>
<th>Diameter</th>
<th>Lattice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>250nm</td>
<td>90nm</td>
<td>Hexagonal</td>
</tr>
<tr>
<td>Green</td>
<td>180nm</td>
<td>140nm</td>
<td>Square</td>
</tr>
<tr>
<td>Blue</td>
<td>270nm</td>
<td>240nm</td>
<td>Hexagonal</td>
</tr>
</tbody>
</table>

Transmission Results

• The results calculated by DiffractMOD agree very well with the reference
Angular Consistency

- The angular sensitivity results also agree with the reference DiffractMOD Results.
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 $\sim 450$nm
- Calculate spectra at optimal point `Period_custom = 150$nm, `Factor = 0.9`
- Retains angular insensitivity but has higher cross-talk
  - Cross-talk can be reduced if slightly higher ‘blue’ wavelength is used ($\sim 480$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 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