Session Time: September 20, 2017 from 1:00 PM to 3:00 PM

Frontier in Optics (FiO 2017)

FDTD with an off-diagonal permittivity tensor component to study the magneto-optical effect in a slow light waveguide

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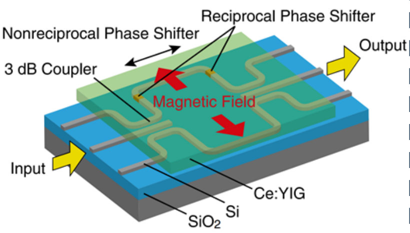
Abstract

We showed x8 higher isolation ratio is possible by using slow light photonic crystal waveguide with integrated magneto-optical material. A modified FDTD is made to model the propagation of light in off-diagonal permittivity material. It is used to study the isolation behavior of a photonic crystal waveguide where circular dichroism dependent material is integrated at the side of the waveguide. Our result shows the possibility on using slow light devices to enhance the magneto-optical effects.

Background

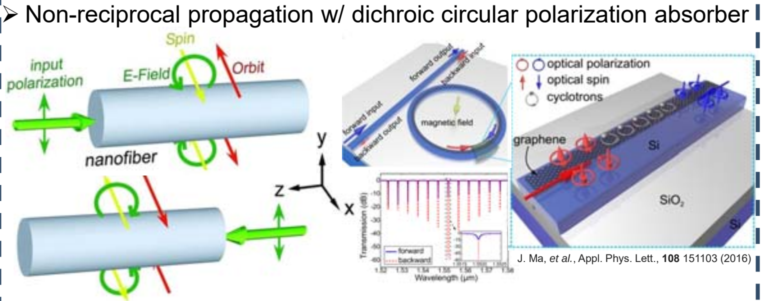
➢ Magneto-optical effects isolator



Y. Shoji, et al., Jpn. J. Appl. Phys. 53 022202 (2014)

- Large isolation ratio is demonstrated
- Only analytical simulation is performed

➢ Non-reciprocal propagation w/ dichroic circular polarization absorber



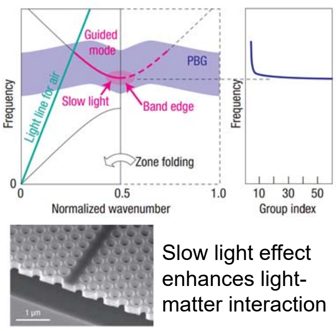
Jan Petersen et al., Science, 346 6205 (2014)

J. Ma, et al., Appl. Phys. Lett., 108 151103 (2016)

➢ The polarization at both sides of the waveguide rotates in one direction

➢ Placing circular dichroic material at the side of WG enables optical isolation

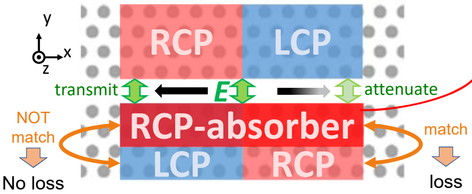
➢ Slow light w/ PhC WG



Slow light effect enhances light-matter interaction

T. Baba, Nat. Photonics., 2.8 465 (2008)

Isolation principle



$$\varepsilon_{tensor} = \varepsilon_{RCD} = \begin{pmatrix} \varepsilon_{xx} & \varepsilon_{xy} & 0 \\ -\varepsilon_{xy} & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{pmatrix}$$

Right circular dichroism (:RCD) materials absorb more RCP light than LCP.

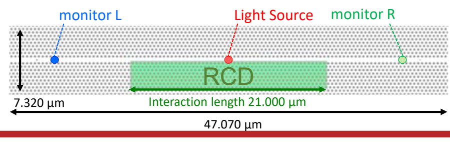
➢ When TE mode light propagates the polarization of the evanescent electric fields E_{ev} rotates at both sides of waveguide in opposite directions

➢ Circular polarization direction dependent absorber (circular dichroism :CD) (i.e. magneto-optical material) at the side of a WG works as non-reciprocal attenuator.

Motivation

Slow light effect can enhance magneto-optical effect?

Structure

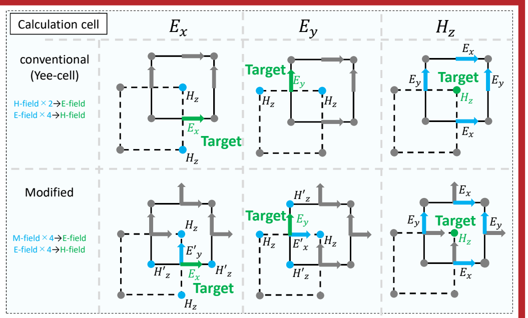


FDTD

➢ Time domain simulation

➢ Time/space discretized Maxwell's equations

➢ Cell setting is modified to calculate tensor permittivity



conventional

$$E_x^{t=n\Delta t}{}_{(i+\frac{1}{2},j)} = \frac{\Sigma^-}{\Sigma^+} E_x^{t=(n-1)\Delta t}{}_{(i+\frac{1}{2},j)} + \frac{1}{\Sigma^+}\frac{2\Delta t}{\Delta y}\left\{H_z^{n-\frac{1}{2}}{}_{(i+\frac{1}{2},j+\frac{1}{2})} - H_z^{n-\frac{1}{2}}{}_{(i+\frac{1}{2},j-\frac{1}{2})}\right\}$$

$$\varepsilon = \begin{pmatrix} \varepsilon_{xx} & \varepsilon_{xy} & \varepsilon_{xz} \\ \varepsilon_{yx} & \varepsilon_{yy} & \varepsilon_{yz} \\ \varepsilon_{zx} & \varepsilon_{zy} & \varepsilon_{zz} \end{pmatrix}, \sigma = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xz} \\ \sigma_{yx} & \sigma_{yy} & \sigma_{yz} \\ \sigma_{zx} & \sigma_{zy} & \sigma_{zz} \end{pmatrix}$$

modified

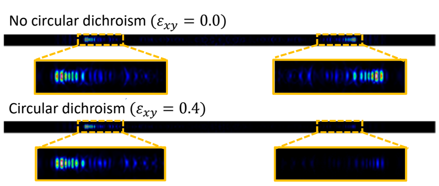
Modified

$$E_x^n\left(i+\frac{1}{2},j\right) = \frac{\Sigma_{yx}^-\Sigma_{xy}^+ - \Sigma_{xx}^-\Sigma_{yy}^+}{\Sigma_{xx}^+\Sigma_{yy}^+ - \Sigma_{yx}^+\Sigma_{xy}^+} E_x^{n-1}\left(i+\frac{1}{2},j\right) + \frac{\Sigma_{yy}^-\Sigma_{xy}^+ - \Sigma_{xy}^-\Sigma_{yy}^+}{\Sigma_{xx}^+\Sigma_{yy}^+ - \Sigma_{yx}^+\Sigma_{xy}^+} E_y^{n-1}\left(i+\frac{1}{2},j\right)$$
$$+ \frac{1}{\Sigma_{xx}^+\Sigma_{yy}^+ - \Sigma_{yx}^+\Sigma_{xy}^+}\left\{2\Delta t\Sigma_{yy}^+\left(\frac{H_z^{n-\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2}\right) - H_z^{n-\frac{1}{2}}\left(i+\frac{1}{2},j-\frac{1}{2}\right)}{\Delta y}\right) + 2\Delta t\Sigma_{xy}^+\left(\frac{H'^{n-\frac{1}{2}}_z(i,j) - H'^{n-\frac{1}{2}}_z(i+1,j)}{\Delta x}\right)\right\}$$

$$\Sigma_{ij}^{\pm} = \sigma_{ij}\Delta t \pm 2\varepsilon_{ij}$$

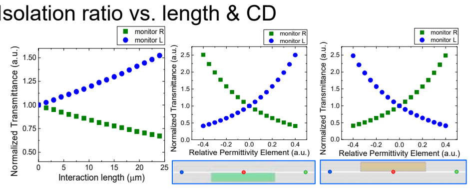
Calculated Results

➢ Pulse propagation



✓ Non-reciprocal propagation is achieved

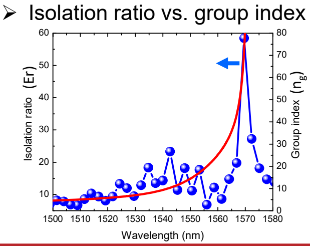
➢ Isolation ratio vs. length & CD



✓ Isolation ∝ interaction length

✓ Isolation ∝ off-diagonal element ε_{xy}

➢ Isolation ratio vs. group index



Slow-light enhancement of magneto-optical effect is observed

Conclusion & Future plan

➢ Conclusion

✓ Circular dichroism based isolator was numerically demonstrated by FDTD calculation

✓ Slow light effect is confirmed to enhance magneto-optical effect

➢ Future Plan

ε_{xy} works as non-reciprocal absorption

Relation of permittivity and conductivity $\varepsilon_{ij} = \delta_{ij} + i\dfrac{\sigma_{ij}}{\omega\varepsilon_0}$

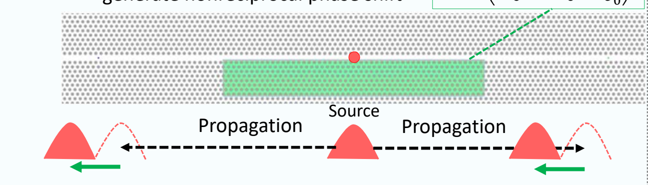
σ_{xy} works as non-reciprocal phase shift(NRPS) ?

Slow light enhancement of NRPS

Example

Asymmetric conductivity tensor may generate nonreciprocal phase shift

$$\tilde{\sigma} = \begin{pmatrix} \sigma_0 & \sigma_{xy} & 0 \\ -\sigma_{xy} & \sigma_0 & 0 \\ 0 & 0 & \sigma_0 \end{pmatrix}$$



Acknowledgment

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