Optics Lab. and Project (Problem Solving)

Orientation & Topics

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About this course

GOALS

- 각 팀별로 최신 광학기술과 관련된 주제와 최종목표를 설정하고 이를 실제로 구현한다. 광학기술의 기본원리와 응용분야를 이해하고 전산 모의, 설계, 최적화, 제작, 광학 특성 측정 등을 직접 수행한다.
- 프로젝트를 진행하면서 발생하는 문제점을 파악하고 팀별로 토의와 아이디어를 창출해서 해결방안을 마련하여 학기 중에 프로젝트를 마무리한다.

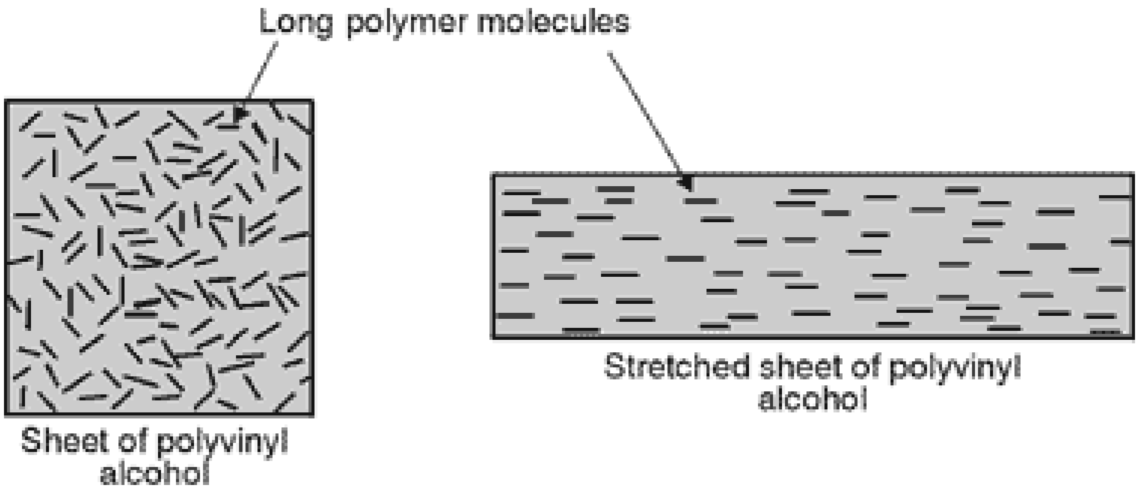
EVALUATION

- Bi-weekly Presentation (60%), Discussion (10%), Final Presentation (30%)
- 첫 발표 (9/20), 중간발표 (11/1), 최종발표 (12/20)

- 학기 중에 마무리를 못하면 2019년 동계현장실습에 참여해서 마무리 가능
- 동계현장실습에서 똑같은 주제로 할 필요는 없음

Wire-Grid Polarizers

Absorptive Polarizers (H-sheet Polaroid)



- H-sheet Polaroids are made from polyvinyl alcohol (PVA) plastic with an iodine doping.

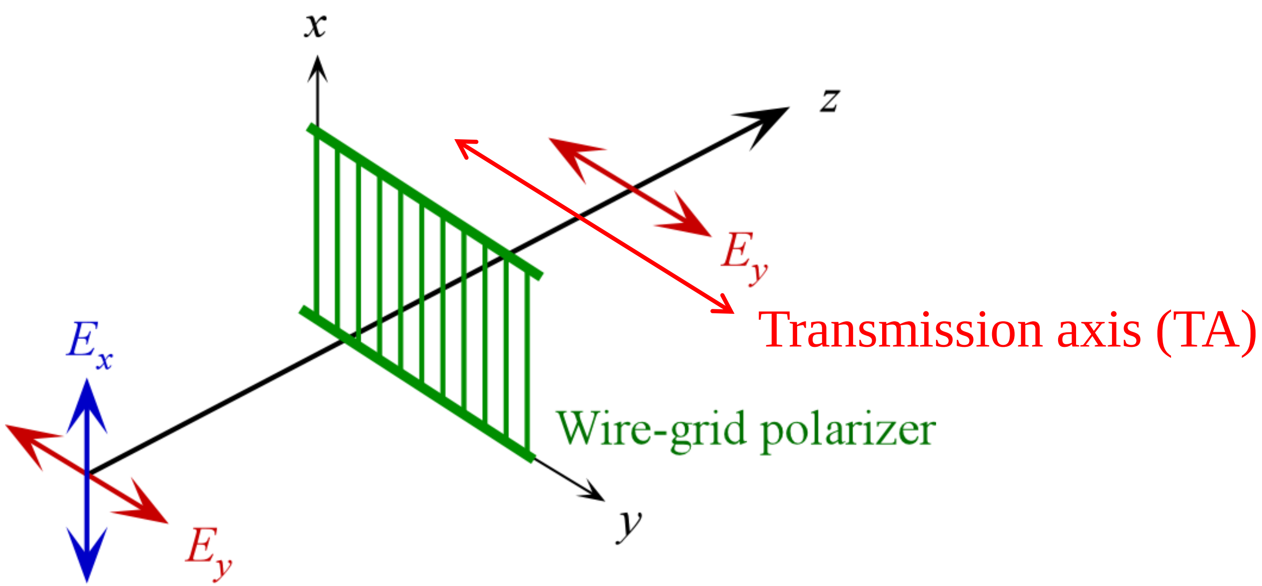
- PVA molecules are aligned parallel to one another by heating and stretching of the sheet.

- When exposed to iodine vapor, iodine dopant attaches to the PVA molecules and makes the conducting along the length of the chains.

- Conduction electrons associated with iodine can move easily along the polymer chains, but not perpendicular to them (*i.e.*, acts like a wire mesh).

- Incident light with the E-field parallel to the molecules is absorbed; light with the E-field perpendicular to the polymer chains is transmitted with little absorption.

Wire-Grid Polarizers (WGPs)

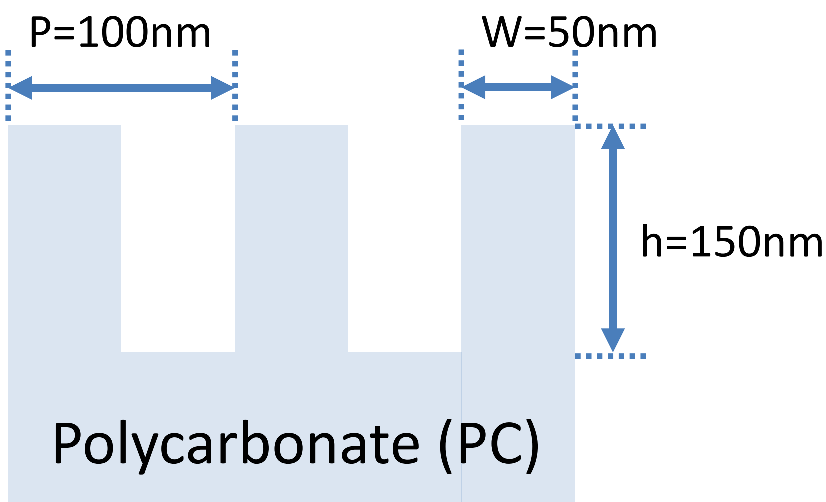


For s-polarization where the E-field is parallel to the direction of wires, incident light can excite electrons in the metal wires to move along the length of the wires, which behave like a metal that reflects light (a small amount of energy lost to Joule heating).

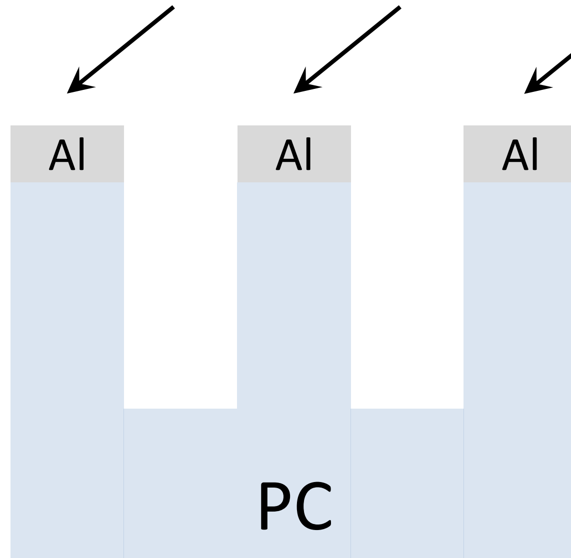
For p-polarization where the E-field is perpendicular to the direction of the wires, the movement of electrons cannot be induced due to a very narrow wire width (subwavelength scale). Thus, most energy is transmitted through the polarizer, which behave like a dielectric.

Project 1-1. Visible Wire-Grid Polarizers (Al monolayer)

Fabrication and Characterization



Oblique Angle Deposition (OAD) of Al

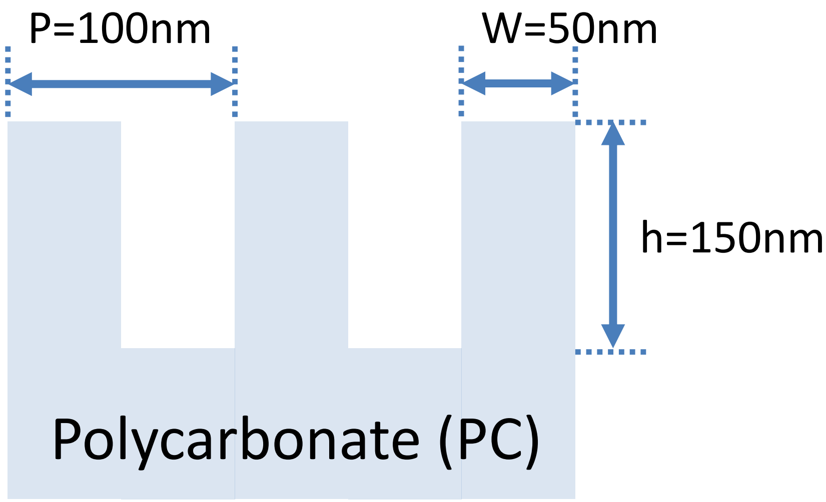


Goals: Understand the working principles of WGP and OAD, and gain knowledge of the operation principles of the fabrication and characterization techniques.

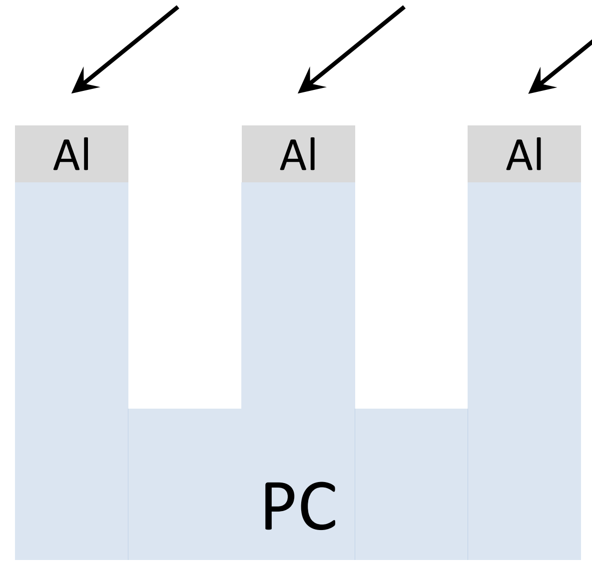
- Fabricate visible WGPs by an e-beam evaporator (at least 2 samples).
- Characterize optical properties of visible WGPs by a spectrophotometer and an ellipsometer.

Project 1-2. Visible WGPs (Al monolayer)

Theoretical Analysis and Optimization (WGP)



Oblique Angle Deposition (OAD) of Al

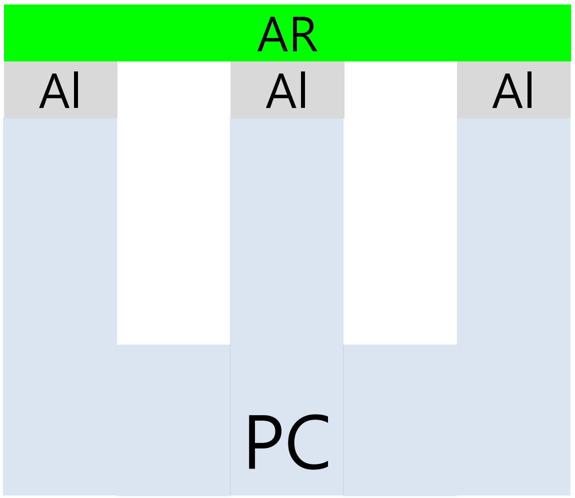


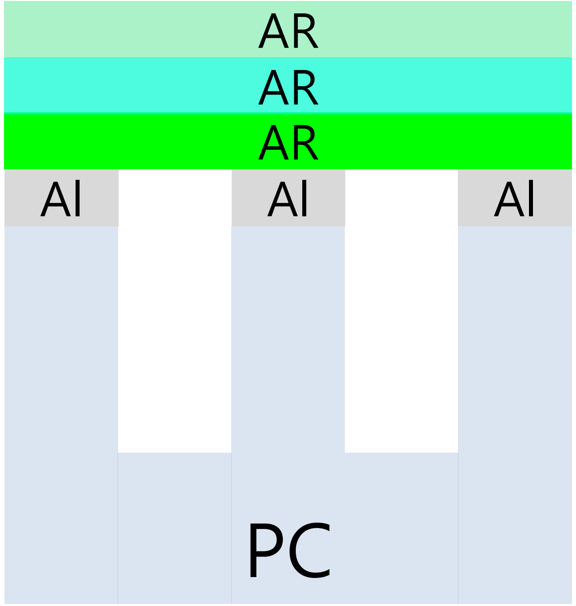
Goals: Study the working principles of WGP, effective medium approximation (EMA), and admittance analysis. Find the optimized WGP parameters.

- Investigate optical properties of WGPs by EMA and admittance analysis.
- Optimize the parameters of the visible WGPs via EMA and admittance analysis.

Project 1-3. Visible WGPs with Anti-reflection (Al monolayer)

Theoretical Analysis and Optimization (WGP w/ AR 1)



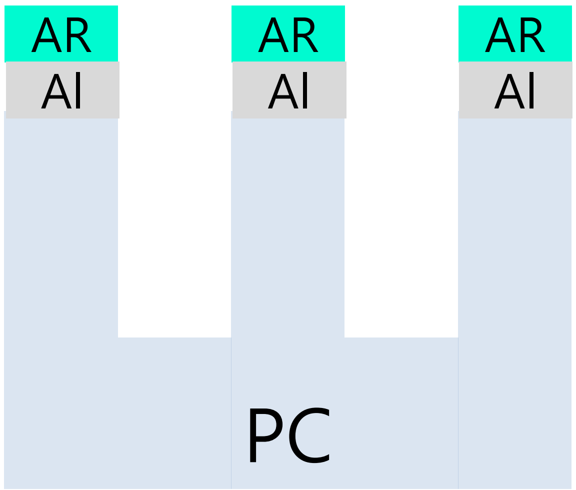


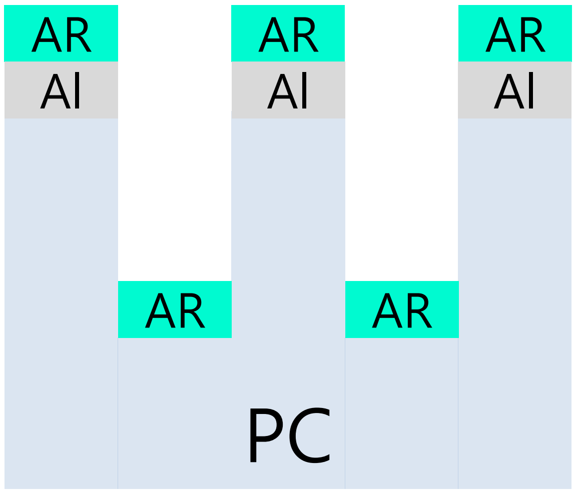
Goals: Study the working principles of WGP, anti-reflection, effective medium approximation (EMA), and admittance analysis. Find the optimized single and triple anti-reflection (AR) layers for visible WGPs.

- Investigate optical properties of WGPs w/ AR by EMA and admittance analysis.
- Optimize single and triple AR layers for the WGPs via EMA and admittance analysis.

Project 1-4. Visible WGPs with AR (Al monolayer)

Theoretical Analysis and Optimization (WGP w/ AR 2)

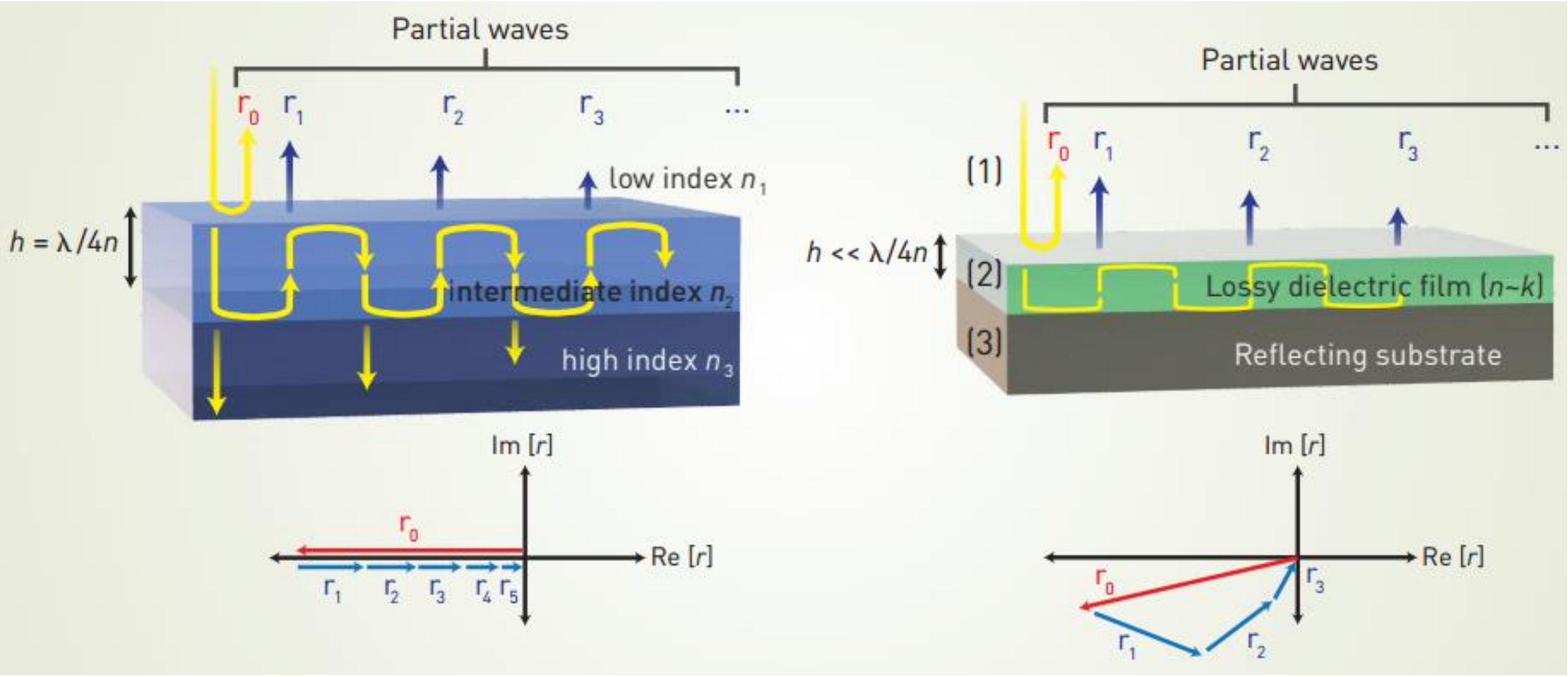




<u>Goals</u>: Study the working principles of WGP, anti-reflection, effective medium approximation (EMA), and admittance analysis. Find the optimized anti-reflection (AR) layers for visible WGPs.

- Investigate optical properties of WGPs w/ AR by EMA and admittance analysis.
- Optimize the AR layers for the WGPs via EMA and admittance analysis.

Ultrathin Fabry–Pérot Nanocavity

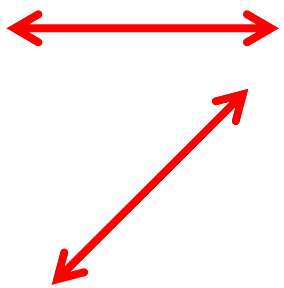


Trivial phase shift: 0 or π

Non-trivial phase shift: between $-\pi$ and π

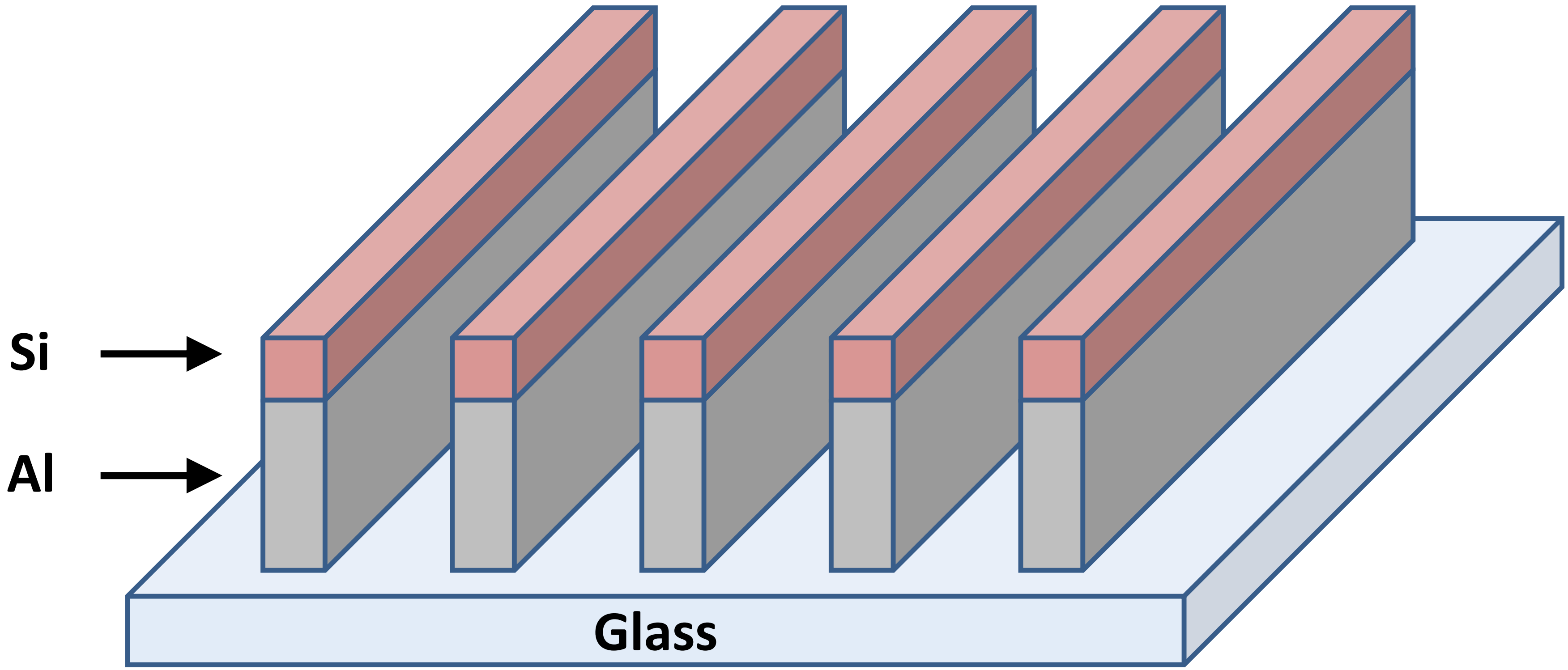
Nat. Mater., **12**, 20-24 (2013)

From planar structure to 1D gratings



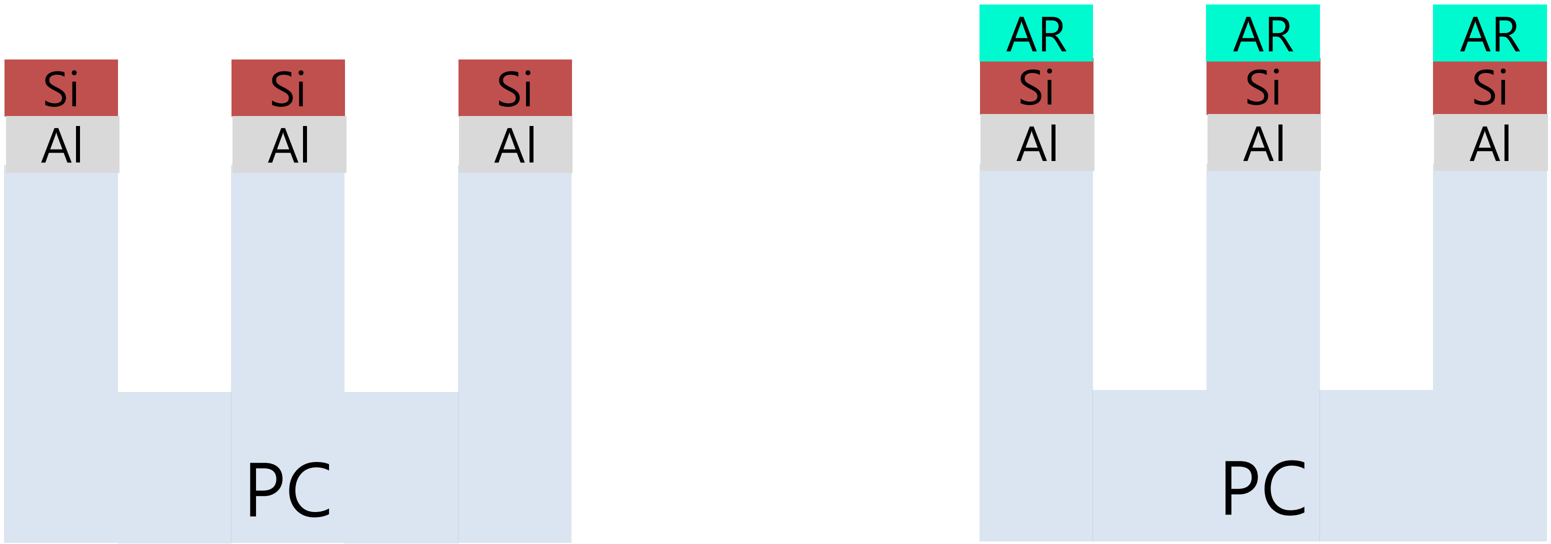
TM: a-Si is just ultra-thin layer (no resonance)

TE: a-Si is bulk (strong resonance behavior)



Project 1-5. Colored Visible WGPs (Al monolayer)

Theoretical Analysis and Optimization (Colored WGP w/ AR)

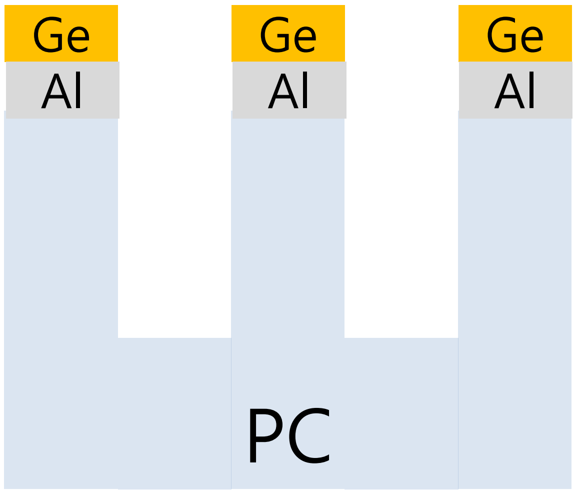


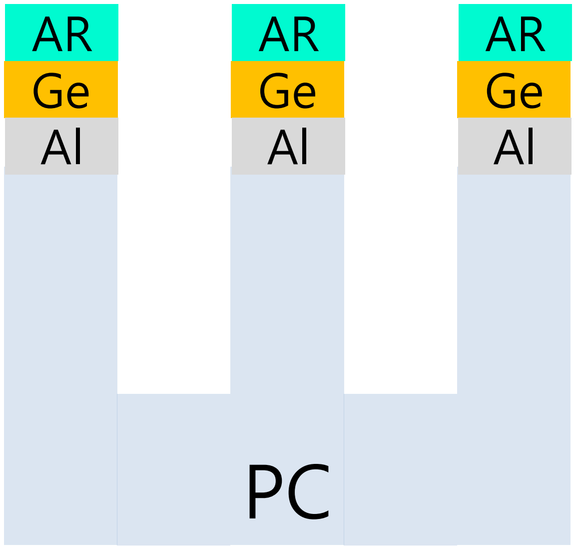
<u>Goals</u>: Study the working principles of WGP, cavity, anti-reflection, effective medium approximation (EMA), and admittance analysis. Study optical properties of colored WGPs and effects of AR on the WGP performance.

- Investigate optical properties of colored WGPs w/o and w/ AR by EMA and admittance analysis.

Project 1-6. Low-Reflective Visible WGPs (Al monolayer)

Theoretical Analysis and Optimization (Low-reflective WGP w/ AR)



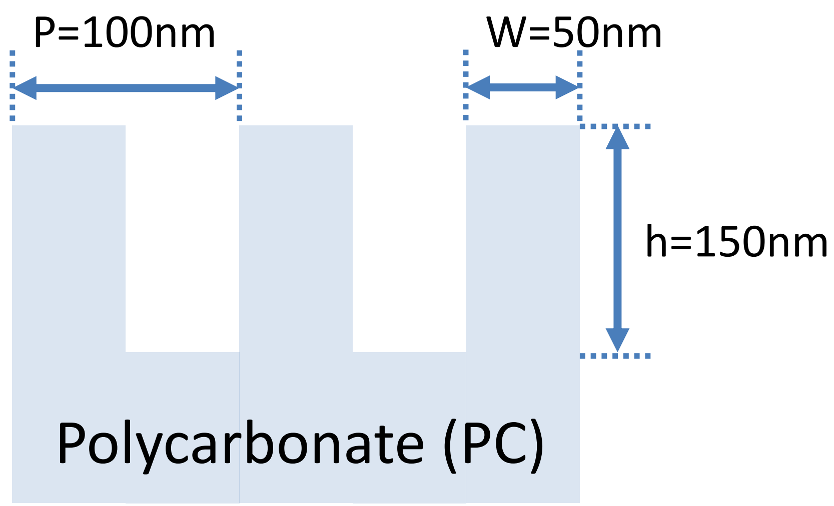


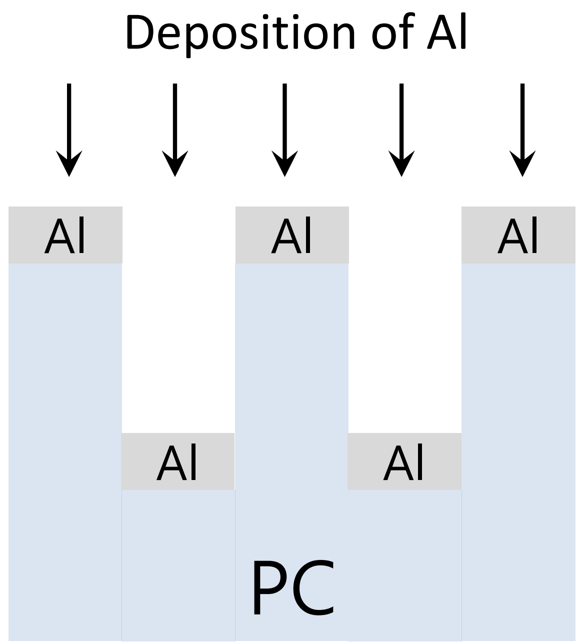
Goals: Study the working principles of WGP, cavity, anti-reflection, effective medium approximation (EMA), and admittance analysis. Study optical properties of low-reflective WGPs and effects of AR on the WGP performance.

- Investigate optical properties of low-reflective WGPs w/o and w/ AR by EMA and admittance analysis.

Project 2-1. Visible WGPs (Al bilayer)

Fabrication and Characterization



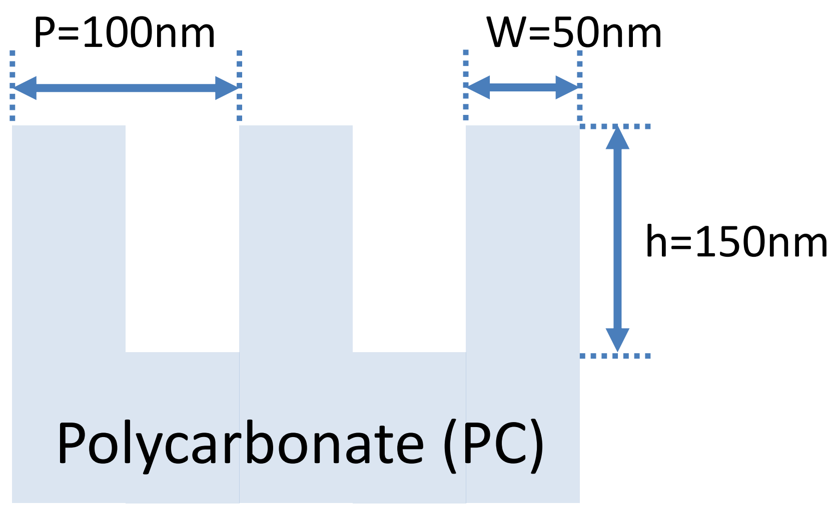


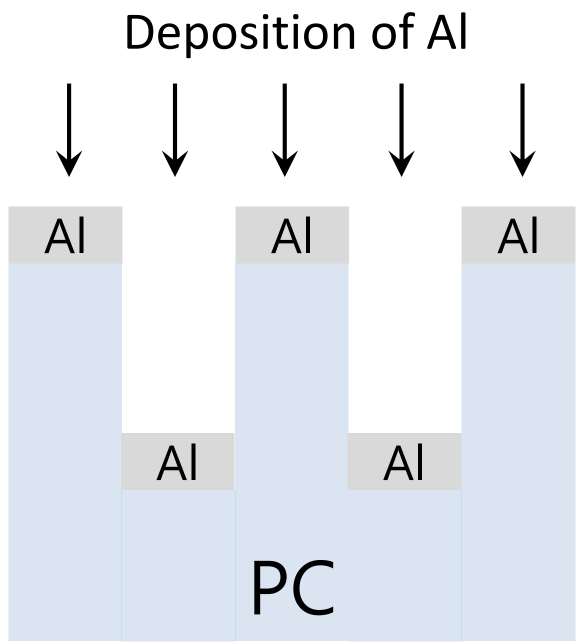
<u>Goals</u>: Understand the working principles of WGP and OAD, and gain knowledge of the operation principles of the fabrication and characterization techniques.

- Fabricate visible WGPs by an e-beam evaporator (at least 2 samples).
- Characterize optical properties of visible WGPs by a spectrophotometer and an ellipsometer.

Project 2-2. Visible WGPs (Al bilayer)

Theoretical Analysis and Optimization (WGP)



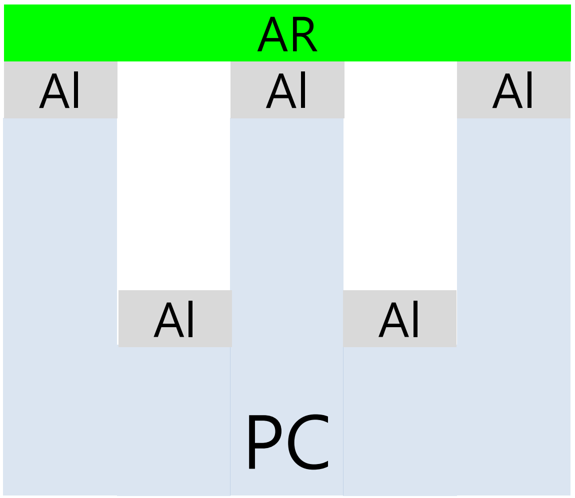


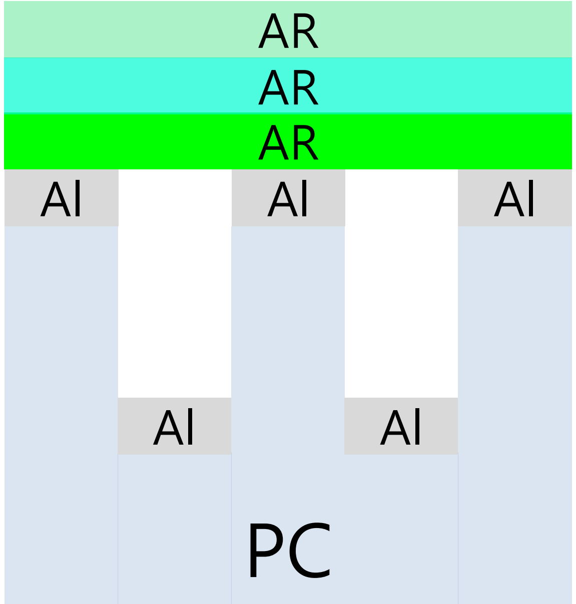
<u>Goals</u>: Study the working principles of WGP, effective medium approximation (EMA), and admittance analysis. Find the optimized WGP parameters.

- Investigate optical properties of WGPs by EMA and admittance analysis.
- Optimize the parameters of the visible WGPs via EMA and admittance analysis.

Project 2-3. Visible WGPs with AR (Al bilayer)

Theoretical Analysis and Optimization (WGP w/ AR 1)





<u>**Goals**</u>: Study the working principles of WGP, anti-reflection, effective medium approximation (EMA), and admittance analysis. Find the optimized single and triple anti-reflection (AR) layers for visible WGPs.

- Investigate optical properties of WGPs w/ AR by EMA and admittance analysis.
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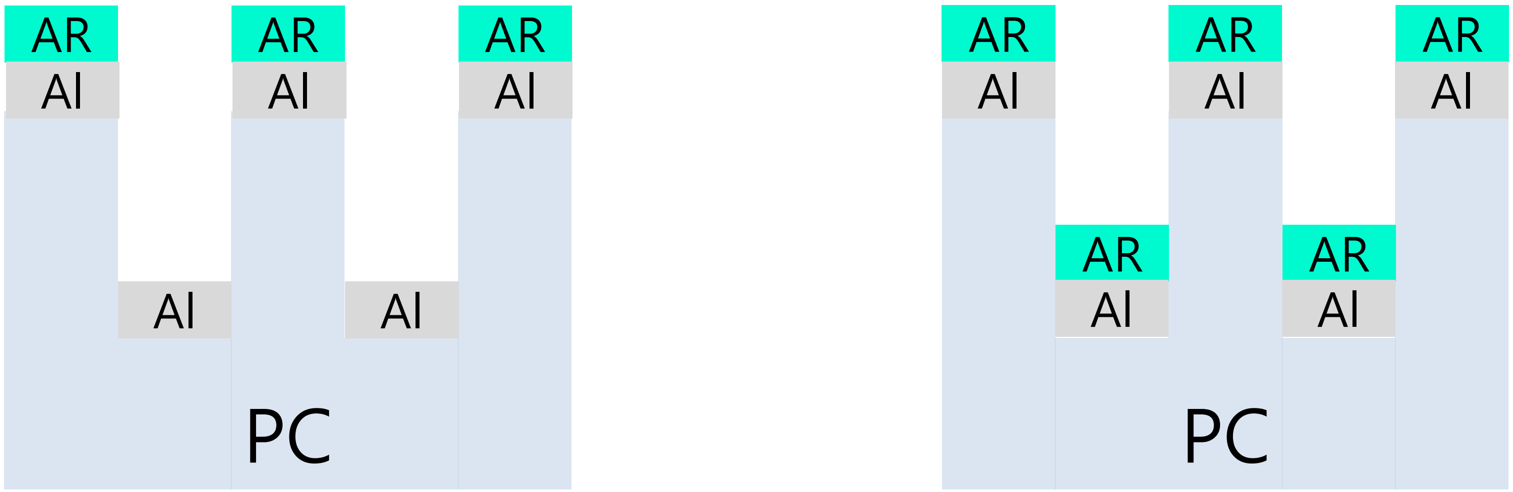
Project 2-4. Visible WGPs with AR (Al bilayer)

Theoretical Analysis and Optimization (WGP w/ AR 2)



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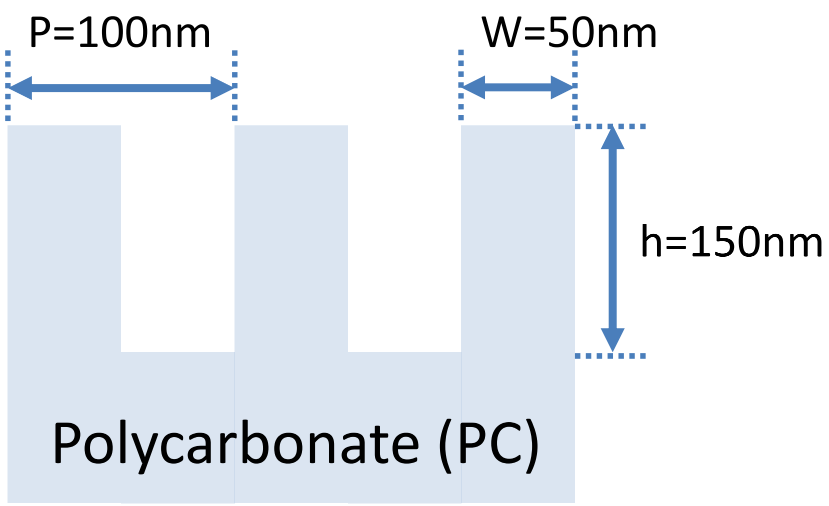
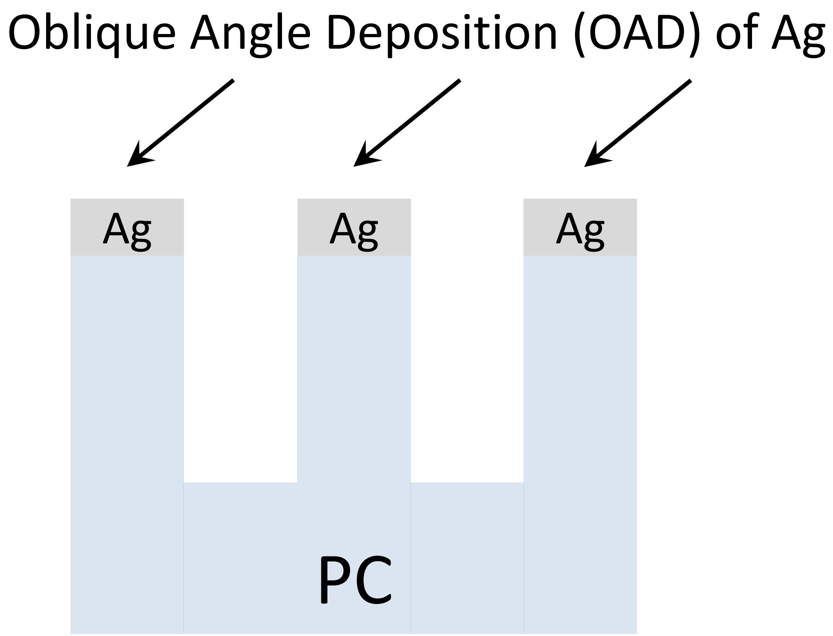
- Investigate optical properties of WGPs w/ AR by EMA and admittance analysis.
- Optimize the AR layers for the WGPs via EMA and admittance analysis.

Project 3. Visible WGPs (Ag monolayer)

Fabrication and Characterization



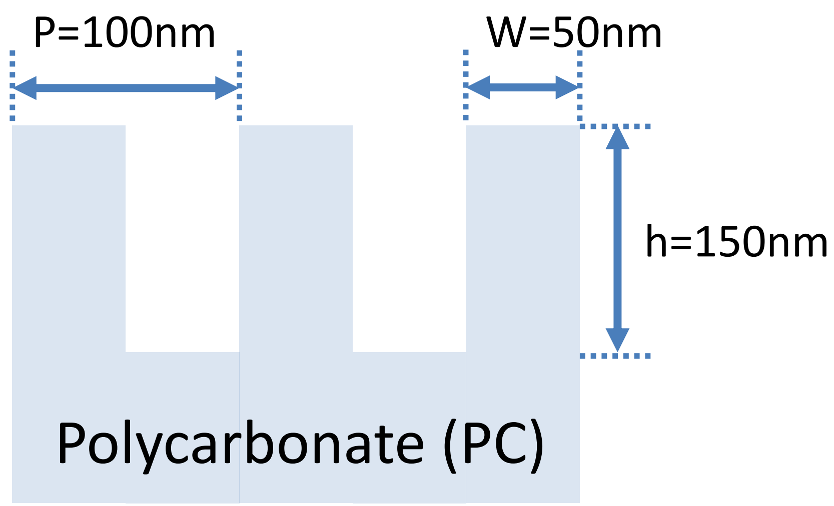


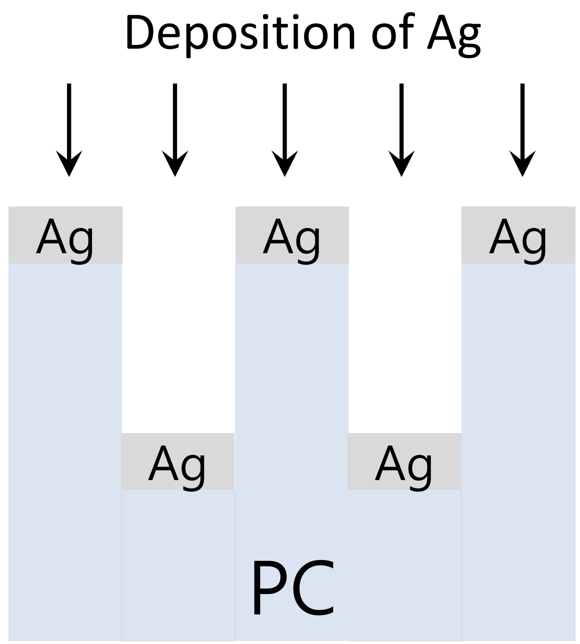
<u>Goals</u>: Understand the working principles of WGP and OAD, and gain knowledge of the operation principles of the fabrication and characterization techniques.

- Fabricate visible WGPs by an e-beam evaporator (at least 2 samples).
- Characterize optical properties of visible WGPs by a spectrophotometer and an ellipsometer.

Project 4. Visible WGPs (Ag bilayer)

Fabrication and Characterization





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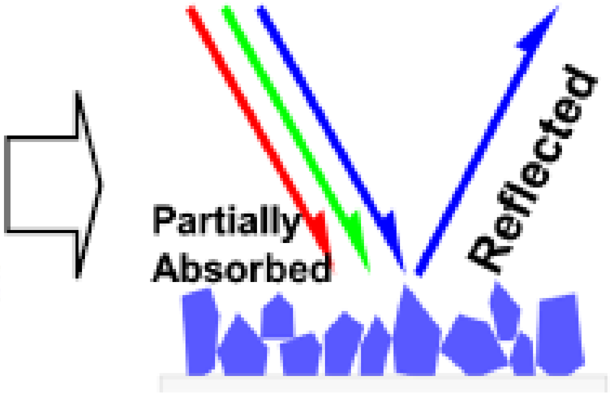
Structural Color Filters

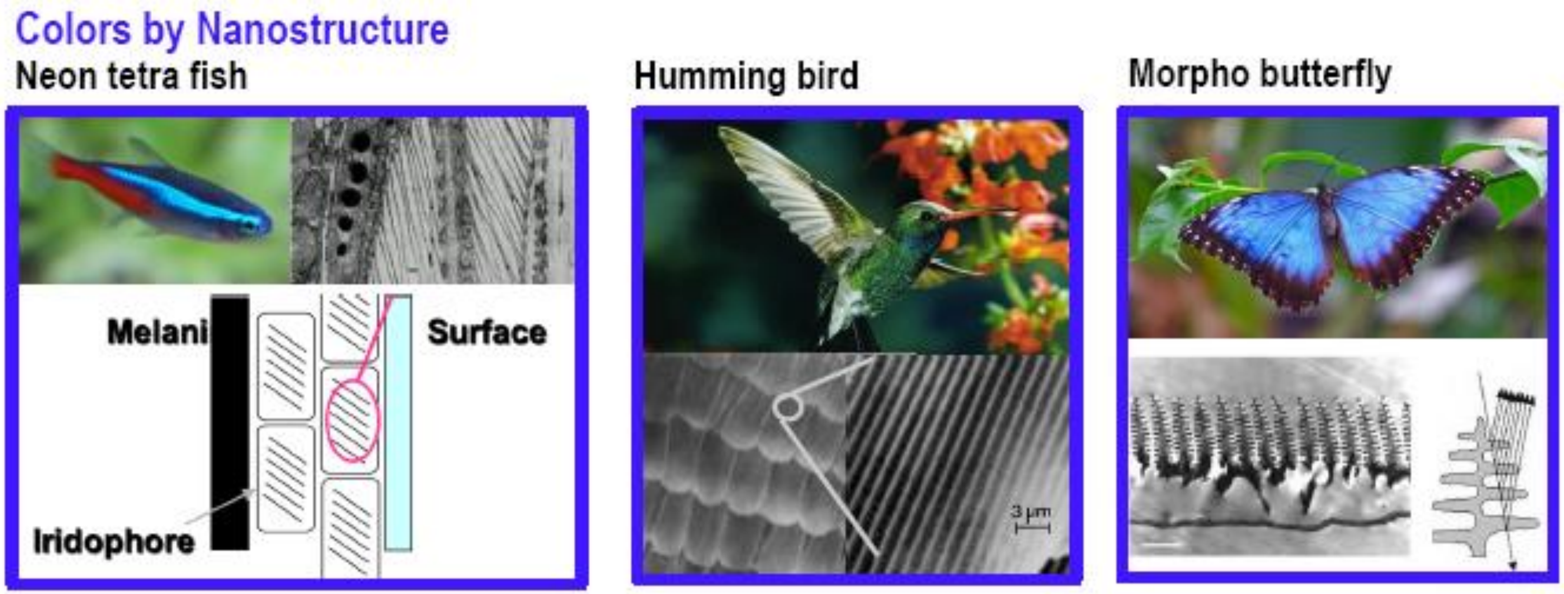
Conventional Coloring Mechanism

Chemical pigments



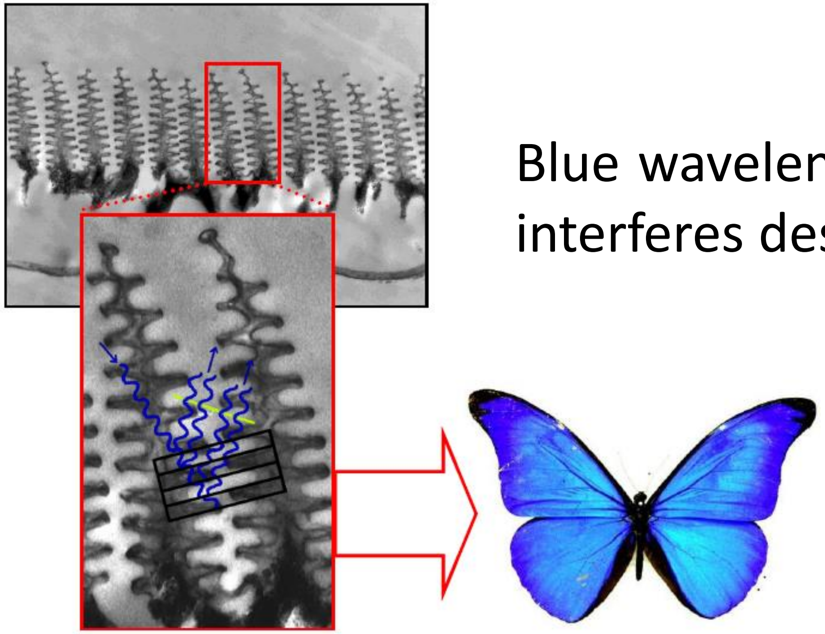
- **Low efficiency (30-50%)**
- **Low stability**
- **Non-glossy**
- **Limited color generation**

Unusual Coloring by Nanostructures



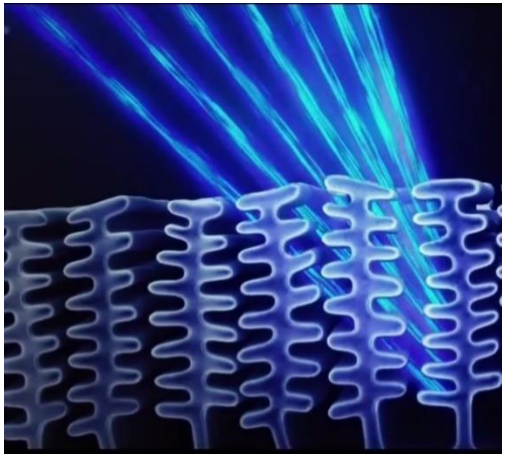
- **High efficiency (>70%)**
- **High stability**
- **Wide color generation**

NanoStructural Color Paint for Automobiles

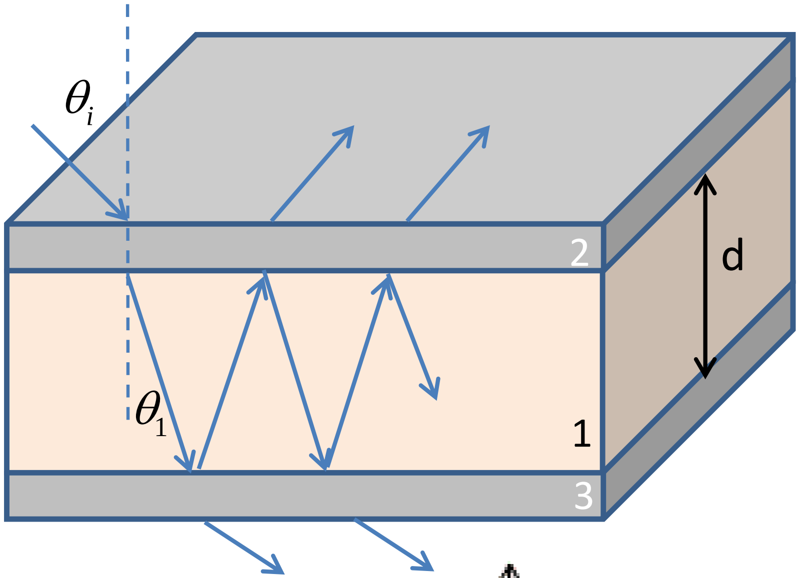


Blue wavelengths fit in the structure while red interferes destructively and is not reflected

NanoStructural Color Paint



Basic Theory of Fabry-Perot Resonance

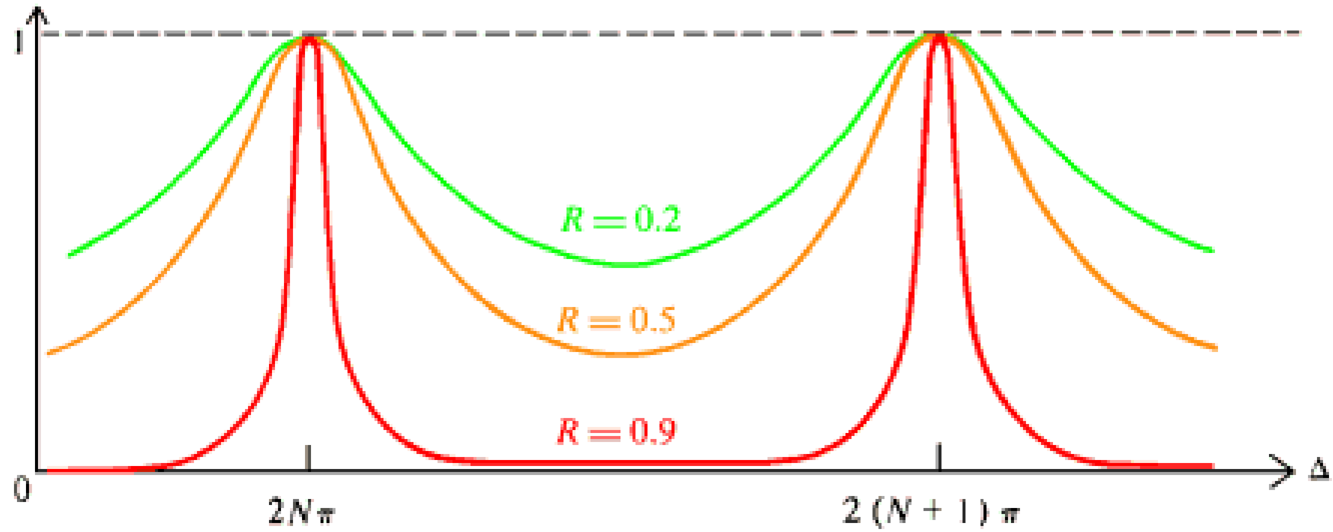


Resonance condition:

$$\phi_{r12} + \phi_{r23} + \phi_{propagation} = 2m\pi$$

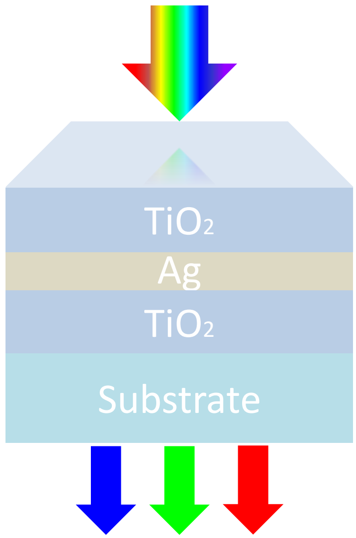
$$\phi_{propagation} = \frac{2\pi n_1}{\lambda} 2d\cos(\theta_1)$$

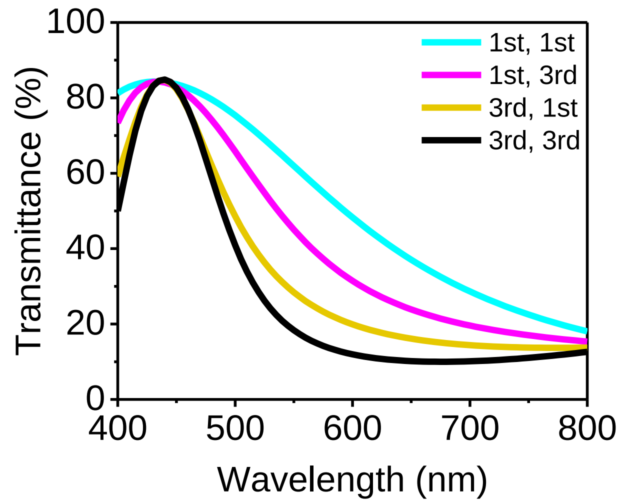
$$F = \frac{\pi\sqrt{R}}{(1-R)}$$

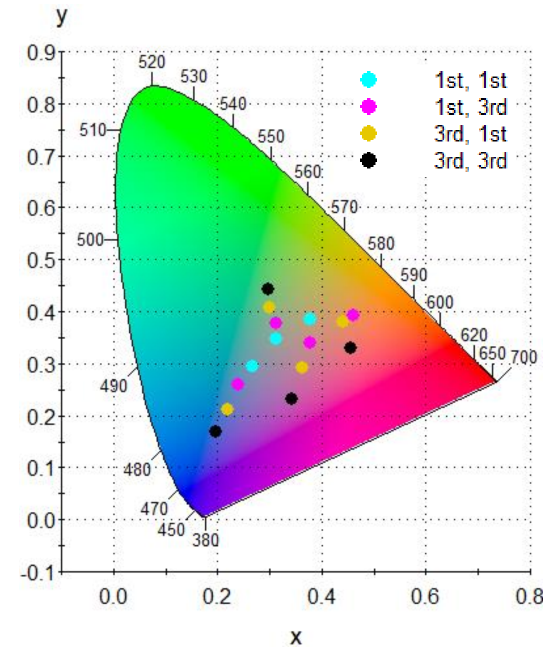


Project 5-1. Structural Color Filters (Blue and Magenta)

Theoretical analysis, Fabrication and Characterization





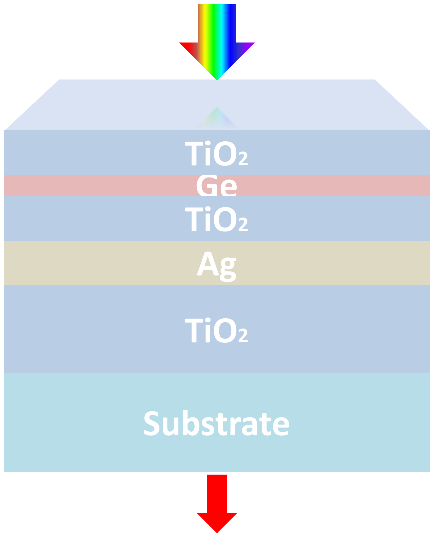


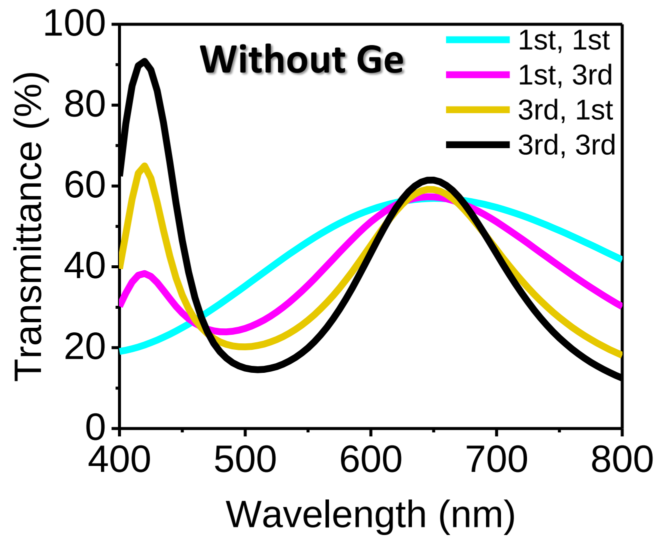
<u>Goals</u>: Understand the working principles of Fabry-Perot cavity, multicavity, higher-order resonance, and gain knowledge of the operation principles of the fabrication and characterization techniques.

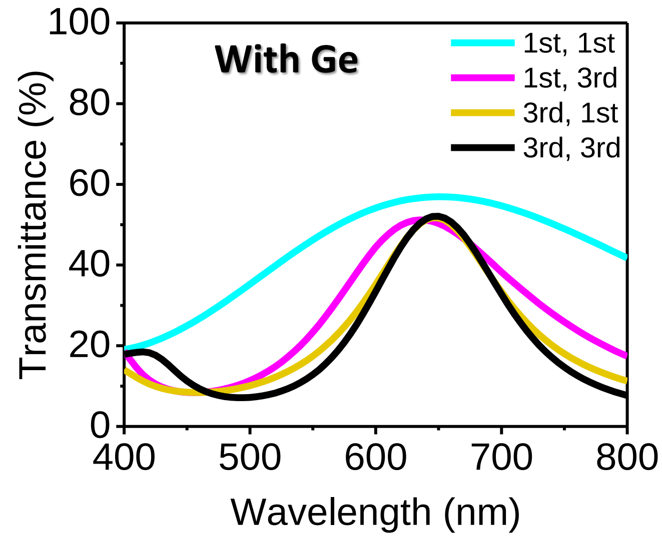
- Theoretical analysis of Fabry-Perot cavity (1st order vs high order) and multicavity.
- Fabricate and characterize optical properties of structural color filters by e-beam evaporator, spectrophotometer, and ellipsometer.

Project 5-2. Structural Color Filters (Green and Red)

Theoretical analysis, Fabrication and Characterization







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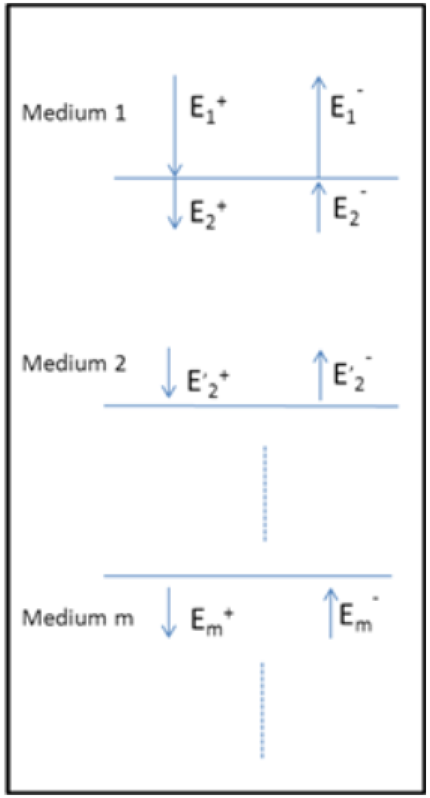
Simulation Code

Project 6. Code Transfer Matrix Method by Any Language

Develop simulation code and Theoretical analysis



Propagation through mediums at *<u>normal incidence</u>*

Superposition of electric field – one wave with positive direction(E^+); one wave with negative direction(E^-)

Propagating through an interface:

$$\begin{bmatrix} E_i^+ \\ E_i^- \end{bmatrix} = \frac{1}{t_{i,j}} \begin{bmatrix} 1 & r_{i,j} \\ r_{i,j} & 1 \end{bmatrix} \begin{bmatrix} E_j^+ \\ E_j^- \end{bmatrix}$$

$$r_{i,j} = -r_{j,i} = \frac{N_i - N_j}{N_i + N_j}, \qquad t_{i,j} = \frac{2N_i}{N_i + N_j}, \quad t_{j,i} = \frac{2N_j}{N_i + N_j};$$

r, t are, respectively, the complex amplitude reflection and transmission Fresnel coefficients; N is the complex refractive index of the layer

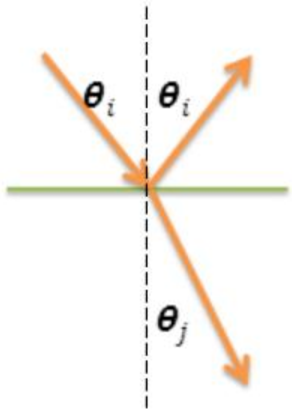
Propagating within a layer:

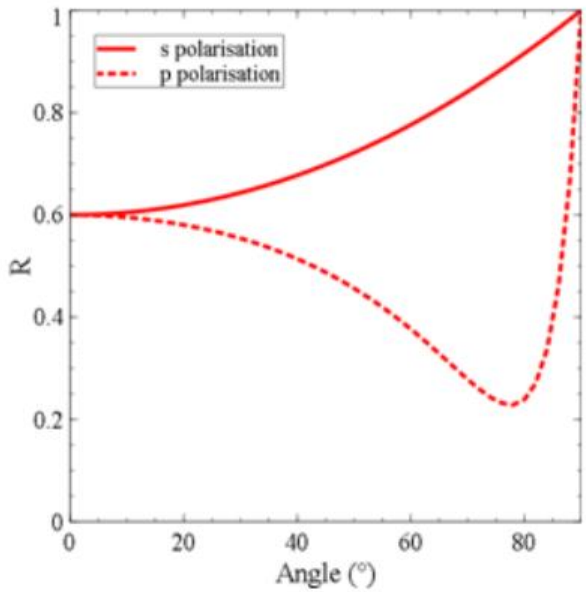
$$\begin{bmatrix} E_i^+ \\ E_i^- \end{bmatrix} = \begin{bmatrix} \Phi^{-1} & 0 \\ 0 & \Phi \end{bmatrix} \begin{bmatrix} E_j^+ \\ E_j^- \end{bmatrix} \qquad \Phi = e^{-i\frac{2\pi}{\lambda}N_i d}$$

Where d is the thickness of medium, ω is the frequency of the propagating light and c is the speed of light

Project 6. Code Transfer Matrix Method by Any Language

Develop simulation code and Theoretical analysis





At interface

P polarization:

$$r_{i,j} = \frac{N_j cos\boldsymbol{\theta}_i - N_i cos\boldsymbol{\theta}_j}{N_j cos\boldsymbol{\theta}_i + N_i cos\boldsymbol{\theta}_j}$$

$$t_{i,j} = \frac{2N_i cos\boldsymbol{\theta}_i}{N_j cos\boldsymbol{\theta}_i + N_i cos\boldsymbol{\theta}_j}$$

S polarization:

$$r_{i,j} = \frac{N_i cos\boldsymbol{\theta}_i - N_j cos\boldsymbol{\theta}_j}{N_i cos\boldsymbol{\theta}_i + N_j cos\boldsymbol{\theta}_j}$$

$$t_{i,j} = \frac{2N_i cos\boldsymbol{\theta}_i}{N_i cos\boldsymbol{\theta}_i + N_j cos\boldsymbol{\theta}_j}$$

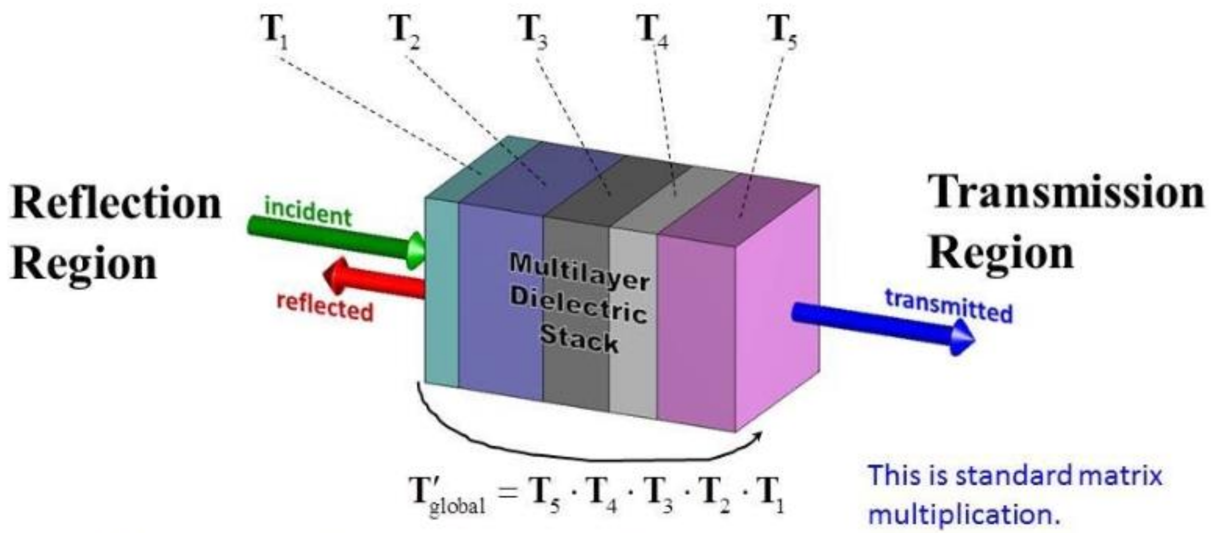
Fresnel coefficiencts for
oblique incidence

Within the layer

$$\Phi = e^{-i\frac{2\pi}{\lambda}N_m d/cos\boldsymbol{\theta}_j}$$

Project 6. Code Transfer Matrix Method by Any Language

Develop a simulation code and Theoretical analysis

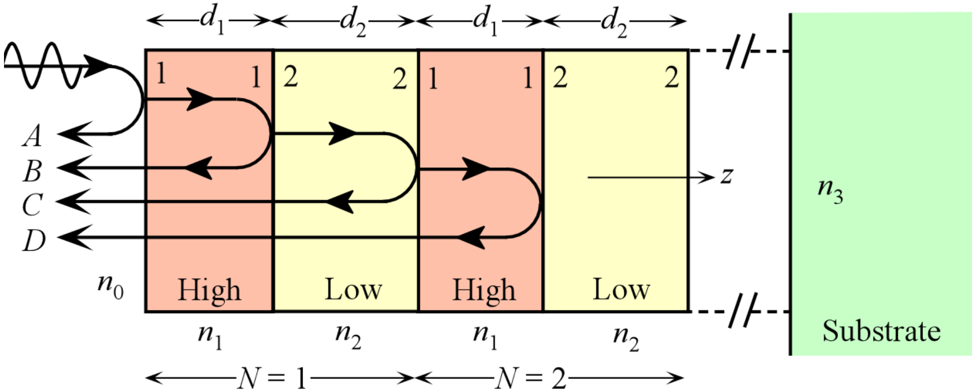


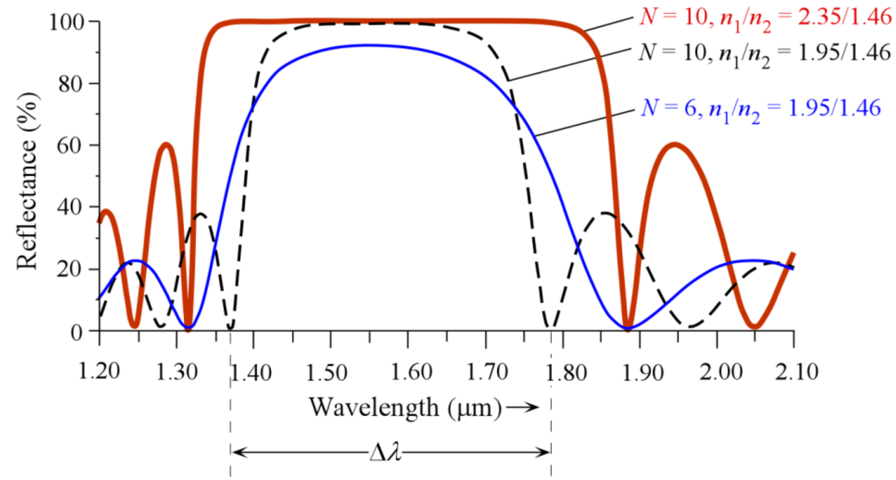
Goals: Develop a simulation code, study optical properties of metal-dielectric-metal Fabry-Perot cavity, and confirm the results by a commercial thin-film software (Essential Macleod).

- Code transfer matrix method by any language (python, matlab, C, etc).
- Study optical properties of a simple Fabry-Perot cavity, and confirm the results by Essential Macleod.

Theoretical analysis, Design and Optimization

Dielectric mirrors





$r_{12} = (n_1 - n_2)/(n_1 + n_2)$
(positive number → no phase change)
$r_{21} = (n_2 - n_1)/(n_2 + n_1)$
(negative → π phase change)
The phase difference between *A* and *B* is

$$\mathbf{0 + \pi + 2k_1d_1 = 0 + \pi + 2(2\pi n_1/\lambda_o)(\lambda_o/4n_1) = 2\pi}$$

Thus, waves *A* and *B* are in phase and **interfere constructively**.

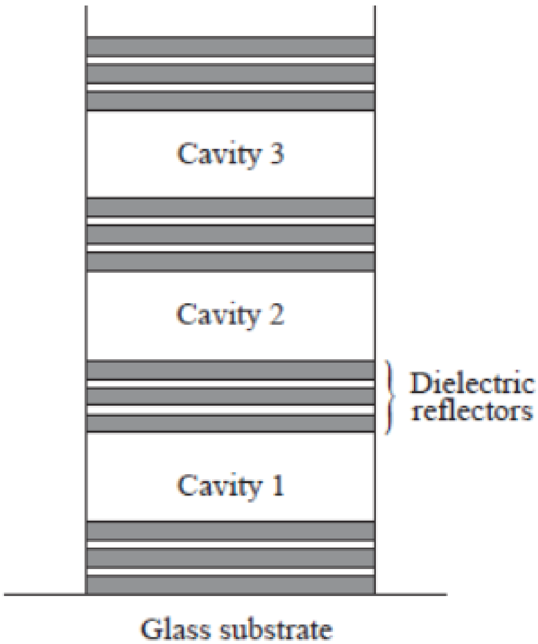
Δλ = Reflectance bandwidth (Stop-band for transmittance)

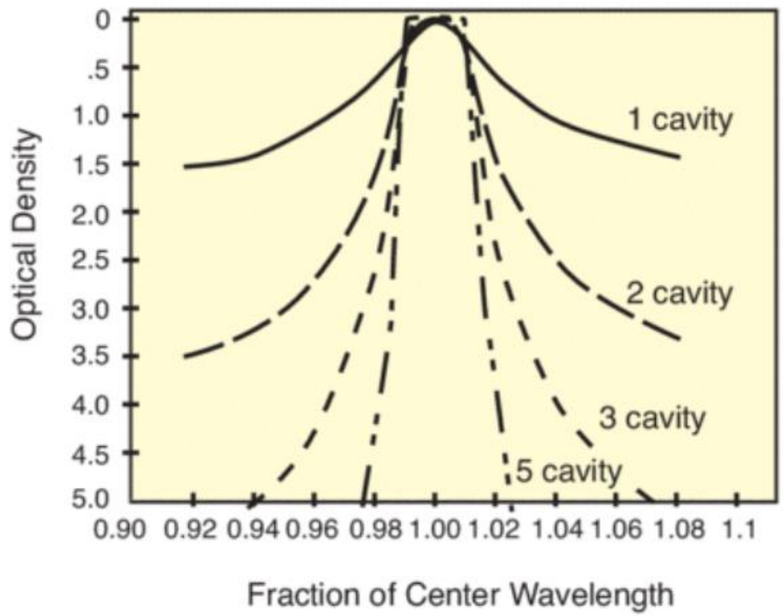
$$\frac{\Delta\lambda}{\lambda_o} \approx (4/\pi)\arcsin\left(\frac{n_1 - n_2}{n_1 + n_2}\right)$$

$$R_N = \left[\frac{n_1^{2N} - (n_0/n_3)n_2^{2N}}{n_1^{2N} + (n_0/n_3)n_2^{2N}}\right]^2$$

Project 7. Ultra-Narrow Band-Pass Filters at 1550 nm

Theoretical analysis, design and optimization



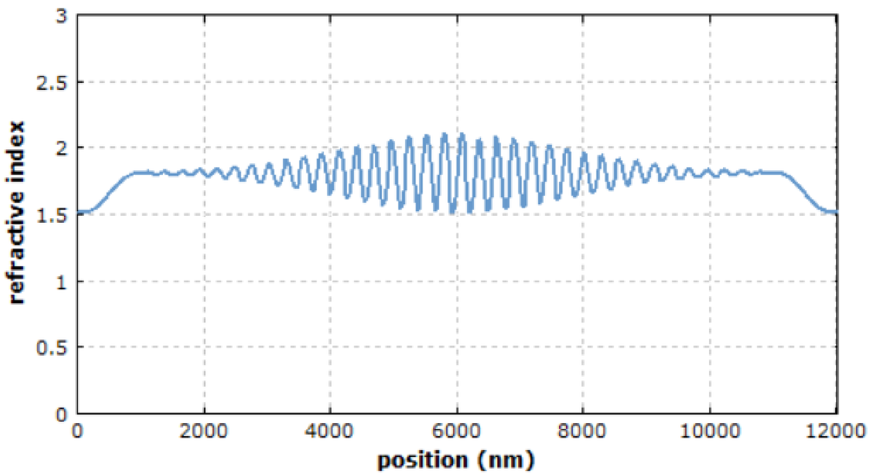


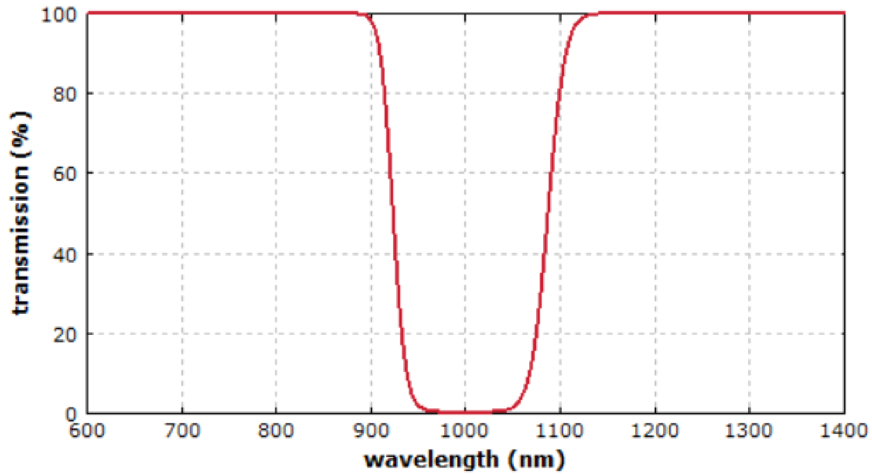
<u>Goals</u>: Understand the working principles of dielectric mirrors, Fabry-Perot cavity, and multicavity. Design the band-pass filters (bandwidth < 1 nm).

- Theoretical analysis, design and optimization of ultra-narrow band-pass filters at 1550 nm based on multicavity via Essential Macleod.

Project 8. Rugate Filters for RGB Reflection Colors

Theoretical analysis, design and optimization



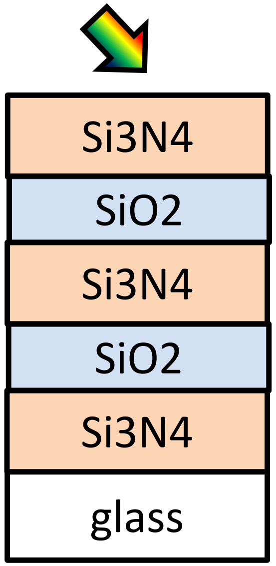


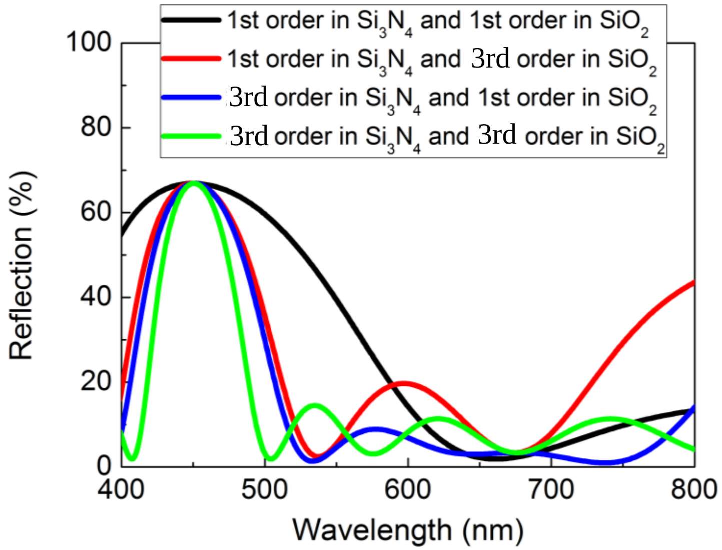
<u>Goals</u>: Understand the working principles of rugate filters (gradient-index filters) and design rugate filters at visible frequencies for RGB reflection color generation.

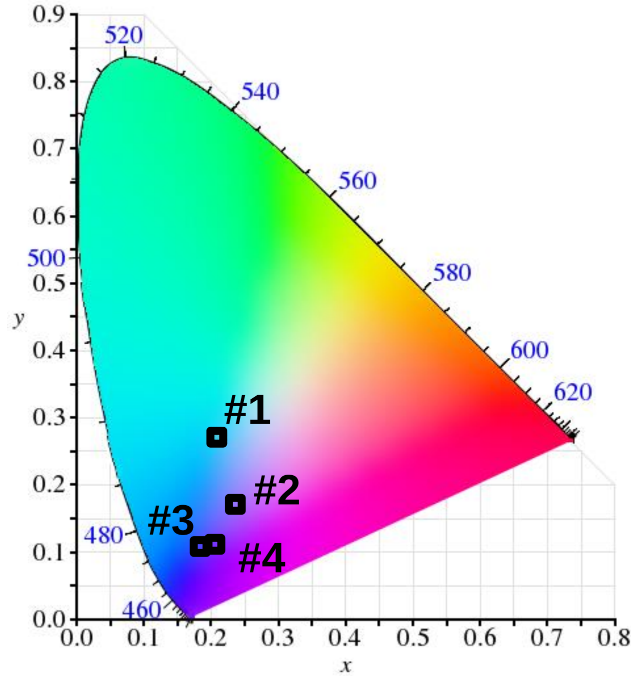
- Theoretical analysis, design and optimization of the structural color filters based on rugate filters for RGB reflection colors by Essential Macleod.

Project 9. Higher-Orders in Dielectric Mirrors (Color Filters)

Theoretical analysis, design and optimization







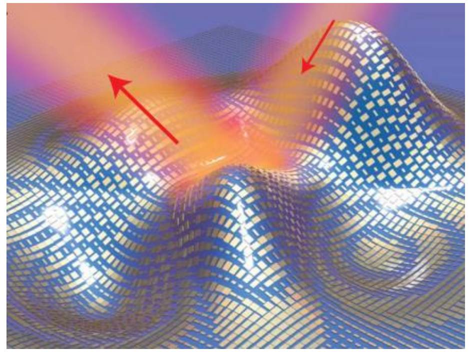
<u>Goals</u>: Understand the working principles of dielectric mirrors and higher-orders, and design the structural color filters creating RGB reflection colors.

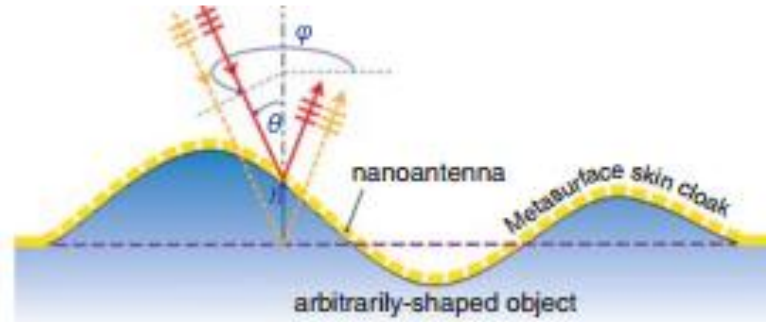
- Theoretical analysis, design and optimization of dielectric mirrors with higher-orders for RGB color generation via Essential Macleod.

Invisibility Cloak based on Ray Optics

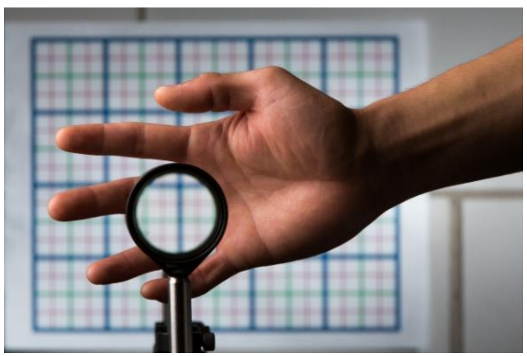
Issues of Existing Invisibility Cloak

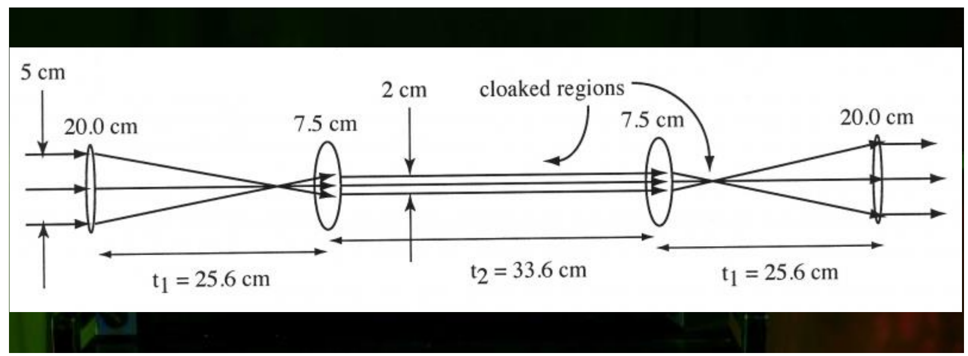
PERLUCOR, CeramTec Inc.





Science **349**, 1310 (2015)

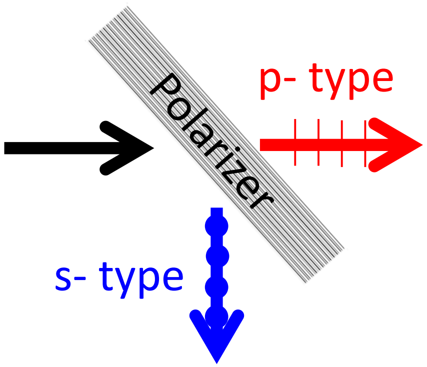


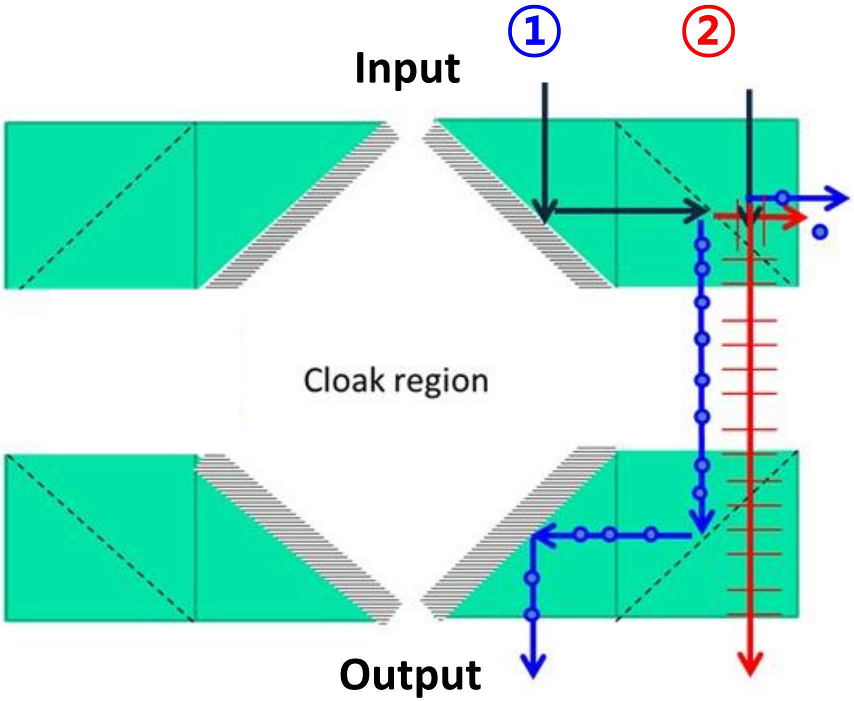


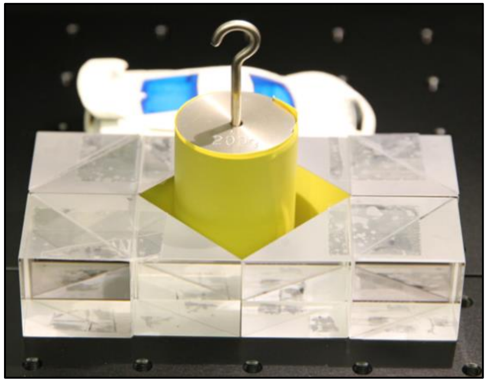
Opt. Express **22**, 29465 (2014)

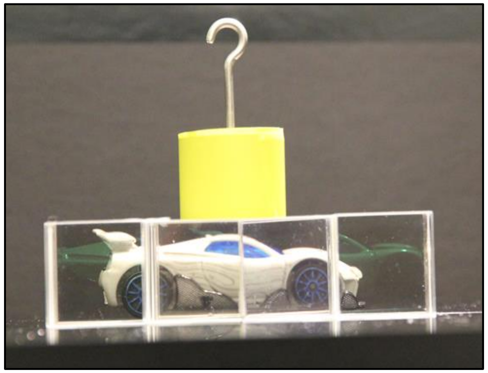
- **Narrow band and low efficiency**
- **Small area and expensive**
- **Too bulky → low cloaking ratio**

Example: Polarizers + Plane Mirrors









1. **No focusing optics**
2. **Good angle-insensitivity**
3. **Easy implementation**
4. **Wide field of view**

Sci. Rep., **6**, 38965 (2016)

Project 10. Ray Optics Cloaking

New design and ray-tracing simulation

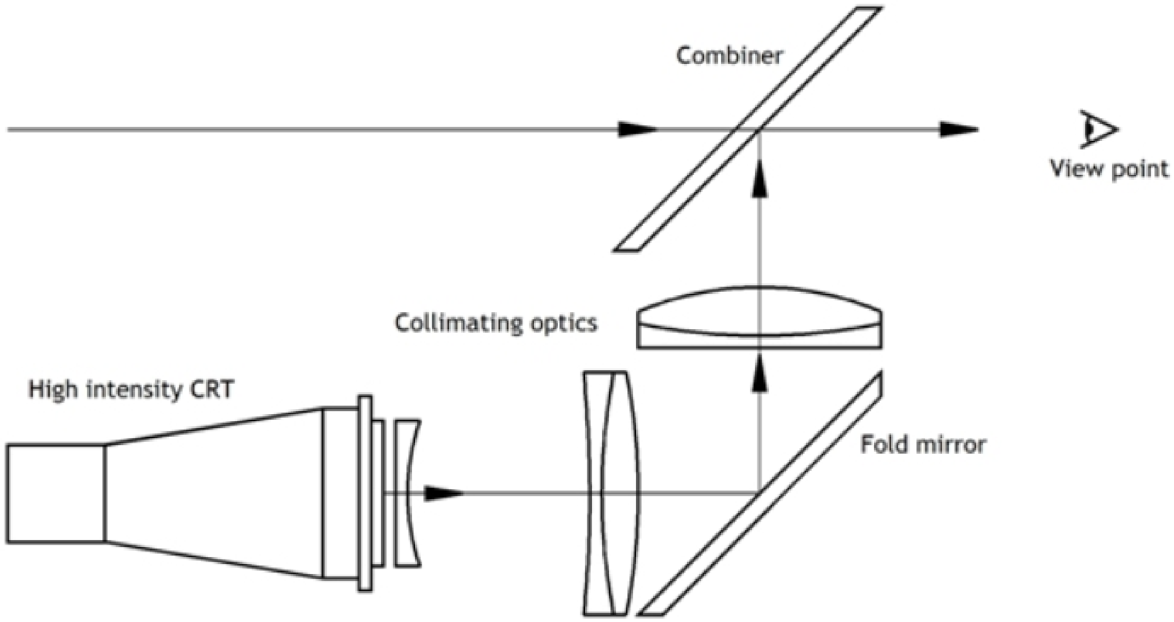
Ray Optics Cloaking

Goals: Develop a new design of the ray optics cloaking and confirm the optical cloaking performance by ray-tracing simulation (Zemax). If time allows, implement your own optical system design (should be cheap!) with commercial elements.

Optical Lens and Mirror Design

Project 11. Heads-up Display Lens and Mirror

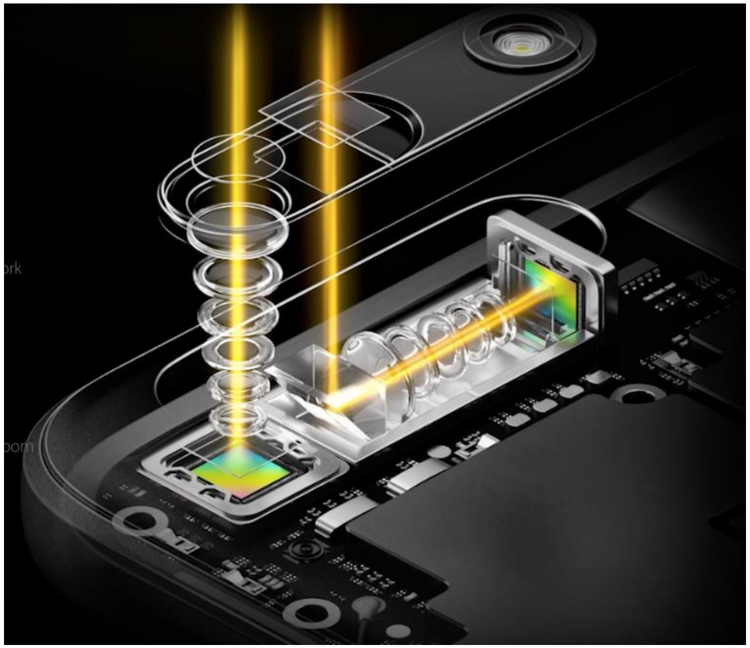
Design Lens and Mirrors for Heads-up Display

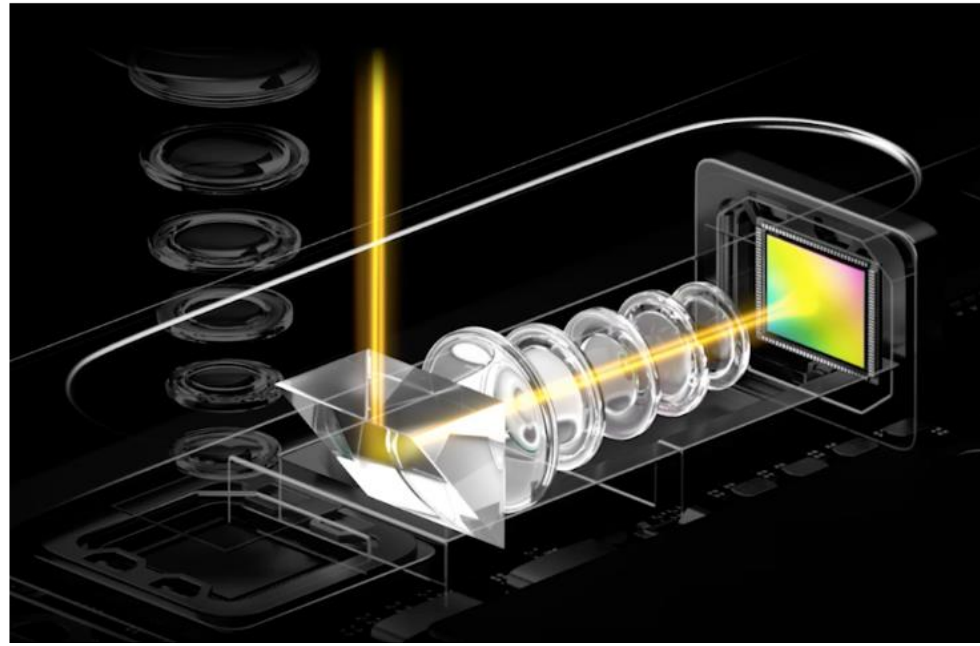


<u>Goals</u>: Understand the working principles of optical systems for heads-up display, and design optical lenses and mirrors by ray-tracing software (Zemax). If time allows, implement your own optical system design (should be cheap!) with commercial elements.

Project 12. Smart Phone Camera Lens

Design Lenses for Smart Phone Camera





<u>Goals</u>: Understand the working principles of a camera lens of recent smart phones, a role of each element of the camera lens and design the camera lens by ray-tracing software (Zemax).

Project 13. Any Optics Topics

List of Project Topics

1. Wire-Grid Polarizers
2. Fabry-Perot Cavity-based Structural Color Filters
3. Transfer Matrix Method Code
4. Ultra-Narrow Band-Pass Filters
5. Dielectric Mirror-based Structural Color Filters
6. Optical Cloaking
7. Lens and Mirror Design for Heads-up Display
8. Smart Phone Camera Lens Design