Enhanced Absorption via Light Trapping using Cholesteric Liquid Crystals

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Today’s Menu

- L‘ Apéritif: **About Optical Trapping**
- L‘ Entrée: **Optical Diodes**
- Le Plat Principal: **Light Trapping**
- Le Dessert : **Unpolarized Trapping**
- Le Digestif

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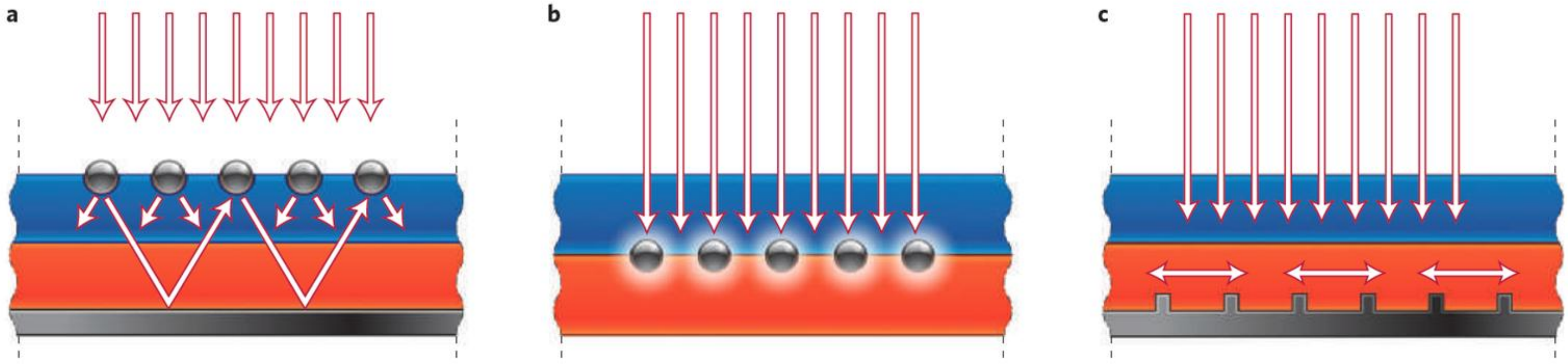
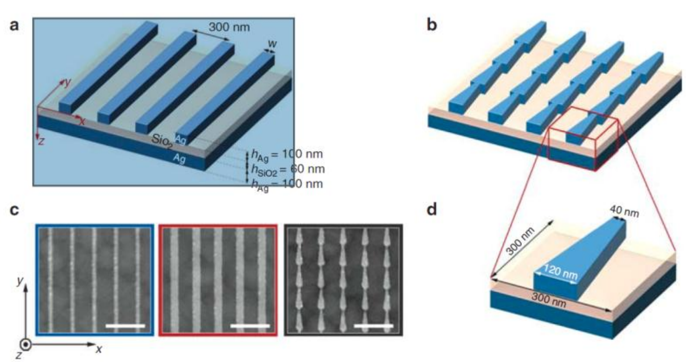
University of Patras, Greece

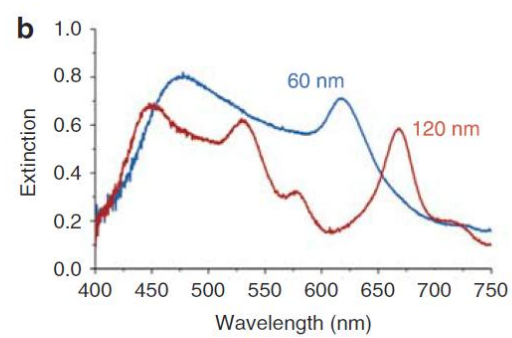
LAMDA GUARD
Advanced Systems Engineering

Optical Trapping Mechanisms
for Solar Cells



Increased scattering | **Localized surface plasmons** | **Surface plasmon polaritons**

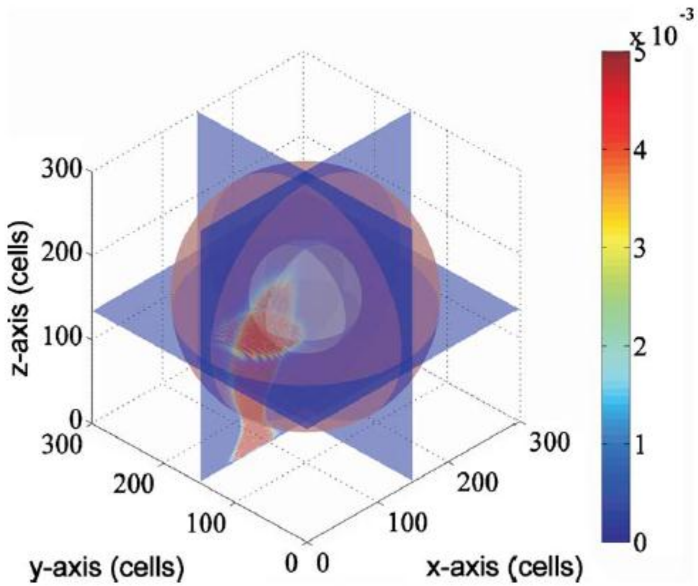


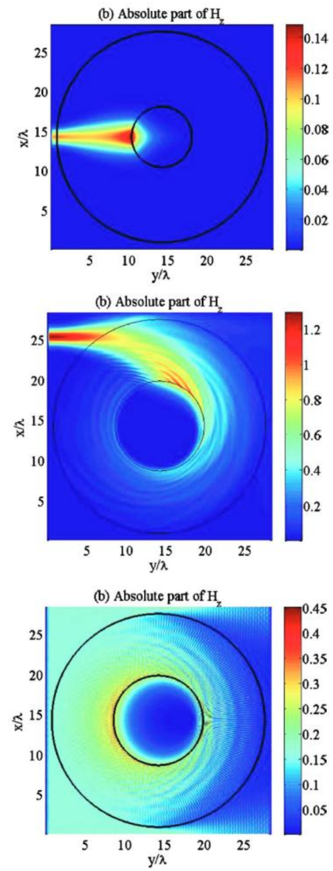


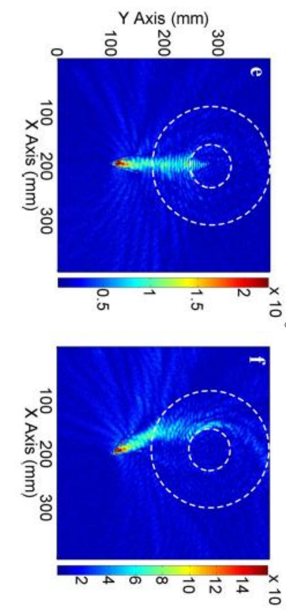
Green and Pillai, Nature Photonics, v.6, p.130 (2012); Aydin et al., Nature Comm., (2011)

Optical Black Hole

Transformation Optics





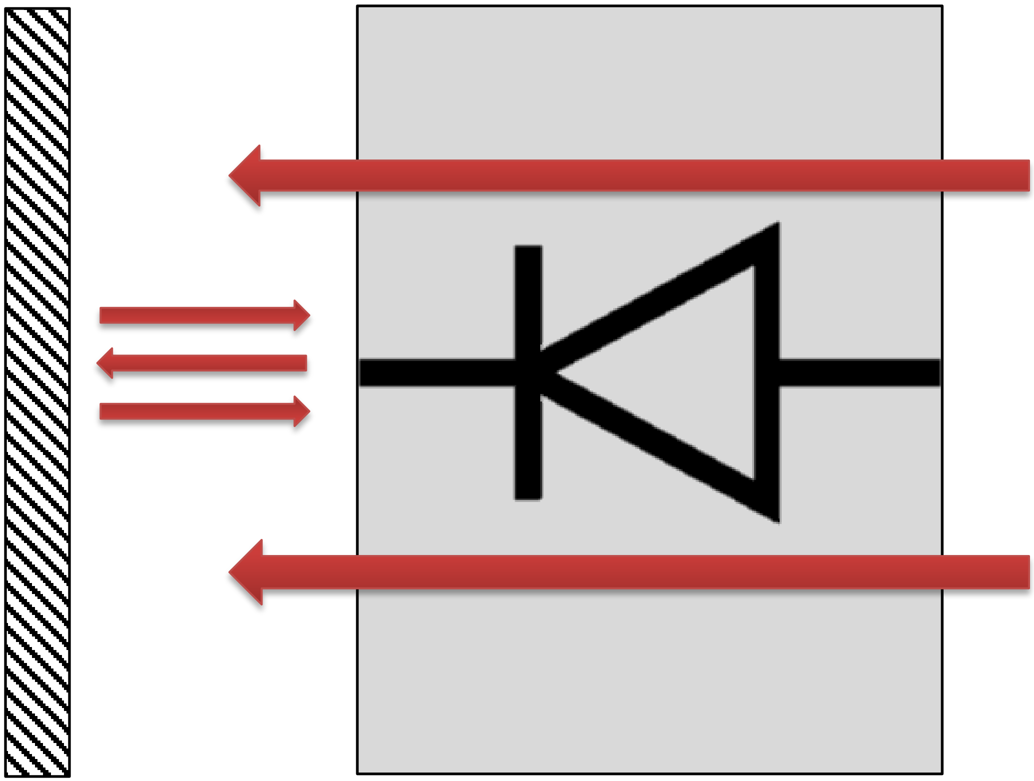


$$\varepsilon(r) = \begin{cases} \varepsilon_0, & r > R_{sh} \\ \varepsilon_0\left(\dfrac{R_{sh}}{r}\right)^2, & R_c \le r \le R_{sh} \\ \varepsilon_c + \imath\gamma, & r < R_c, \end{cases}$$

Argyropoulos et al., JOSAB 27, 2020 (2010); Cheng et al., New J. Phys. 12 063006 (2010)

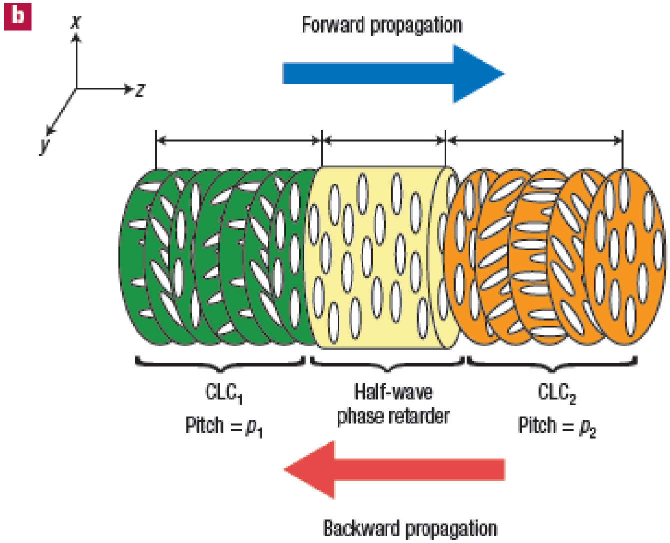
A New Hope

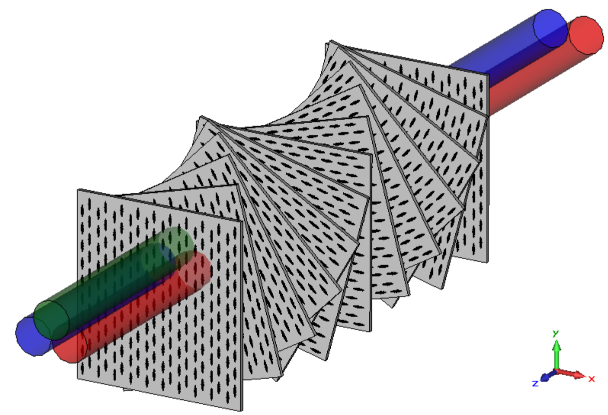
using Optical Diodes

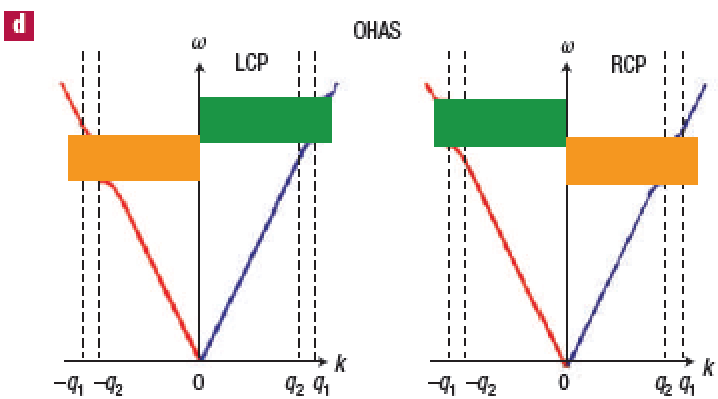


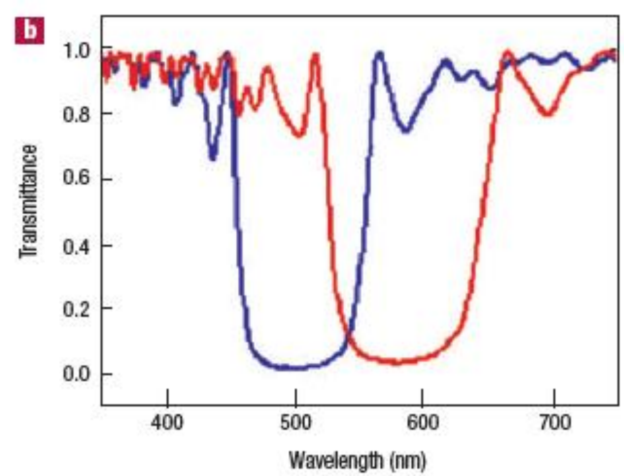
Cholesteric Liquid Crystals

Diodes for Circularly Polarized Light

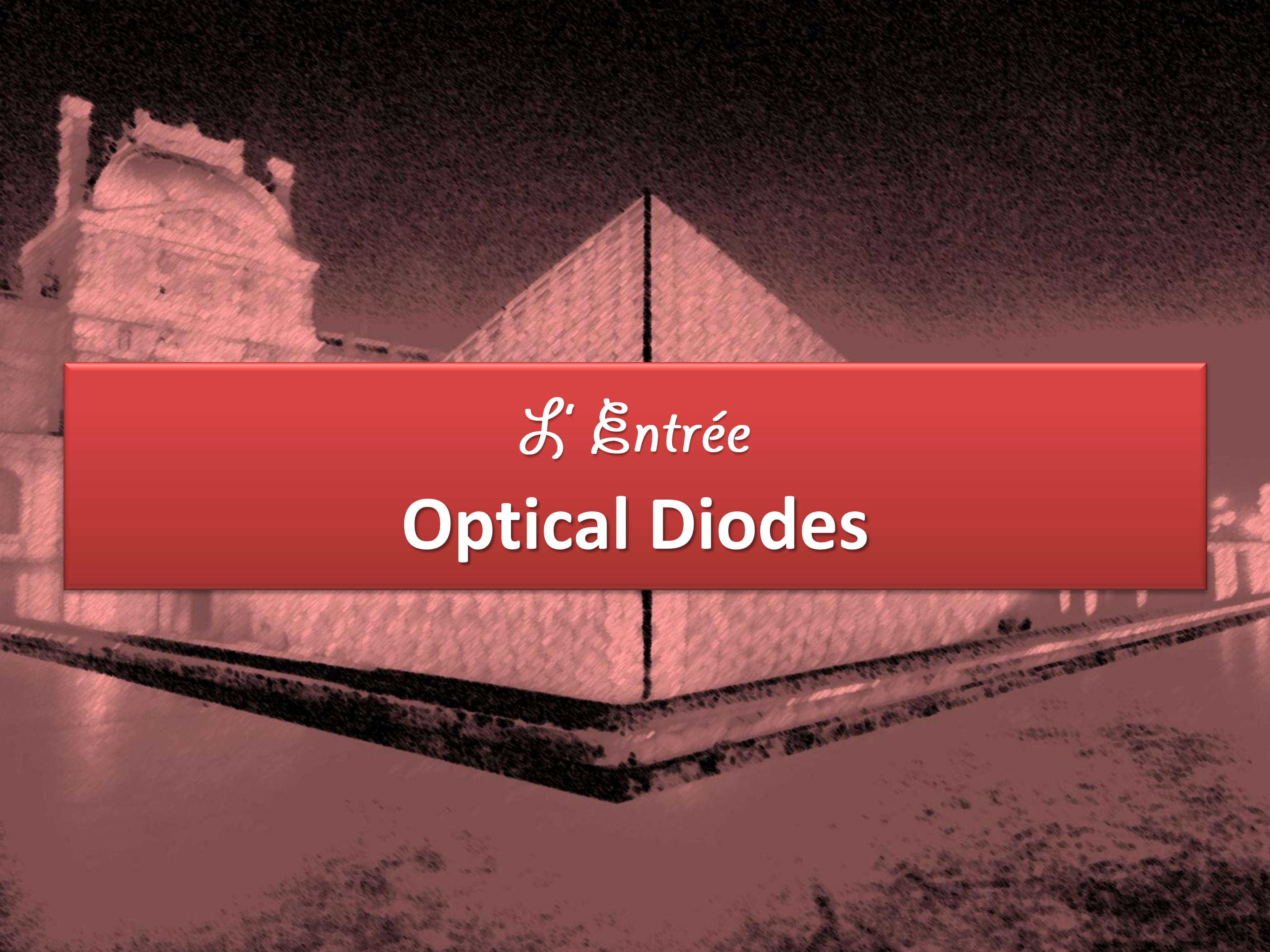








Hwang et al., Nature Materials (2005)

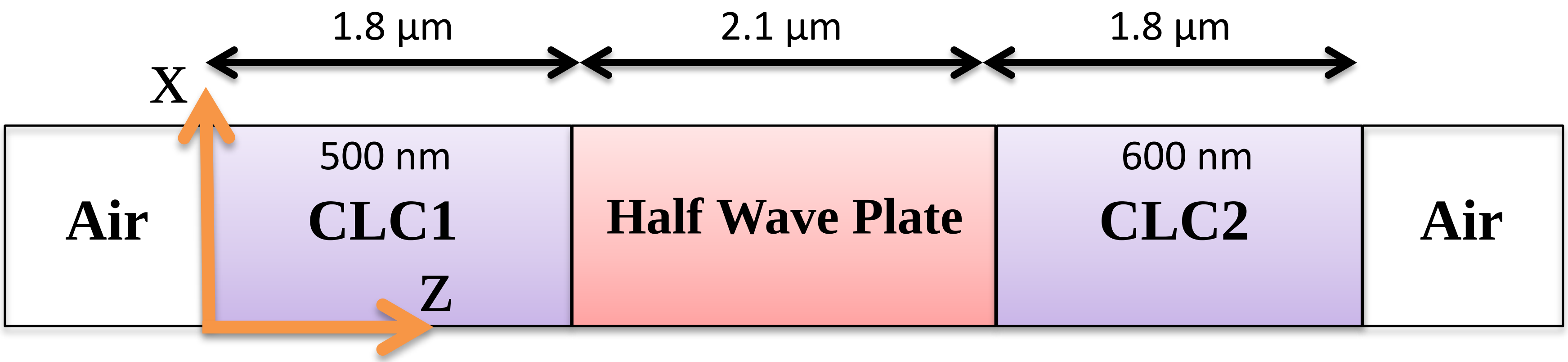


L' Entrée

Optical Diodes

COMSOL Simulation Details

Left-handed Helices



$$p_1 = 315\,nm \quad n_{1o} = 1.50 \quad n_{1e} = 1.75$$

$$n_{2o} = 1.50 \quad n_{2e} = 1.63$$

$$p_2 = 366\,nm \quad n_{3o} = 1.50 \quad n_{3e} = 1.75$$

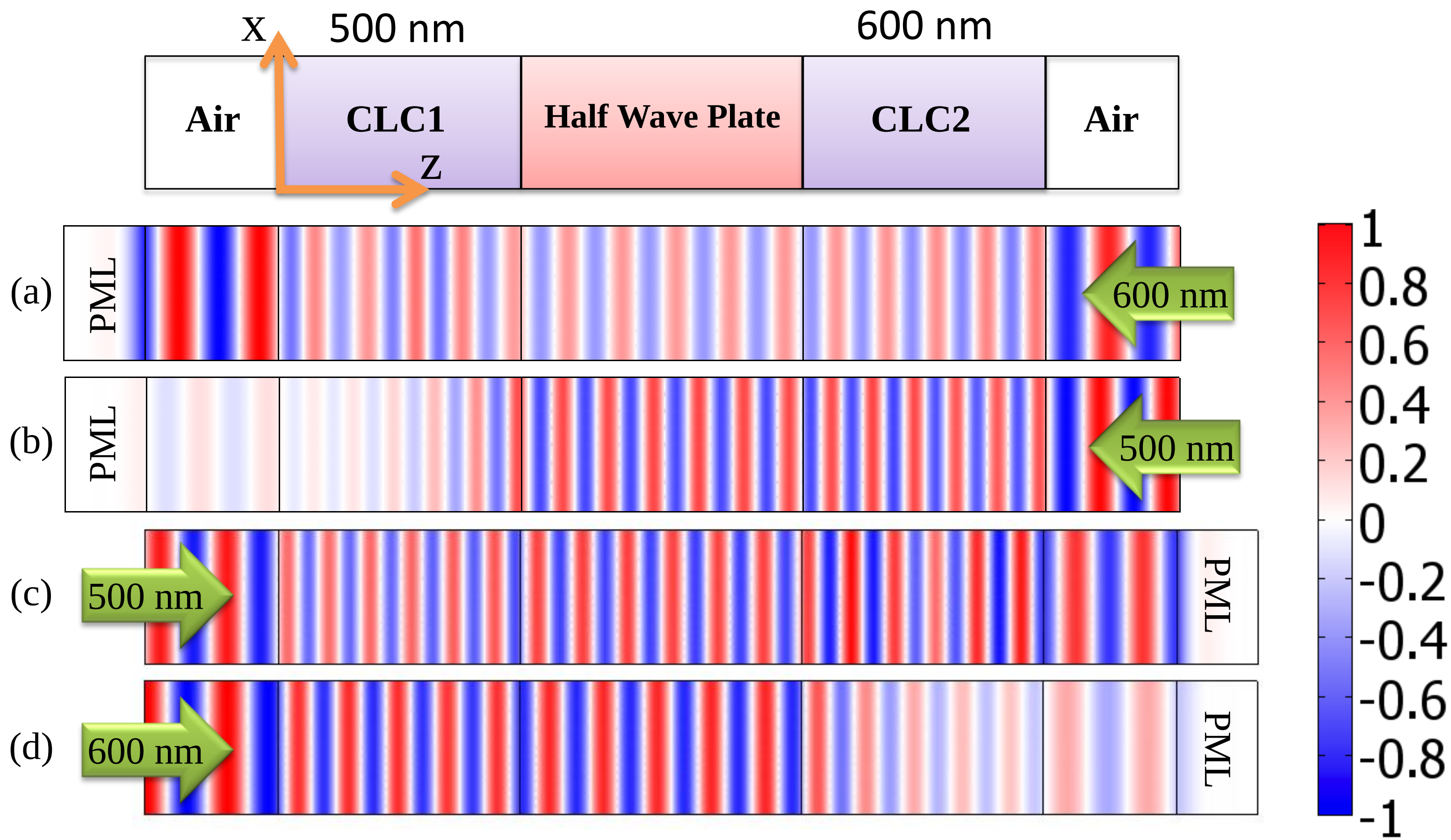
$$\vec{E} = \left(\hat{x} \pm j\hat{y}\right) e^{\mp jkz}$$

$$\varepsilon(z) = \begin{pmatrix} \bar{\varepsilon} + \Delta\varepsilon\cos 2\varphi & \Delta\varepsilon\sin 2\varphi & 0 \\ \Delta\varepsilon\sin 2\varphi & \bar{\varepsilon} - \Delta\varepsilon\cos 2\varphi & 0 \\ 0 & 0 & n_o^2 \end{pmatrix}$$

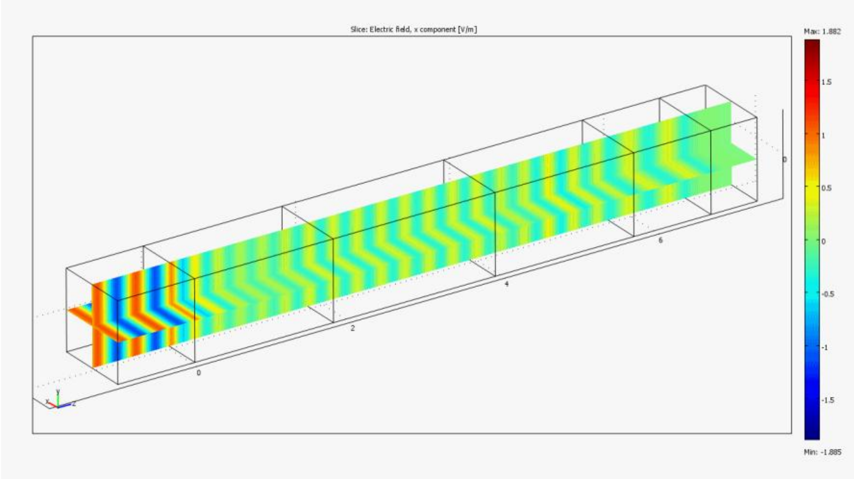
$$\varphi = 2\pi\left(z - z_0\right)/p$$

Simulation Results

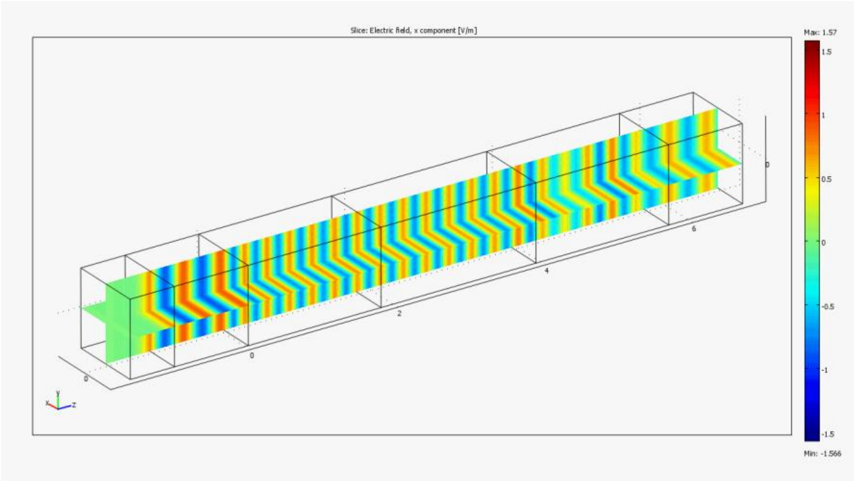
RCP Waves on Left-Handed Helices



Diode Effect



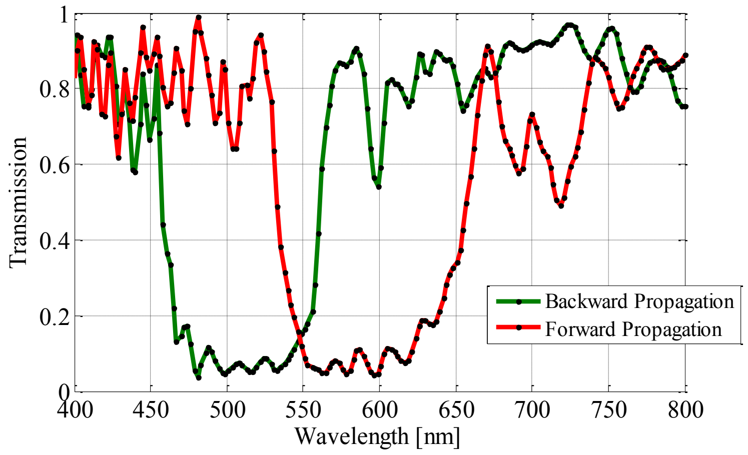
Forward Propagation:
No transmission



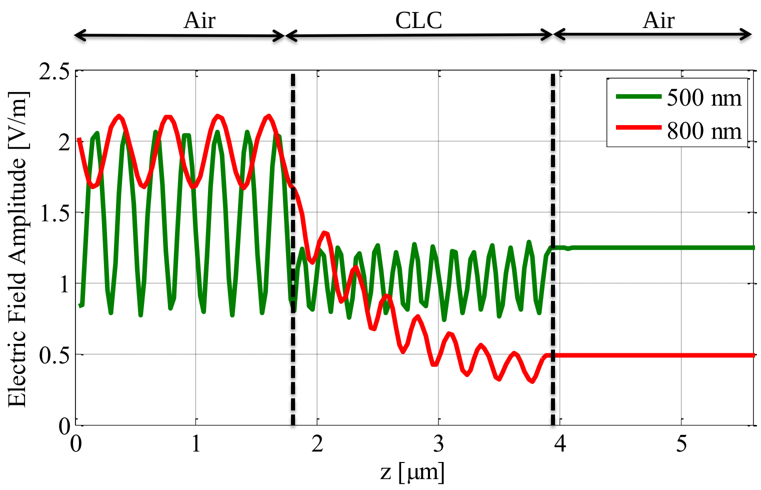
Backward Propagation:
Transmission

Transmission Curves

Transmission vs. wavelength



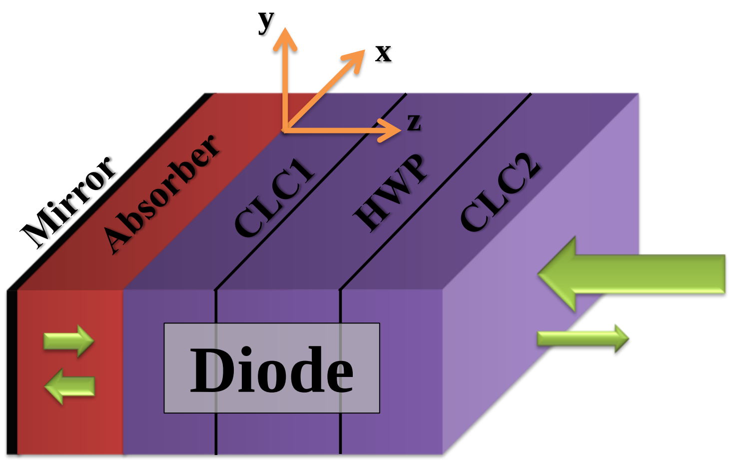
Field vs. distance



Le Plat Principal

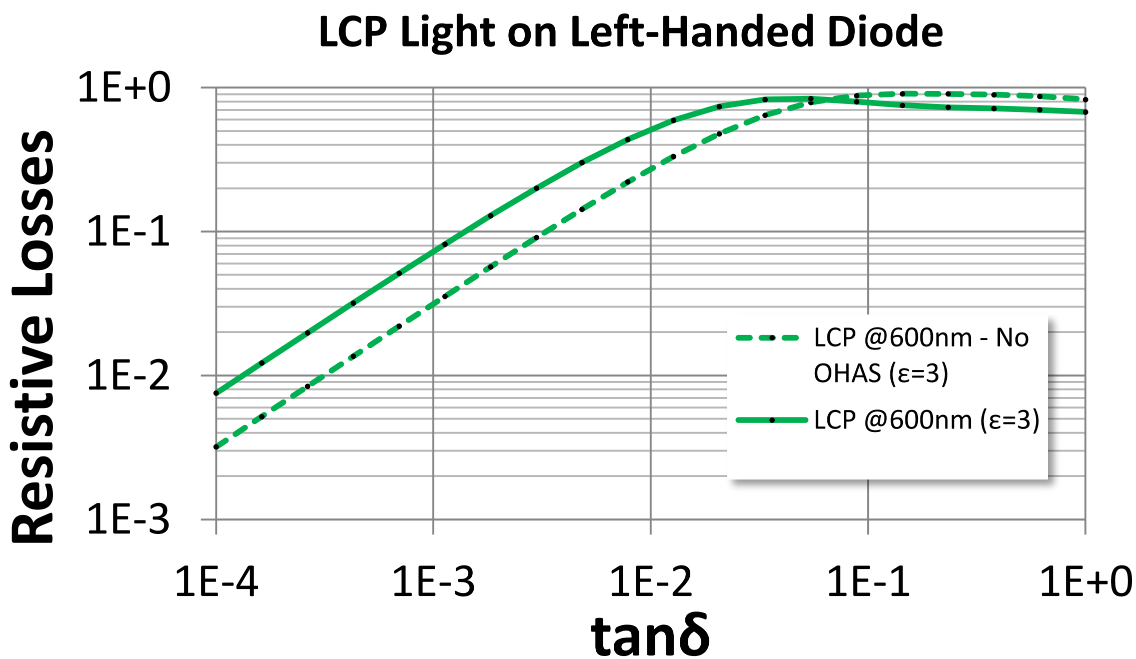
Light Trapping

Making a Trapping Device



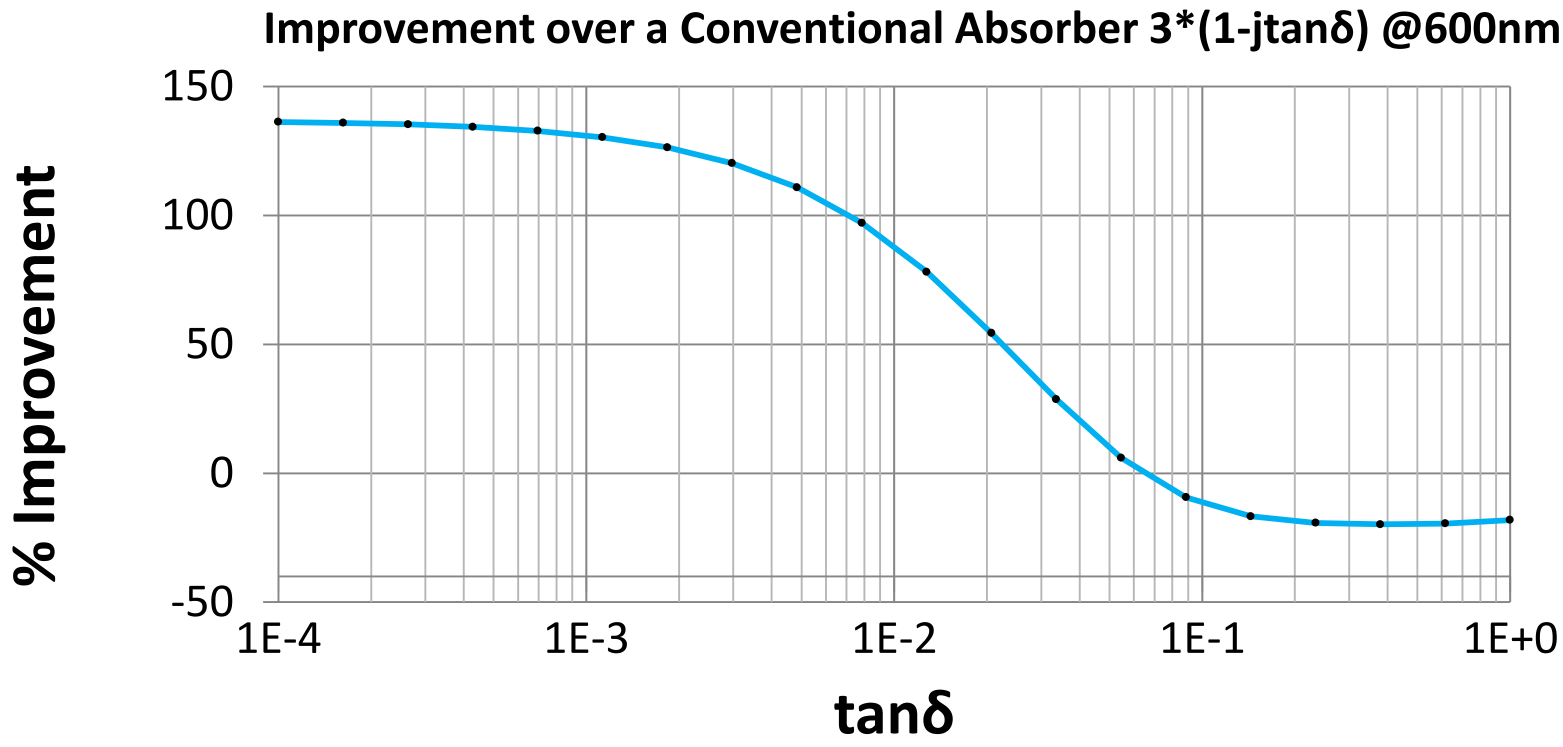
- Place a 1um-thick absorbing layer (e.g. solar cell) immediately after the diode
- Absorber modeled with relative $\varepsilon=3*(1-j*\tan\delta)$
  - $\tan\delta$ can be varied for different absorbing effects
  - Real part =3 for improved matching to the diode permittivity
- Terminate the diode using a reflecting surface – the polarization rotation is reversed and light does not transmit back into the device → **trapping**

Absorption Scans



- For very weak absorption factors, direct absorption (free space instead of diode) is better
- But for medium and strong absorption, the diode almost **doubles** the trapped/absorbed energy

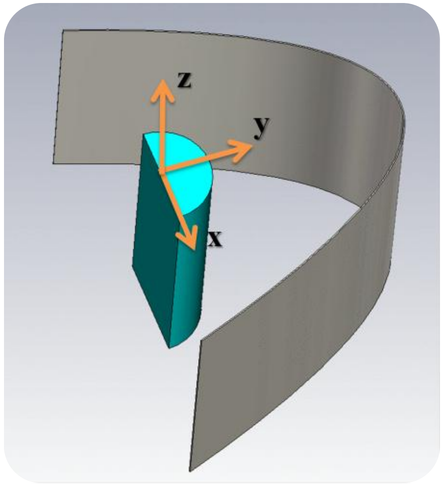
Absorption Scans



- The graph shows how much more energy is absorbed when placing the diode in front of an absorbing layer

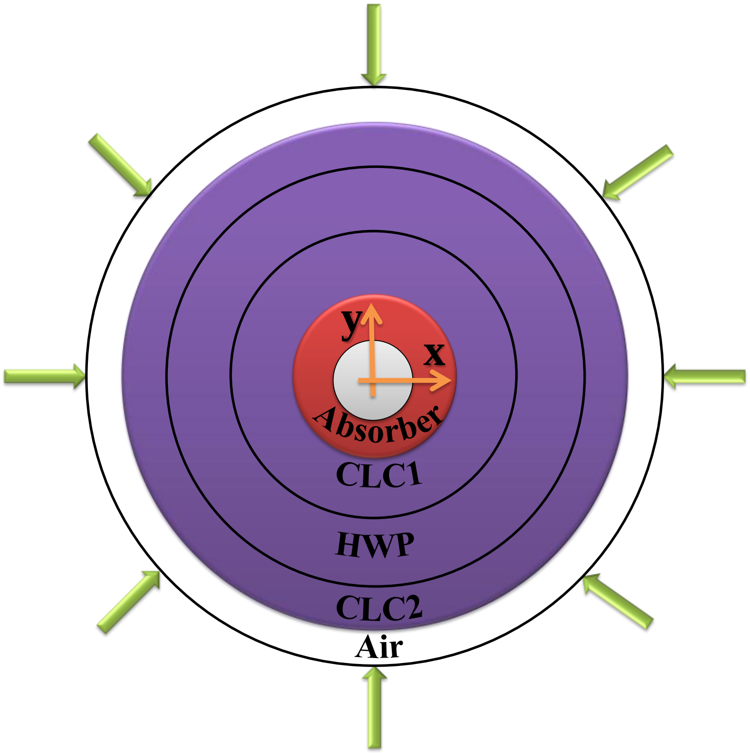
Cylindrical Optical Trapping

Parabolic Reflectors



http://www.solarthermalmagazine.com

Cylindrical Light Trapping Model



$$\varepsilon(r,\theta)=\begin{pmatrix} n_o^2+\Delta\varepsilon\sin^2\varphi\sin^2\theta & \Delta\varepsilon\cos\theta\sin\theta\cos^2\varphi & \Delta\varepsilon\cos\theta\sin\varphi\sin\theta \\ \Delta\varepsilon\cos\theta\sin\theta\cos^2\varphi & n_o^2+\Delta\varepsilon\cos^2\theta\sin^2\varphi & -\Delta\varepsilon\cos\theta\sin\varphi\cos\varphi \\ \Delta\varepsilon\cos\theta\sin\varphi\sin\theta & -\Delta\varepsilon\cos\theta\sin\varphi\cos\varphi & n_o^2+\Delta\varepsilon\cos^2\varphi \end{pmatrix}$$

$$\varphi(r)=2\pi(r-r_0)/p$$

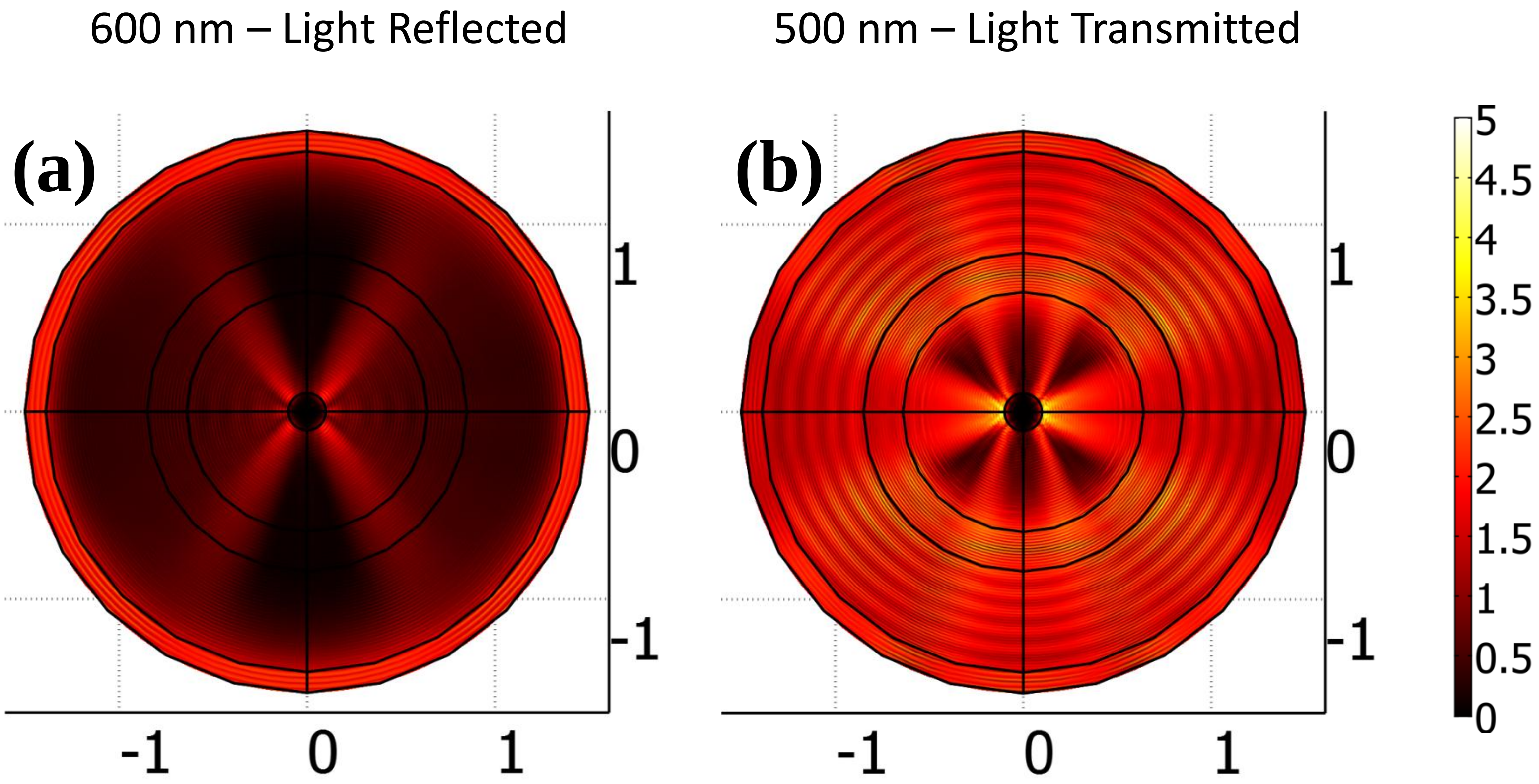
$$\theta=\tan^{-1}(y/x)$$

- Input wave:

$$\vec{E}=\left(\hat{\theta}+j\hat{z}\right)e^{+j\vec{k}\cdot\vec{r}}$$

- Absorber ε=3*(1-j*tanδ)
- 6 layers: Free space, CLC1, HWP, CLC2, Absorber, Mirror
- CLCs are 3 times longer to improve reflective properties (field naturally increases as sqrt(r) due to inward propagation)

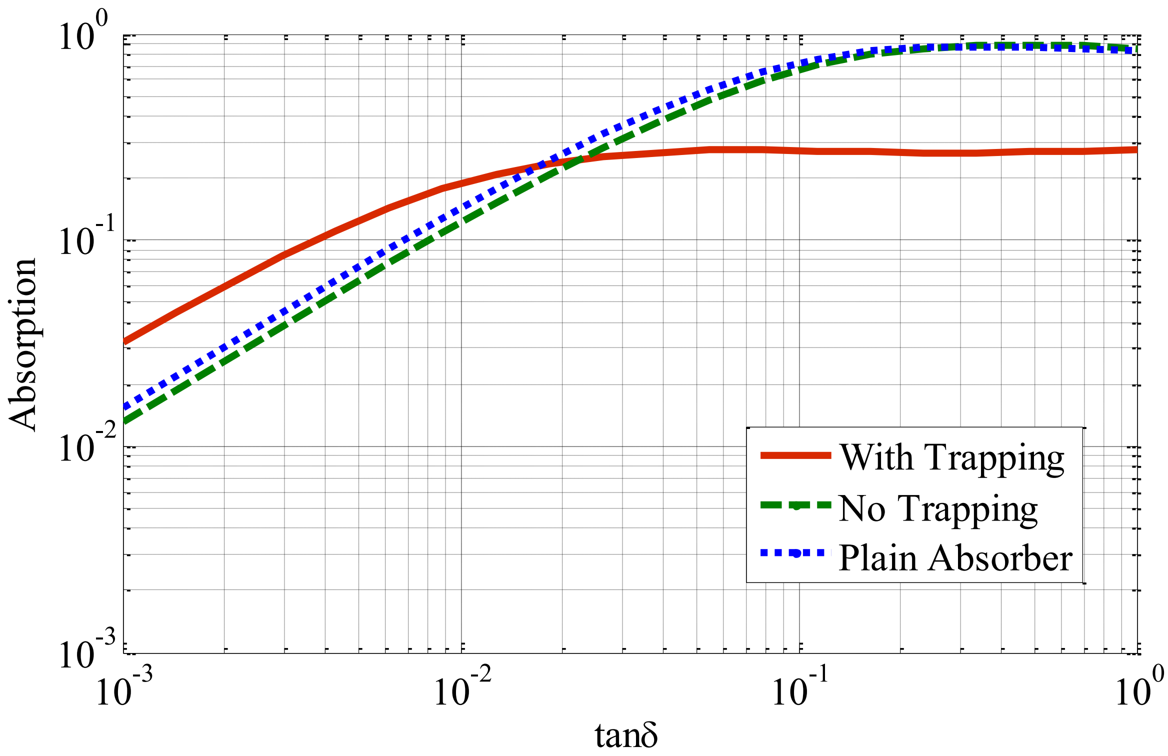
Cylindrical Diode Operation



- Reflective properties of diode are maintained in cylindrical geometry
- Transmission properties are also maintained, but the fields are not as smooth as in the planar geometry

Total Resistive Losses

as a function of core loss tangent, 600nm



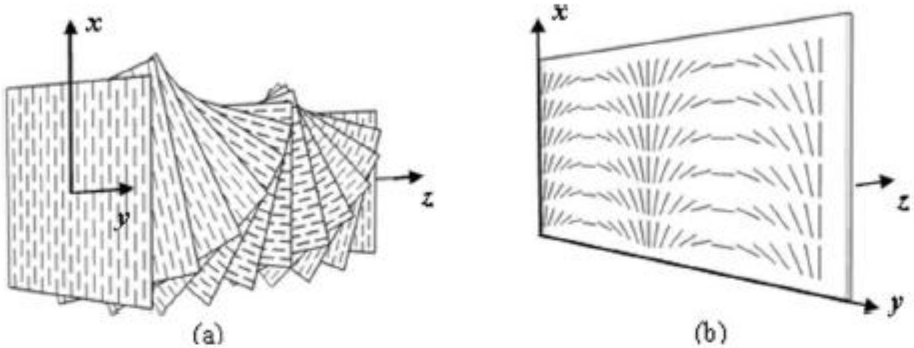
- With the diode the absorption is enhanced as in the planar case compared to free space
- Assuming absorptive material of equal volume in free space

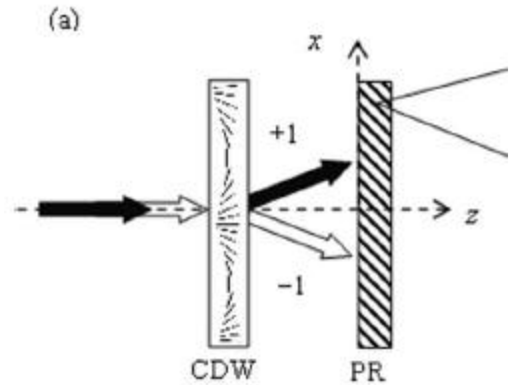
Le Dessert

Unpolarized Light Trapping

Operation for Both Polarizations

Using Cycloidal Waveplates

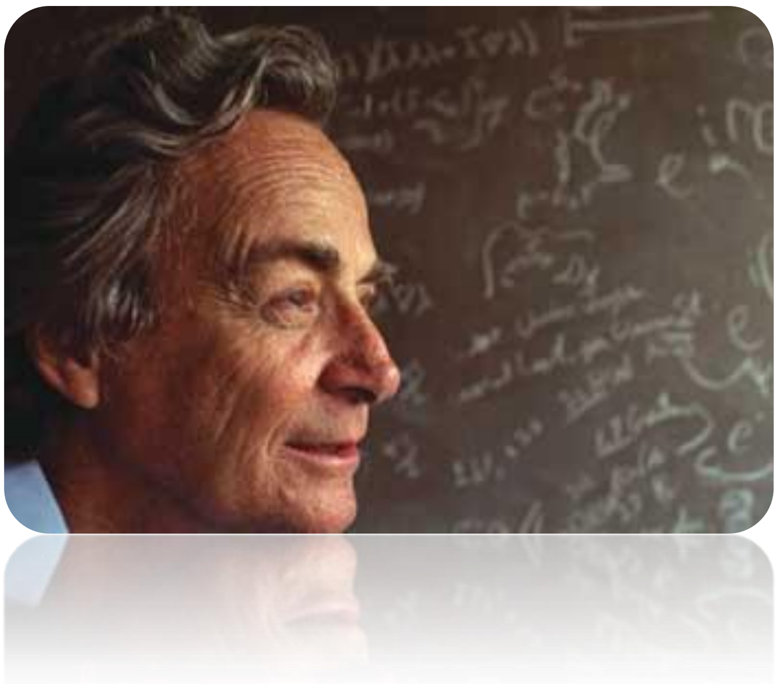




Tabiryan et al., AIP Advances, 1, 022153, (2011)

Le Digestif

Feynman on Metamaterials



I can't see what exactly would happen,

but I can hardly doubt that when we have some control of the arrangement of things in the small scale,

we will get an enormously greater range of possible properties that substances can have.

1959

R. Feynman, There's Plenty of Room at the Bottom
http://www.zyvex.com/nanotech/feynman.html

Thank You!

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