Plane Wave in a Material

-materialOpticsCmd.pyc

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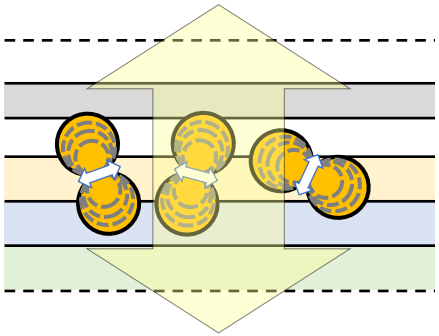
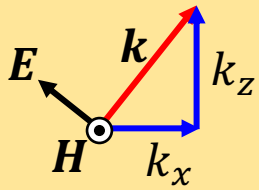


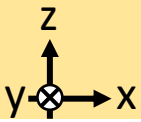
Objective

- This execution file can calculate the plane wave properties in a material with isotropic refractive index or the uniaxial refractive index.
- The refractive index of material should be pre-loaded by material manager system.

material ω

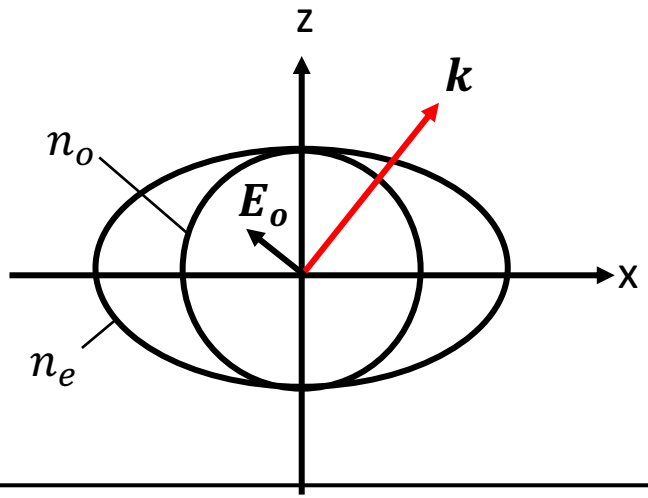


$k_z(\omega, k_x, k_y)$



dispersion relation

Uniaxial refractive index



Theory

Time Dependent/Plane Wave Anisotropic Source Free Maxwell's Equations

$$e^{i(\boldsymbol{k}\cdot\boldsymbol{r}-\omega t)}$$

$$\begin{aligned}
&\boldsymbol{\nabla}\cdot\bar{\bar{\epsilon}}_r\epsilon_0\boldsymbol{E}=0\\
&\boldsymbol{\nabla}\cdot\bar{\bar{\mu}}_r\mu_0\boldsymbol{H}=0\\
&\boldsymbol{\nabla}\times\boldsymbol{E}=i\omega\bar{\bar{\mu}}_r\mu_0\boldsymbol{H}\\
&\boldsymbol{\nabla}\times\boldsymbol{H}=-i\omega\bar{\bar{\epsilon}}_r\epsilon_0\boldsymbol{E}
\end{aligned}
\xrightarrow{e^{i\boldsymbol{k}\cdot\boldsymbol{r}}}
\begin{aligned}
&\boldsymbol{k}\cdot\bar{\bar{\epsilon}}_r\epsilon_0\boldsymbol{E}=0\\
&\boldsymbol{k}\cdot\bar{\bar{\mu}}_r\mu_0\boldsymbol{H}=0\\
&\boldsymbol{k}\times\boldsymbol{E}=\omega\bar{\bar{\mu}}_r\mu_0\boldsymbol{H}\\
&\boldsymbol{k}\times\boldsymbol{H}=-\omega\bar{\bar{\epsilon}}_r\epsilon_0\boldsymbol{E}
\end{aligned}$$

Wave Equation

$$\boldsymbol{k}\times(\bar{\bar{\mu}}_r)^{-1}\boldsymbol{k}\times\boldsymbol{E}+\omega^2\mu_0\epsilon_0\bar{\bar{\epsilon}}_r\boldsymbol{E}=\boldsymbol{0}$$

$$k_o^2=\omega^2\mu_0\epsilon_0$$

$$\boldsymbol{k}\times\boldsymbol{v}=\begin{bmatrix}0&-k_z&k_y\\k_z&0&-k_x\\-k_y&k_x&0\end{bmatrix}\begin{bmatrix}v_x\\v_y\\v_z\end{bmatrix}\equiv\bar{\bar{k}}\boldsymbol{v}$$

$$(\bar{\bar{k}}(\bar{\bar{\mu}}_r)^{-1}\bar{\bar{k}}+k_o^2\bar{\bar{\epsilon}}_r)\boldsymbol{E}=\overline{\overline{W_E}}\boldsymbol{E}=\boldsymbol{0}$$

$$(\bar{\bar{k}}(\bar{\bar{\epsilon}}_r)^{-1}\bar{\bar{k}}+k_o^2\bar{\bar{\mu}}_r)\boldsymbol{H}=\overline{\overline{W_H}}\boldsymbol{H}=\boldsymbol{0}$$

$$\det\left(\overline{\overline{W_E}}\right)=0$$

$\overline{\overline{W_E}}=\bar{\bar{k}}(\bar{\bar{\mu}}_r)^{-1}\bar{\bar{k}}+k_o^2\bar{\bar{\epsilon}}_r$-Electric Wave Matrix

$\overline{\overline{W_H}}=\bar{\bar{k}}(\bar{\bar{\epsilon}}_r)^{-1}\bar{\bar{k}}+k_o^2\bar{\bar{\mu}}_r$ -Magnetic Wave Matrix

Theory-Dispersion Relation

$\det(\overline{\overline{W_E}}) = 0$ → a function of k_x, k_y, k_z *and* $k_o(\omega)$ → dispersion relation

k_z is a function of k_x, k_y and ω → k_z can be solved when k_x, k_y and ω are given.

Then insert into $\overline{\overline{W_E}}\boldsymbol{E} = 0$, the corresponding fields can be known.

Notation, symbols with prime are in the absolute coordinate and symbols without stand for the coordinate in the crystal.

1. $\boldsymbol{v}' = \overline{\overline{\mathrm{R}}}\boldsymbol{v}$ vector transformation or vector definition
2. $\overline{\overline{T}}' = \overline{\overline{R}}\,\overline{\overline{T}}\,\overline{\overline{R}}^T$ tensor transformation

$$\rightarrow \boldsymbol{\alpha}' = \overline{\overline{\mathrm{R}}}\boldsymbol{\alpha} = \overline{\overline{\mathrm{R}}}\left(\overline{\overline{T}}\boldsymbol{\beta}\right) = \overline{\overline{\mathrm{R}}}\,\overline{\overline{T}}\left(\overline{\overline{\mathrm{R}}}^{\boldsymbol{T}}\overline{\overline{\mathrm{R}}}\right)\boldsymbol{\beta} = \overline{\overline{R}}\,\overline{\overline{T}}\,\overline{\overline{R}}^T\boldsymbol{\beta}' = \overline{\overline{T}}'\boldsymbol{\beta}'$$

The length of vector is conservative $\langle \boldsymbol{v}'|\boldsymbol{v}'\rangle = \langle \boldsymbol{v}|\boldsymbol{v}\rangle$, where the bra should be complex conjugate. Note, here define two length, $\|\boldsymbol{v}\| = \sqrt{v_x v_x^* + v_y v_y^* + v_z v_z^*}$, $v = \sqrt{v_x^2 + v_y^2 + v_z^2}$

Theory-Dispersion Relation

In crystal coordinate

$$\overline{\overline{\mu_r}} = \bar{\bar{I}}$$

$$\det\left(\overline{\overline{W_E}}\right) = \det\left(\bar{\bar{k}}\bar{\bar{k}} + k_o^2\bar{\bar{\epsilon}}_r\right)$$

$$= \det\left(\begin{bmatrix} k_o^2\epsilon_{11} - (k_y^2 + k_z^2) & k_xk_y & k_xk_z \\ k_xk_x & k_o^2\epsilon_{22} - (k_x^2 + k_z^2) & k_yk_z \\ k_xk_z & k_yk_z & k_o^2\epsilon_{33} - (k_x^2 + k_y^2) \end{bmatrix}\right)$$

$$\det\left(\overline{\overline{W_E}}\right) = \det\left(\begin{bmatrix} k_o^2\epsilon_{11} - (k_y^2 + k_z^2) & k_xk_y & k_xk_z \\ k_xk_y & k_o^2\epsilon_{22} - (k_x^2 + k_z^2) & k_yk_z \\ k_xk_z & k_yk_z & k_o^2\epsilon_{33} - (k_x^2 + k_y^2) \end{bmatrix}\right)$$

$$= k_o^6\epsilon_{11}\epsilon_{22}\epsilon_{33} + k^2k_o^2\left(\epsilon_{11}k_x^2 + \epsilon_{22}k_y^2 + \epsilon_{33}k_z^2\right)$$
$$-k_o^4[k_x^2\epsilon_{11}(\epsilon_{22} + \epsilon_{33}) + k_y^2\epsilon_{22}(\epsilon_{11} + \epsilon_{33}) + k_z^2\epsilon_{33}(\epsilon_{11} + \epsilon_{22})]$$

Theory-Dispersion Relation

In absolute coordinate

$$\det\left(\overline{\overline{W_E}}\right) = k_o^6\epsilon_{11}\epsilon_{22}\epsilon_{33}$$
$$+ k^2k_o^2\left[\epsilon_{11}\left(R_{11}k'_x + R_{12}k'_y + R_{13}k'_z\right)^2 + \epsilon_{22}\left(R_{21}k'_x + R_{22}k'_y + R_{33}k'_z\right)^2\right.$$
$$\left.+ \epsilon_{33}\left(R_{31}k'_x + R_{32}k'_y + R_{33}k'_z\right)^2\right]$$
$$- k_o^4\left[\left(R_{11}k'_x + R_{12}k'_y + R_{13}k'_z\right)^2\epsilon_{11}(\epsilon_{22} + \epsilon_{33})\right.$$
$$\left.+ \left(R_{21}k'_x + R_{22}k'_y + R_{33}k'_z\right)^2\epsilon_{22}(\epsilon_{11} + \epsilon_{33}) + \left(R_{31}k'_x + R_{32}k'_y + R_{33}k'_z\right)^2\epsilon_{33}(\epsilon_{11} + \epsilon_{22})\right]$$
$$= 0$$

4 solutions: $k'_{z,1}$, $k'_{z,2}$, $k'_{z,3}$, $k'_{z,4}$

Theory-Dispersion Relation (Isotropic)

$\epsilon_{11} = \epsilon_{22} = \epsilon_{33}$

In crystal coordinate

$$\det(\overline{\overline{W_E}}) = k_o^6\epsilon_{11}^3 + \epsilon_{11}k^4k_o^2 - 2\epsilon_{11}^2k_o^4k^2 = k_o^2\epsilon_{11}(k^2 - k_o^2\epsilon_{11})^2 = 0 \rightarrow \text{Degenerate}$$

$$k^2 - k_o^2\epsilon_{11} = 0$$

$$k_z = \pm\sqrt{k_o^2\epsilon_{11} - k_t^2} \qquad k_t^2 = k_x^2 + k_y^2$$

In absolute coordinate

$$k'_z = \pm\sqrt{k_o^2\epsilon_{11} - k_t'^2}$$

Theory-Dispersion Relation (Isotropic)

$$\overline{\overline{W_E}}\boldsymbol{E} = \begin{bmatrix} k'_x k'_x & k'_x k'_y & k'_x k'_z \\ k'_x k'_y & k'_y k'_y & k'_y k'_z \\ k'_x k'_z & k'_y k'_z & k'_z k'_z \end{bmatrix} \boldsymbol{E} \rightarrow \begin{bmatrix} k'_x & k'_y & k'_z \\ k'_x & k'_y & k'_y \\ k'_x & k'_y & k'_z \end{bmatrix} \boldsymbol{E} = \boldsymbol{0}.$$

$$\boldsymbol{k} \cdot \boldsymbol{E} = 0 \rightarrow \boldsymbol{e_1} = \begin{bmatrix} -\frac{k\prime_y}{k\prime_t} \\ \frac{k\prime_x}{k\prime_t} \\ 0 \end{bmatrix} \; and \; \boldsymbol{e_2} = \begin{bmatrix} -\frac{k\prime_x k\prime_z}{k\prime_t k} \\ -\frac{k\prime_y k\prime_z}{k\prime_t k} \\ \frac{k\prime_t}{k} \end{bmatrix} \rightarrow \textit{compatible to uniaxial case and TE, TM}$$

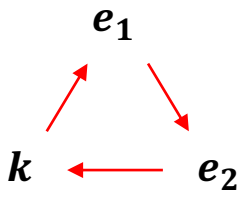
***** $\mathbf{z} \times \boldsymbol{k} \rightarrow \boldsymbol{e_1}$

**** *Special Case* **** *(Definition)*

$$k'_x = k'_y = 0$$

$$\boldsymbol{k} = \begin{bmatrix} 0 \\ 0 \\ k'_z = k \end{bmatrix}$$

$$\boldsymbol{e_1} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \; and \; \boldsymbol{e_2} = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$



Theory-Dispersion Relation (Uniaxial)

$\epsilon_{11} = \epsilon_{22}, \epsilon_{33}$

In crystal coordinate

$$\det\left(\overline{\overline{W_E}}\right) = k_o^2(k^2 - k_o^2\epsilon_{11})(\boldsymbol{k}^T\bar{\bar{\epsilon}}_r\boldsymbol{k} - k_o^2\epsilon_{11}\epsilon_{33}) = 0$$

$$\overline{\overline{W_E}} = \begin{bmatrix} k_o^2\epsilon_{11} - (k_y^2 + k_z^2) & k_xk_y & k_xk_z \\ k_xk_x & k_o^2\epsilon_{11} - (k_x^2 + k_z^2) & k_yk_z \\ k_xk_z & k_yk_z & k_o^2\epsilon_{33} - (k_x^2 + k_y^2) \end{bmatrix}$$

Theory-Dispersion Relation (Uniaxial)

$$\det\left(\overline{\overline{W_E}}\right) = k_o^2 \underbrace{(k^2 - k_o^2\epsilon_{11})}_{\text{Type I}} \underbrace{(\boldsymbol{k}^T \overline{\overline{\epsilon_r}} \boldsymbol{k} - k_o^2\epsilon_{11}\epsilon_{33})}_{\text{Type II}} = 0$$

Type I (ordinary wave, similar to isotropic refractive index)

$$k^2 - k_o^2\epsilon_{11} = 0 \qquad k'_{z,1,3} = \pm\sqrt{k_o^2\epsilon_{11} - k'^2_t}$$

$$k'_{z,1} = \sqrt{k_o^2\epsilon_{11} - k'^2_t} \qquad k'_{z,3} = \sqrt{k_o^2\epsilon_{11} - k'^2_t}$$

$$\boldsymbol{e'_1} = \begin{bmatrix} -\frac{k'_y}{k'_t} \\ \frac{k'_x}{k_t} \\ 0 \end{bmatrix}$$

Special Case

$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$k'_x = k'_y = 0$$

$$\boldsymbol{e'_3} = \begin{bmatrix} -\frac{k'_y}{k'_t} \\ \frac{k'_x}{k_t} \\ 0 \end{bmatrix}$$

Special Case

$$\begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$k'_x = k'_y = 0$$

Theory-Dispersion Relation (Uniaxial)

Type II (extraordinary wave)

In crystal coordinate

$$\boldsymbol{k}^T \bar{\bar{\epsilon}}_r \boldsymbol{k} - k_o^2 \epsilon_{11}\epsilon_{33} = 0 \qquad k_t^2 \epsilon_{11} + k_z^2 \epsilon_{33} - k_o^2 \epsilon_{11}\epsilon_{33} = 0$$

$$k^2 = \left(1 - \frac{\epsilon_{11}}{\epsilon_{33}}\right) k_t^2 + k_o^2 \epsilon_{11}$$

In absolute coordinate

$$Ak'^2_z - 2Bk'_z + C = 0$$

$$k'_{z,2,4} = \frac{B \pm \sqrt{B^2 - AC}}{A}$$

$$\boldsymbol{e}'_{2,4} \parallel \bar{\bar{\mathrm{R}}} \begin{bmatrix} -\dfrac{k_x k_{z,2,4}}{k_t k} \\ -\dfrac{k_y k_{z,2,4}}{k_t k} \\ \dfrac{\epsilon_{11} k_t}{\epsilon_{33} k} \end{bmatrix}$$

$$A = 1 - \left(1 - \frac{\epsilon_{11}}{\epsilon_{33}}\right)(R_{13}^2 + R_{23}^2)$$

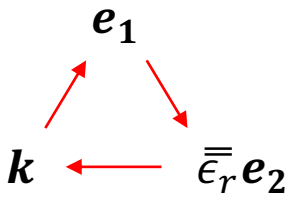
$$B = \left(1 - \frac{\epsilon_{11}}{\epsilon_{33}}\right)\left[R_{13}\left(R_{11}k'_x + R_{12}k'_y\right) + R_{23}\left(R_{21}k'_x + R_{12}k'_y\right)\right]$$

$$\mathrm{C} = k_t^2 - \left(1 - \frac{\epsilon_{11}}{\epsilon_{33}}\right)\left[\left(R_{11}k'_x + R_{12}k'_y\right)^2 + \left(R_{21}k'_x + R_{12}k'_y\right)^2\right] - k_o^2\epsilon_{11}$$

Special Case

$$\bar{\bar{\mathrm{R}}} \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$k_x = k_y = 0$$



How to execute plane wave calculator

In the following example, please execute material manager system with materialMgrCmd-Example-2.txt in the example directory.

```
>python materialMgrCmd.py ./Example/materialMgrCmd-Example-2.txt
```

python: windows
python3: mac, linux

Example path

```
[A]: er                      [N]3TPYMB(#2)
                             [N]B3PYMPM_isotropic(#1)
                             [N]B3PYMPM_uniaxial(#1)
                             [N]B3PYMPM(#1)
-------------------------------------------------------------------------
[A]: Fluorescence            [N]cbp_irppy3(#1)
-------------------------------------------------------------------------
[A]: Phosphorescence         /*Empty*/
-------------------------------------------------------------------------
[A]: DOF                     [N]cbp_irppy3(#1)
-------------------------------------------------------------------------
[A]: wavelengthunitstr       /*Empty*/
-------------------------------------------------------------------------
[A]: Attribute/ [N]: Name(# of data)
```

The **most important** in plane wave calculator.

Currently phosphorescence is useless

In the plane wave calculator, Fluorescence and DOF would not influence the results so they can be empty.

How to execute plane wave calculator

python: windows
python3: mac, linux

```
>python materialOpticsCmd.pyc
```

Execution file

Type user name

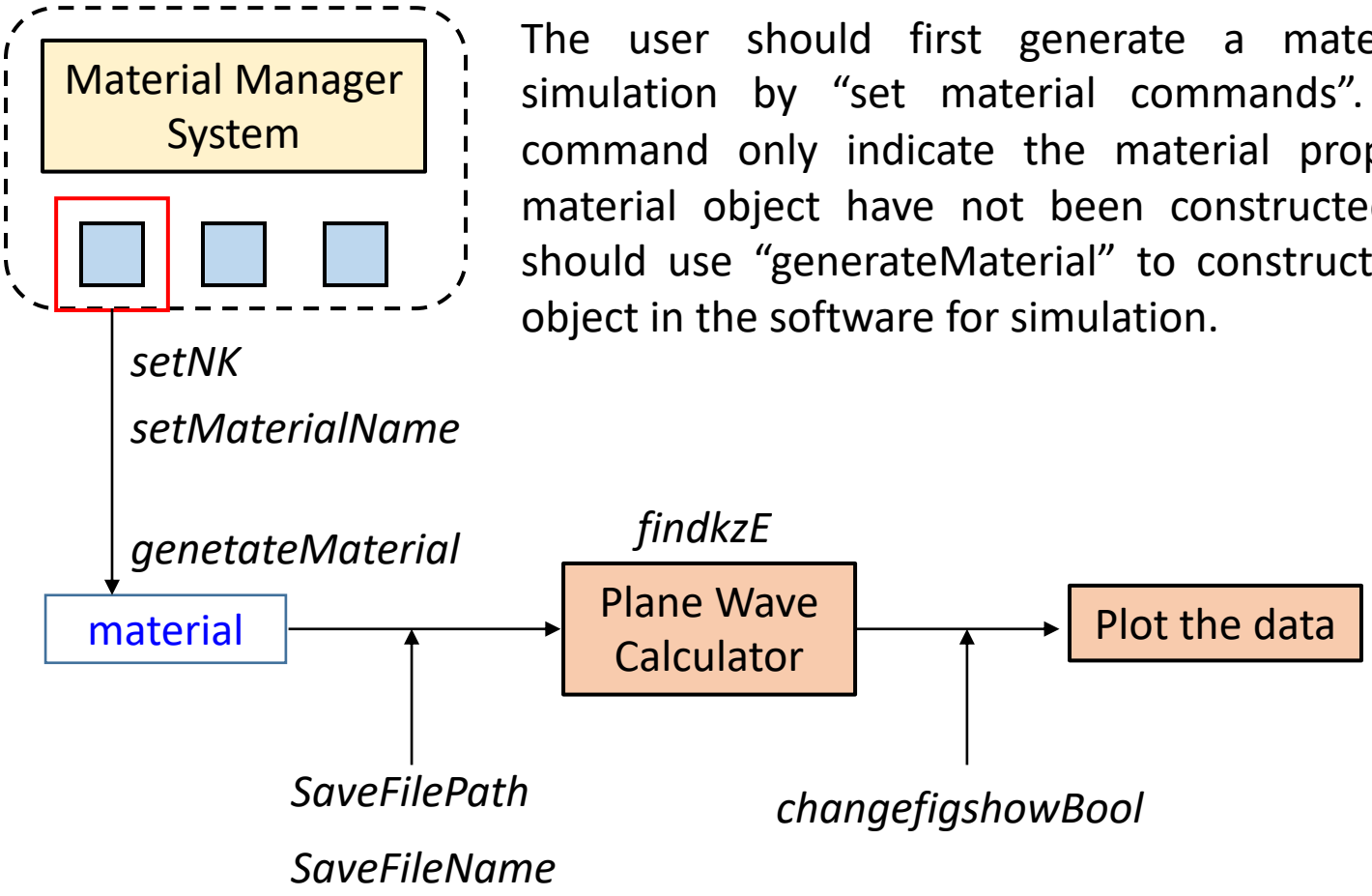
```
>>> Please insert username : user-1
Now reading nk file (..\..\..\sim\mater
Now reading nk file (..\..\..\sim\mater
Now reading nk file (..\..\..\sim\material n k/B3PYMPM_isotropic.mat)
Now reading nk file (..\..\..\sim\material n k/B3PYMPM_uniaxial.mat)
Now reading nk file (..\..\..\sim\material n k/B3PYMPM_uniaxial.mat)
Now reading spectrum file (..\..\..\sim\material PL/cbp_irppy3.spc)
Now reading dipole orientation factor file (..\..\..\sim\material eta/cbp_irppy3.eta)
Successfully reading materialMgr.mMgr
Now printing the information stored in the material manager...
[A]: er                 [N]3TPYMB(#2)
                        [N]B3PYMPM_isotropic(#1)
                        [N]B3PYMPM_uniaxial(#1)
                        [N]B3PYMPM(#1)
-------------------------------------------------------------------------------
[A]: Fluorescence       [N]cbp_irppy3(#1)
-------------------------------------------------------------------------------
[A]: Phosphorescence    /*Empty*/
-------------------------------------------------------------------------------
[A]: DOF                [N]cbp_irppy3(#1)
-------------------------------------------------------------------------------
[A]: wavelengthunitstr  [N]nm(#1)
                        [N]um(#1)
                        [N]m(#1)
-------------------------------------------------------------------------------
[A]: Attribute/ [N]: Name(# of data)



-------------------------------------------------------------------------------
Start running GOODLAB anisotropic simulator ver1.0 Sat Apr 11 14:53:56 2020
-------------------------------------------------------------------------------


************************************  GOODLAB SIMULATOR Info  ************************************
Optical Planar OLED Simulation Tool/Console interface
Anisotropic Version 1.0
Author : Wei-Kai Lee
Publication Date : 2019/03/15

Copyright(c) 2019 Wei-Kai Lee. All right reserved.
[1] Calculates the eigen modes related characteristics of the material in material manager.
************************************  GOODLAB SIMULATOR Info  ************************************
```

Help

Use “?” or “help” to list all the command in the plane wave calculator.

```
<mOpticsCmd> ?
User Control Command
=======================================
1. Settting Command:
changeUser              exit

Material Manager Command
=======================================
1. Settting Command:
printMgr                saveMgr

material Optics Command
=======================================
1. Set material properties:
setNK                   setFluo
setPhos                 setDOF
setMaterialName

2. Generate Material:
generateMaterial

3. Material:
deleteMaterial          printMaterial

4. Results:
SaveFilePath            SaveFileName
findkzEResultsFilePath findkzEResultsFileName
changefigshowBool       printSettingInfo

5. Execution:
findkzE                 loadfindkzE

6. Plot:
plotkvsWV               plotkzvsWV
plotEvsWV
plotkvsf                plotkzvsf
plotEvsf
plotkvskxky             plotkzvskxky
plotEvskxky
```

Calculating Workflow



The user should first generate a material object for simulation by “set material commands”. Since the set command only indicate the material properties and the material object have not been constructed yet, the user should use “generateMaterial” to construct a real material object in the software for simulation.

Setting Information

```
<mOpticsCmd> help printSettingInfo
Print the information of setting.

<mOpticsCmd> printSettingInfo
er :
Fluorescence :
Phosphorescence :
DOF :
Mateiral Name : No name
Figure Show Bool : True
The material object is empty
```

The material properties have not been set yet.
All the material properties are empty.

Whether to show the figure when plot command.

There is no material object generated.

Set

```
>>> SaveFileName B3PYMPM_isotropic
>>> SaveFilePath ../../Example/materialOpticsCmd/B3PYMPM/Isotropic/Test_vs_WV
>>> changefigshowBool F
>>> setNK B3PYMPM_isotropic
>>> setFluo cbp_irppy3
>>> setMaterialName B3PYMPM_isotropic
>>> printSettingInfo

er : B3PYMPM_isotropic
Fluorescence : cbp_irppy3
Phosphorescence :
DOF :
Mateiral Name : B3PYMPM_isotropic
Save File Path : ../../Example/materialOpticsCmd/B3PYMPM/Isotropic/Test_vs_WV
Save File Name : B3PYMPM_isotropic
Figure Show Bool : False
The material object is empty
```

save file name

save file path

Set material nk

Set material PL

Set material name

The material object has not been generated.

Generate

```
>>> generateMaterial

>>> printSettingInfo

er : B3PYMPM_isotropic
Fluorescence : cbp_irppy3
Phosphorescence :
DOF :
Mateiral Name : B3PYMPM_isotropic
Save File Path : ../../Example/materialOpticsCmd/B3PYMPM/Isotropic/Test_vs_WV
Save File Name : B3PYMPM_isotropic
Figure Show Bool : False
Material Name : B3PYMPM_isotropic
Permittivity Note :
     PATH:..\..\..\sim\material n k/
     FILENAME:B3PYMPM_isotropic
-----------------------------------------
Fluorescence[0] Note :
     PATH:..\..\..\sim\material PL/
     FILENAME:cbp_irppy3
-----------------------------------------
Phosphorescence[0] Note :
     /*Empty*/
-----------------------------------------
Dipole Orientation Factor[0] Note :
     /*Empty*/
-----------------------------------------
```

Generate material object

Material object information

print material

```
>>> printMaterial

Material Name : B3PYMPM_isotropic
Permittivity Note :
     PATH:..\..\..\sim\material n k/
     FILENAME:B3PYMPM_isotropic
-------------------------------------------------
Fluorescence[0] Note :
     PATH:..\..\..\sim\material PL/
     FILENAME:cbp_irppy3
-------------------------------------------------
Phosphorescence[0] Note :
     /*Empty*/
-------------------------------------------------
Dipole Orientation Factor[0] Note :
     /*Empty*/
-------------------------------------------------
```

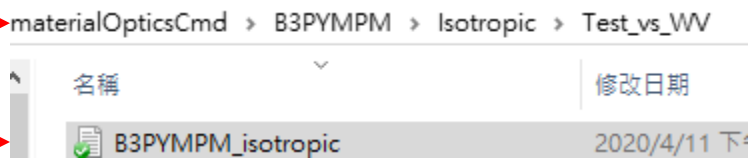
Calculation (Isotropic)

```
>>> help findkzE

Calculate the kz of corresponding wavelength, kx/ko, ky/ko. Can be run after setNK and generateMaterial.
[Usage] findkzE [wv] [kx/ko] [ky/ko] - single value, start:spacing:end, (v1,v2,v3,v4)

>>> findkzE 400:1:780  0:1:2  0:1:2
```

wavelength | kx/ko | ky /ko

Parameter scans

```
Save File Path : ../../Example/materialOpticsCmd/B3PYMPM/Isotropic/Test_vs_WV
Save File Name : B3PYMPM_isotropic
```



Data in the file (Isotropic)

Input

wavelength

kx/ko

ky /ko

Wave number in vacuum

Wave number in material

wv	kx/ko	ky/ko	ko	Re(k/ko)	Im(k/ko)
400.00000	0.00000	0.00000	1.57080e-02	1.95760e+00	0.00000e+00
400.00000	1.00000	0.00000	1.57080e-02	1.95760e+00	0.00000e+00
400.00000	2.00000	0.00000	1.57080e-02	1.95760e+00	0.00000e+00
400.00000	0.00000	1.00000	1.57080e-02	1.95760e+00	0.00000e+00
400.00000	1.00000	1.00000	1.57080e-02	1.95760e+00	0.00000e+00
400.00000	2.00000	1.00000	1.57080e-02	1.95760e+00	0.00000e+00
400.00000	0.00000	2.00000	1.57080e-02	1.95760e+00	0.00000e+00
400.00000	1.00000	2.00000	1.57080e-02	1.95760e+00	0.00000e+00
400.00000	2.00000	2.00000	1.57080e-02	1.95760e+00	0.00000e+00
401.00000	0.00000	[illegible]	1.56688e-02	1.95663e+00	0.00000e+00

0:1:2 0:1:2

Parameter scans

Dispersion relation

Data in the file (Isotropic)

$$k'_{z,1} = \sqrt{k_o^2 \epsilon_{11} - k'^2_t} \qquad k'_{z,3} = -\sqrt{k_o^2 \epsilon_{11} - k'^2_t}$$

Re(kz1/ko)	Im(kz1/ko)	Re(kz3/ko)	Im(kz3/ko)
1.95760e+00	0.00000e+00	-1.95760e+00	0.00000e+00
1.68291e+00	0.00000e+00	-1.68291e+00	0.00000e+00
0.00000e+00	4.09637e-01	-0.00000e+00	-4.09637e-01
1.68291e+00	0.00000e+00	-1.68291e+00	0.00000e+00
1.35359e+00	0.00000e+00	-1.35359e+00	0.00000e+00
0.00000e+00	1.08065e+00	-0.00000e+00	-1.08065e+00
0.00000e+00	4.09637e-01	-0.00000e+00	-4.09637e-01
0.00000e+00	1.08065e+00	-0.00000e+00	-1.08065e+00
0.00000e+00	2.04152e+00	-0.00000e+00	-2.04152e+00
1.95663e+00	0.00000e+00	-1.95663e+00	0.00000e+00
1.68179e+00	0.00000e+00	-1.68179e+00	0.00000e+00

Data in the file (Isotropic)

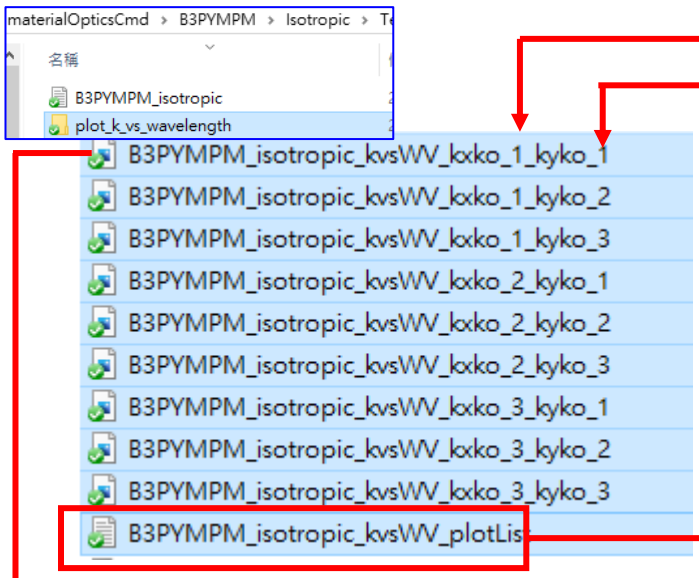
Abs(E1x)	Angle(E1x)	Abs(E1y)	Angle(E1y)	Abs(E1z)	Angle(E1z)
1.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00
0.00000e+00	1.80000e+02	1.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00
0.00000e+00	1.80000e+02	1.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00
1.00000e+00	1.80000e+02	0.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00
7.07107e-01	1.80000e+02	7.07107e-01	0.00000e+00	0.00000e+00	0.00000e+00
4.47214e-01	1.80000e+02	8.94427e-01	0.00000e+00	0.00000e+00	0.00000e+00
1.00000e+00	1.80000e+02	0.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00
8.94427e-01	1.80000e+02	4.47214e-01	0.00000e+00	0.00000e+00	0.00000e+00
7.07107e-01	1.80000e+02	7.07107e-01	0.00000e+00	0.00000e+00	0.00000e+00
1.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00

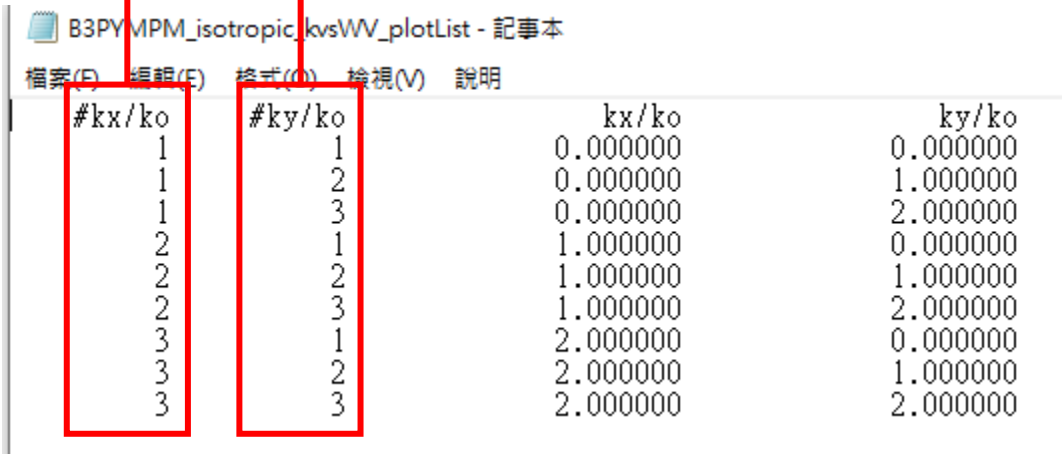
$$\boldsymbol{e_1} = \begin{bmatrix} -\dfrac{k'_y}{k'_t} \\ \dfrac{k'_x}{k'_t} \\ 0 \end{bmatrix}$$

Plot the data (Isotropic)

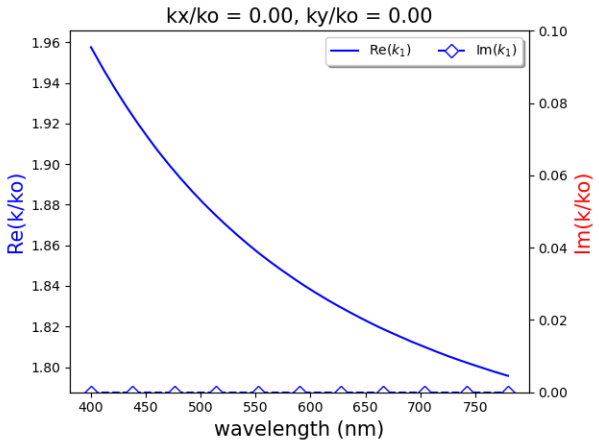
```
>>> plotkvsWV
```

File Index



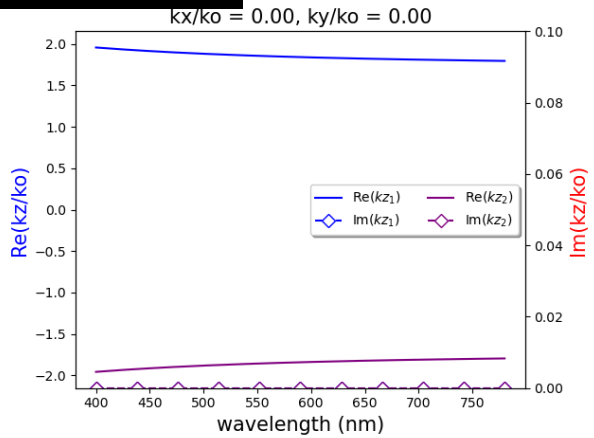


#kx/ko	#ky/ko	kx/ko	ky/ko
1	1	0.000000	0.000000
1	2	0.000000	1.000000
1	3	0.000000	2.000000
2	1	1.000000	0.000000
2	2	1.000000	1.000000
2	3	1.000000	2.000000
3	1	2.000000	0.000000
3	2	2.000000	1.000000
3	3	2.000000	2.000000

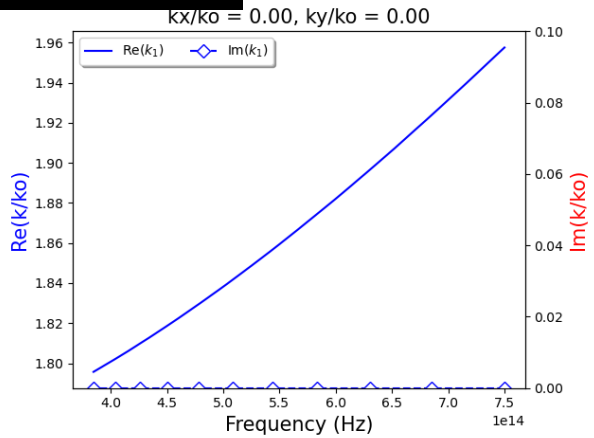


Plot the data (Isotropic)

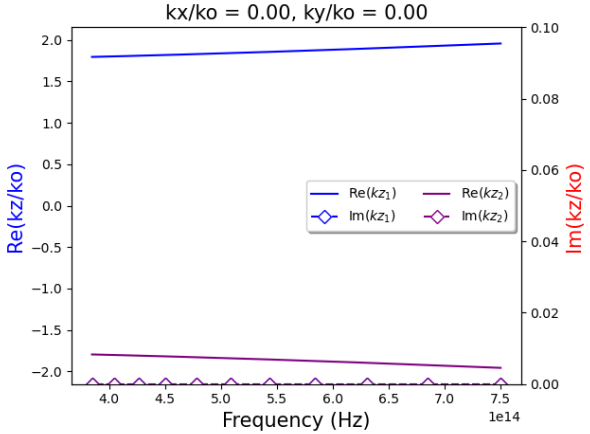
```
>>> plotkzvsWV
```



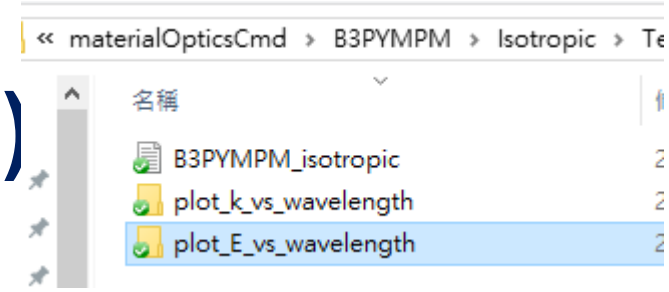

```
>>> plotkvsf
```




```
>>> plotkzvsf
```

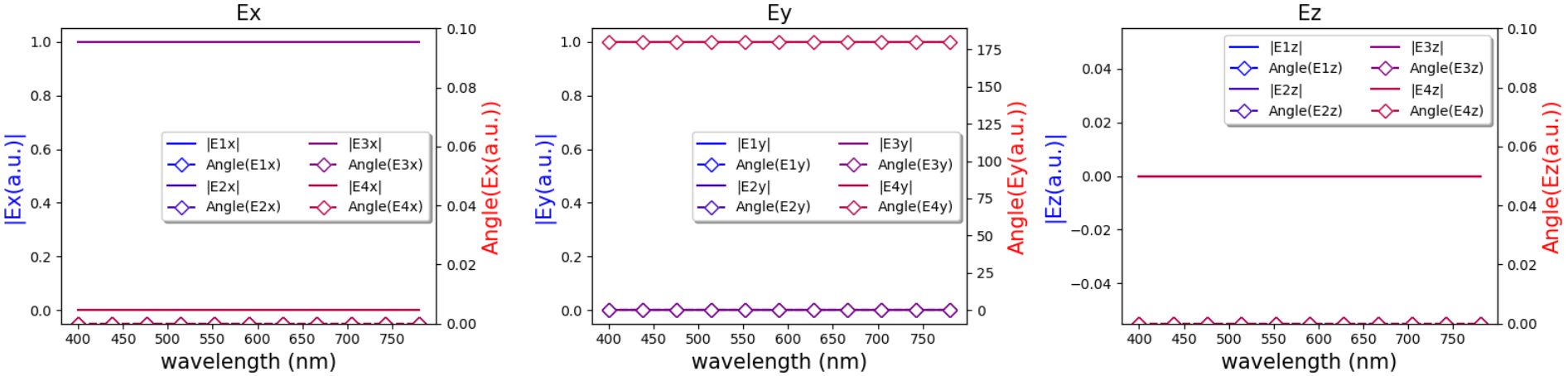


Plot the data (Isotropic)



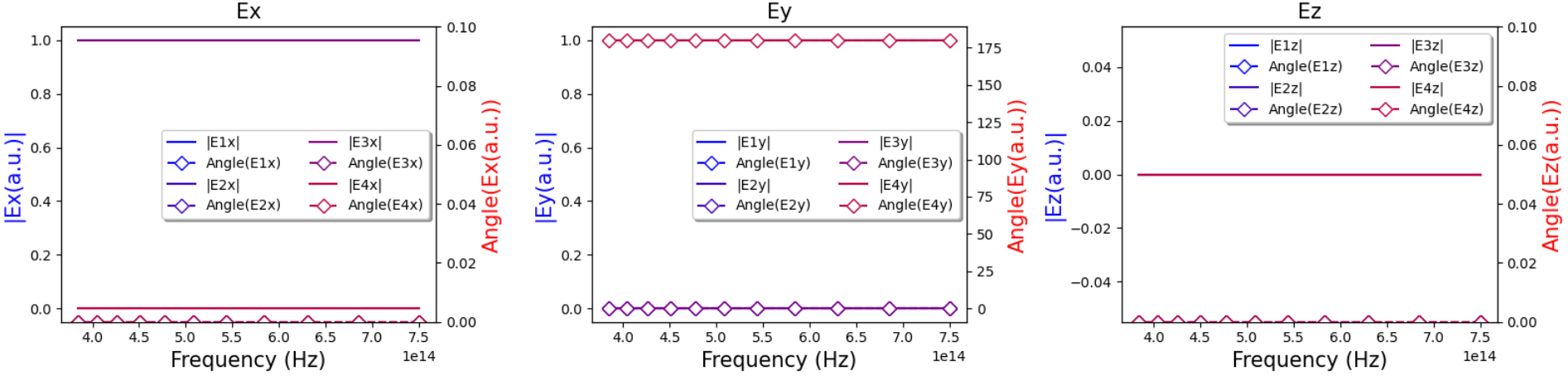

```
>>> plotEvsWV
```

B3PYMPM_isotropic_Evsf_kxko_1_kyko_1




```
>>> plotEvsf
```

B3PYMPM_isotropic_EvsWV_kxko_1_kyko_1



Calculation (Isotropic)

```
>>> SaveFileName B3PYMPM_isotropic

>>> SaveFilePath ../../Example/materialOpticsCmd/B3PYMPM/Isotropic/Test_vs_kxky

>>> printSettingInfo

er : B3PYMPM_isotropic
Fluorescence : cbp_irppy3
Phosphorescence :
DOF :
Mateiral Name : B3PYMPM_isotropic
Save File Path : ../../Example/materialOpticsCmd/B3PYMPM/Isotropic/Test_vs_kxky
Save File Name : B3PYMPM_isotropic
Figure Show Bool : False
Material Name : B3PYMPM_isotropic
Permittivity Note :
     PATH:..\..\..\sim\material n k/
     FILENAME:B3PYMPM_isotropic
-------------------------------------------------------------------------------
Fluorescence[0] Note :
     PATH:..\..\..\sim\material PL/
     FILENAME:cbp_irppy3
-------------------------------------------------------------------------------
Phosphorescence[0] Note :
     /*Empty*/
-------------------------------------------------------------------------------
Dipole Orientation Factor[0] Note :
     /*Empty*/
-------------------------------------------------------------------------------

>>> findkzE 520   -2.0:0.01:2.5   -2.5:0.01:2.5

>>> plotkvskxky

>>> plotkzvskxky

>>> plotEvskxky
```

save file name

save file path

kx/ko

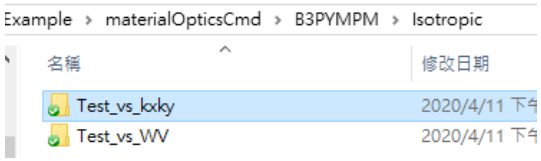
ky /ko

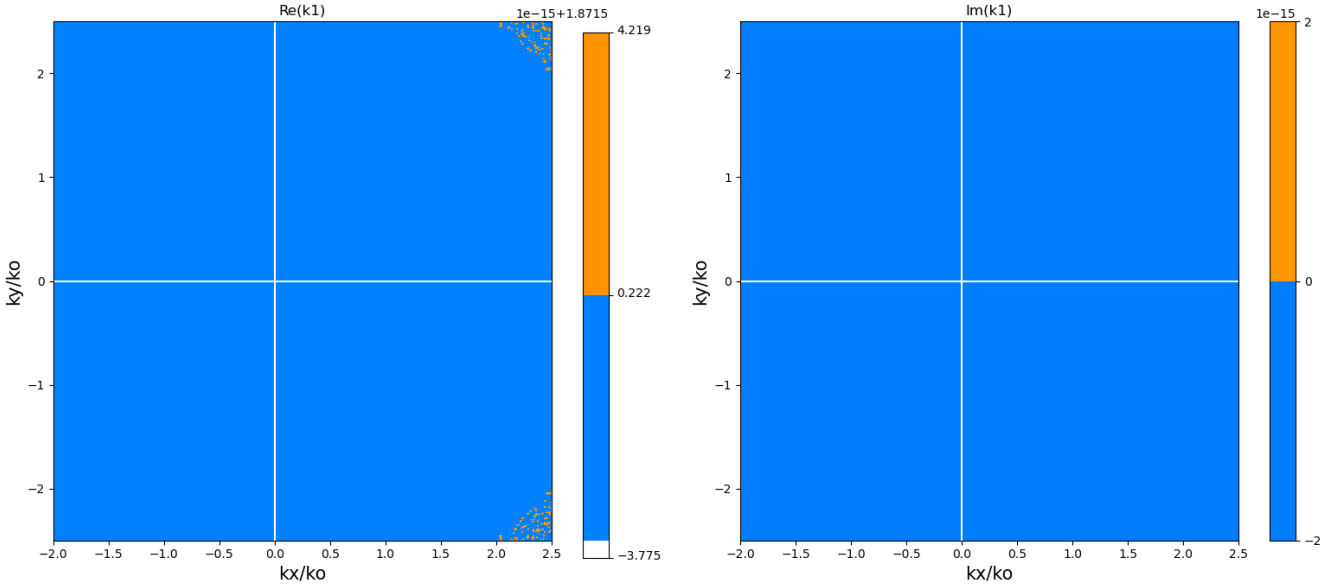
single wavelength

Contour Plot

Plot the data (Isotropic)

```
>>> plotkvskxky
```





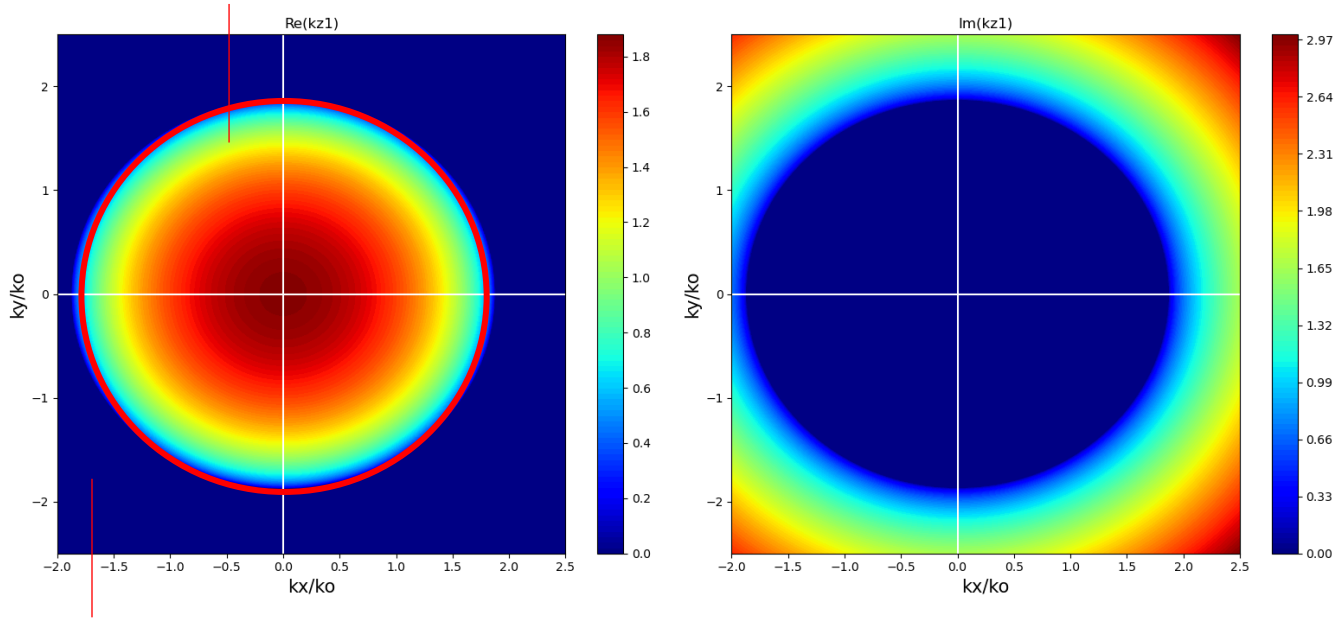
Independent on kx and ky

Plot the data (Isotropic)

```
>>> plotkzvskxky
```

$$k'_{z,1} = \sqrt{k_o^2 \epsilon_{11} - k'^2_t}$$

Propagation wave

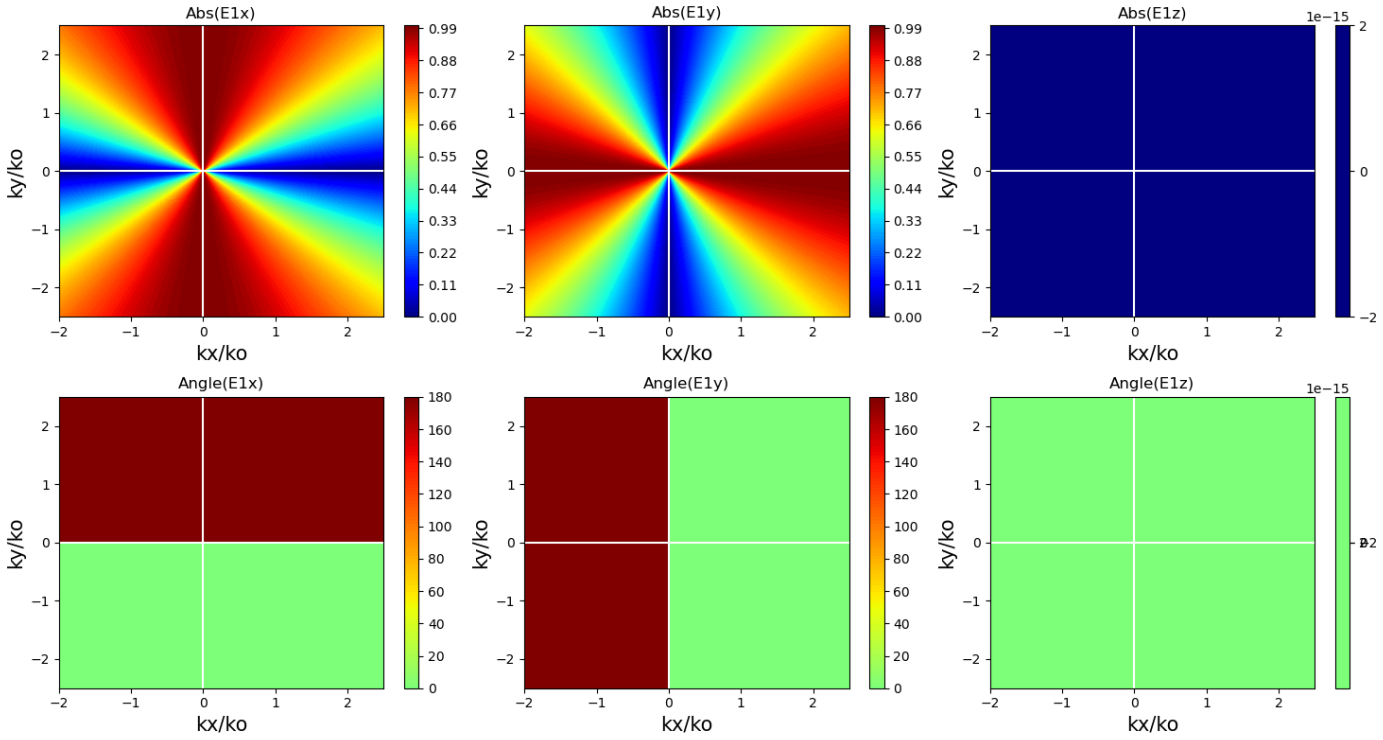


Evanescent wave

Plot the data (Isotropic)

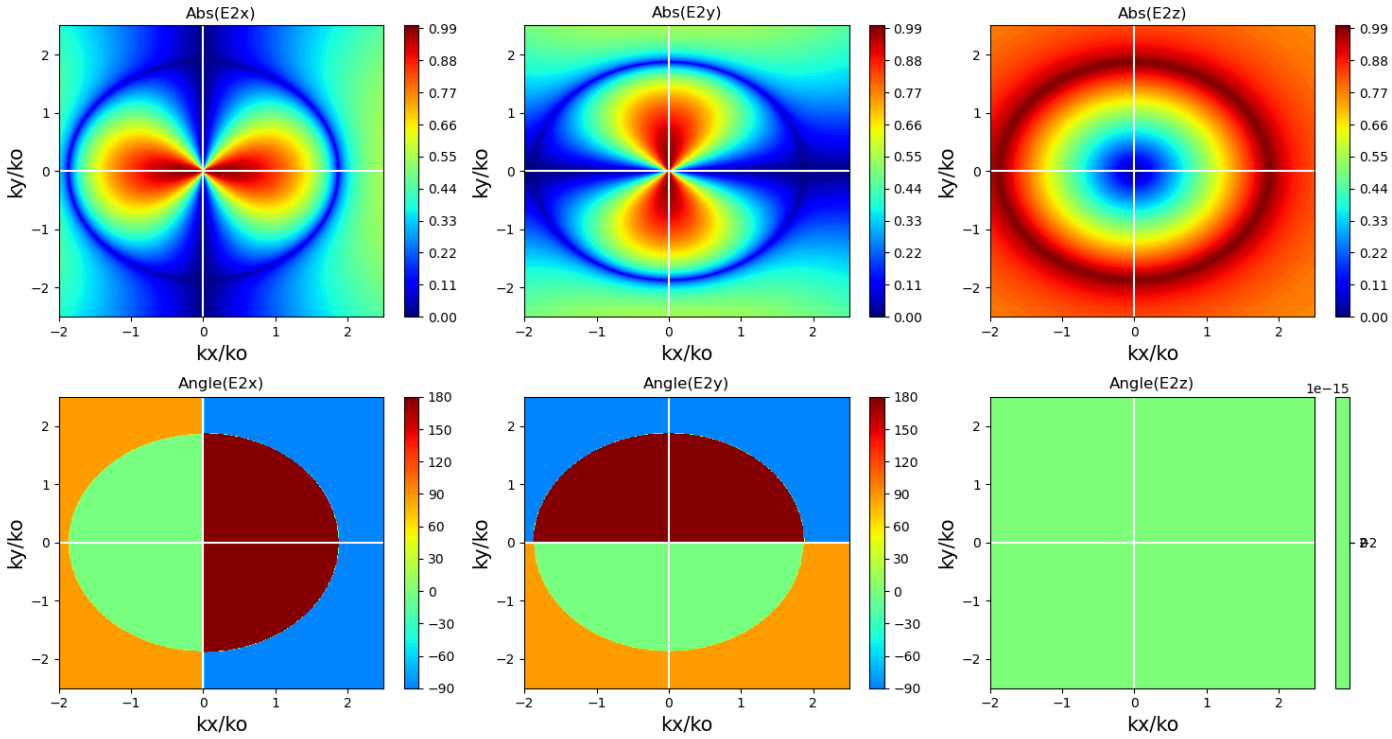
```
>>> plotEvskxky
```

$$\boldsymbol{e_1} = \begin{bmatrix} -\frac{k'_y}{k'_t} \\ \frac{k'_x}{k'_t} \\ 0 \end{bmatrix}$$



Plot the data (Isotropic)

$$e_2 = \begin{bmatrix} -\frac{k'_x k'_z}{k'_t k} \\ -\frac{k'_y k'_z}{k'_t k} \\ \frac{k'_t}{k} \end{bmatrix}$$



Delete material

```
>>> deleteMaterial

>>> printSettingInfo

er :
Fluorescence :
Phosphorescence :
DOF :
Mateiral Name : No name
Save File Path : ../../Example/materialOpticsCmd/B3PYMPM/Isotropic/Test_vs_kxky
Save File Name : B3PYMPM_isotropic
Figure Show Bool : False
The material object is empty


>>> printMaterial

Please set the material first.
```

Calculation (Uniaxial)

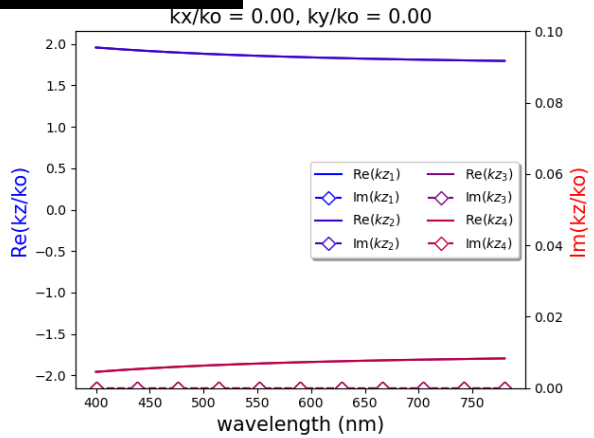
```
>>> SaveFileName B3PYMPM

>>> SaveFilePath ../../Example/materialOpticsCmd/B3PYMPM/Uniaxial/Test_vs_WV

>>> setNK B3PYMPM

>>> setMaterialName B3PYMPM

>>> generateMaterial

>>> printSettingInfo

er : B3PYMPM
Fluorescence :
Phosphorescence :
DOF :
Mateiral Name : B3PYMPM
Save File Path : ../../Example/materialOpticsCmd/B3PYMPM/Uniaxial/Test_vs_WV
Save File Name : B3PYMPM
Figure Show Bool : False
Material Name : B3PYMPM
Permittivity Note :
     PATH:..\..\..\sim\material_n_k/
     FILENAME:B3PYMPM_uniaxial
------------------------------------------------------------------------------
Fluorescence[0] Note :
     /*Empty*/
------------------------------------------------------------------------------
Phosphorescence[0] Note :
     /*Empty*/
------------------------------------------------------------------------------
Dipole Orientation Factor[0] Note :
     /*Empty*/
------------------------------------------------------------------------------
```

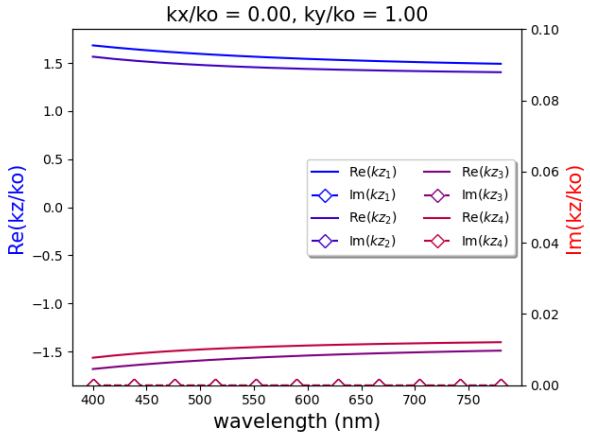
Calculation (Uniaxial)

```
>>> findkzE 400:1:780   0:1:2   0:1:2
>>> plotkvsWV
>>> plotkzvsWV
>>> plotEvsWV
>>> plotkvsf
>>> plotkzvsf
>>> plotEvsf
```

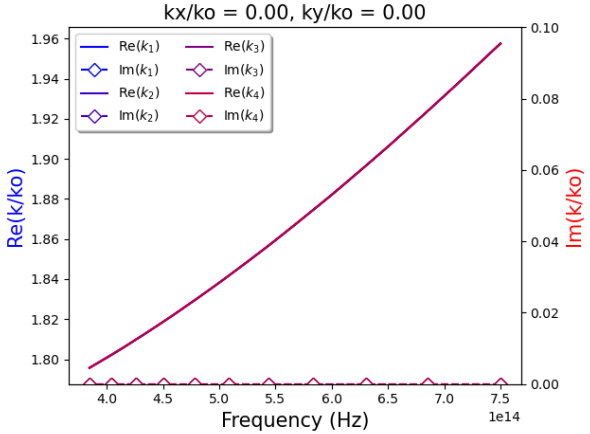
Plot the data (Uniaxial)

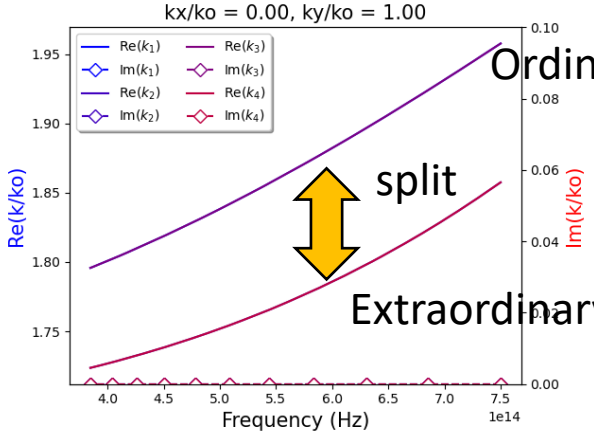
```
>>> plotkzvsWV
```





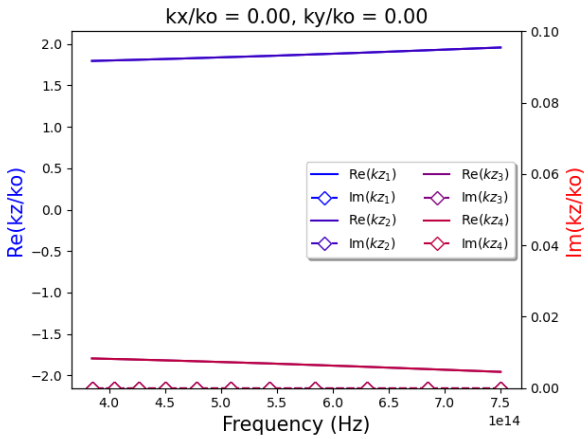

```
>>> plotkvsf
```

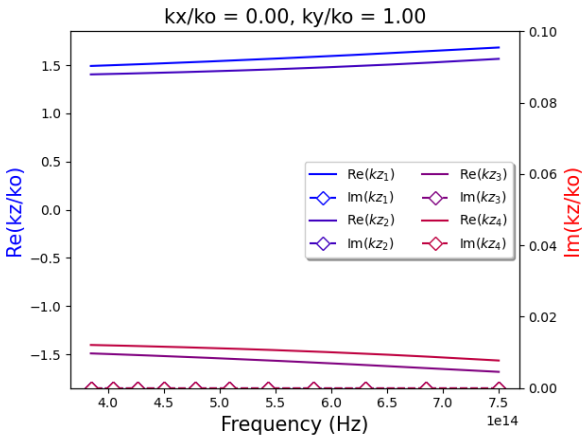




Plot the data (Uniaxial)

```
>>> plotkzvsf
```

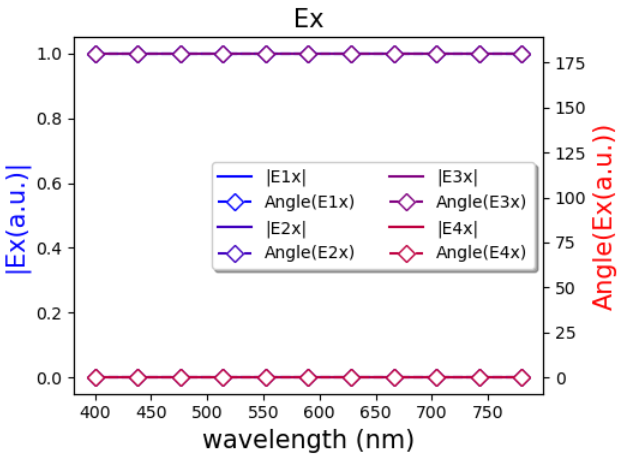


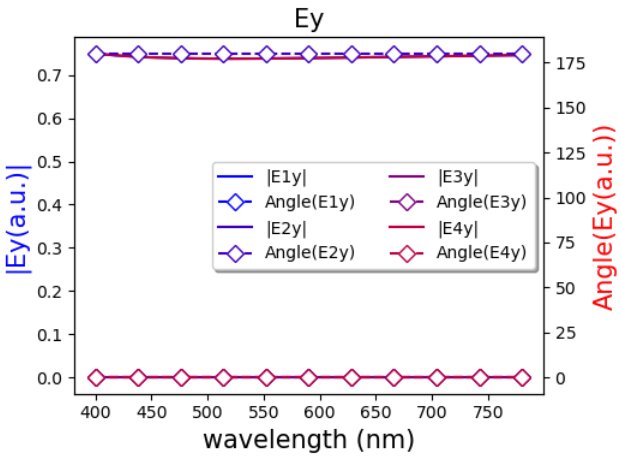


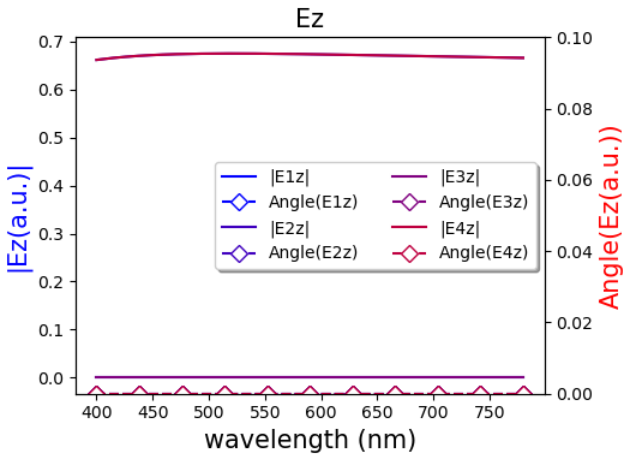
Plot the data (Uniaxial)

```
>>> plotEvsWV
```

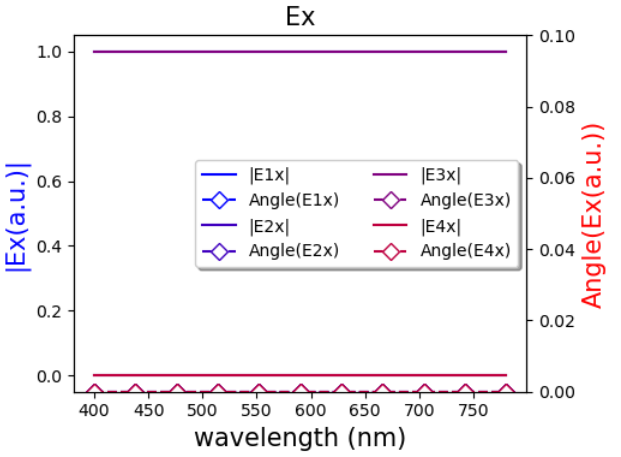
B3PYMPM_EvsWV_kxko_1_kyko_1

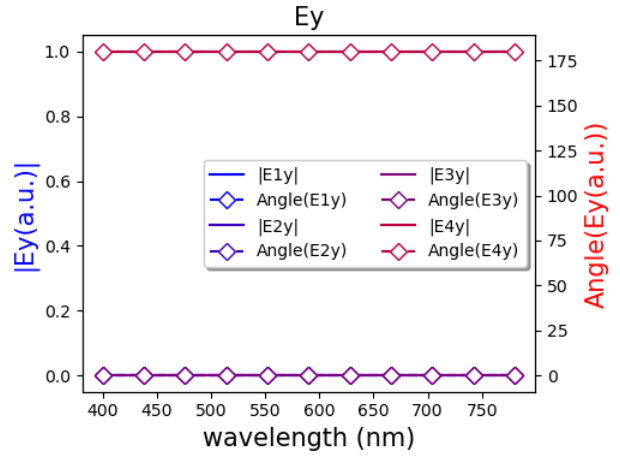


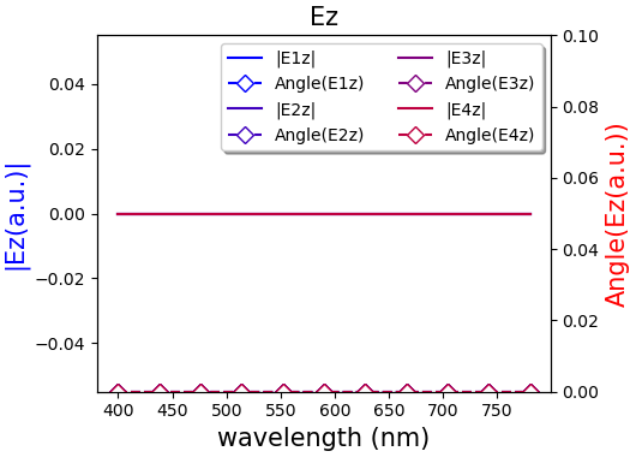




B3PYMPM_EvsWV_kxko_1_kyko_2







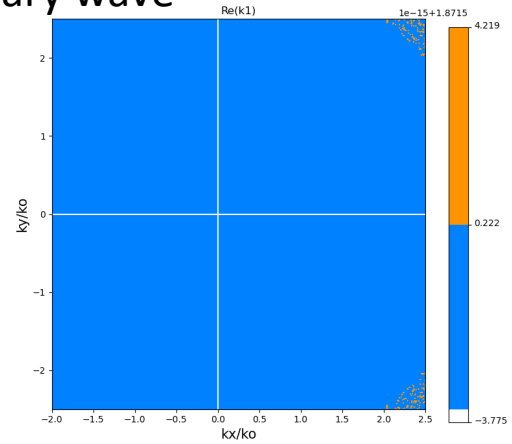
Calculation (Uniaxial)

```
>>> SaveFileName B3PYMPM

>>> SaveFilePath ../../Example/materialOpticsCmd/B3PYMPM/Uniaxial/Test_vs_kxky

>>> printSettingInfo

er : B3PYMPM
Fluorescence :
Phosphorescence :
DOF :
Mateiral Name : B3PYMPM
Save File Path : ../../Example/materialOpticsCmd/B3PYMPM/Uniaxial/Test_vs_kxky
Save File Name : B3PYMPM
Figure Show Bool : False
Material Name : B3PYMPM
Permittivity Note :
     PATH:..\..\..\sim\material n k/
     FILENAME:B3PYMPM_uniaxial
------------------------------------------------------------------------------
Fluorescence[0] Note :
     /*Empty*/
------------------------------------------------------------------------------
Phosphorescence[0] Note :
     /*Empty*/
------------------------------------------------------------------------------
Dipole Orientation Factor[0] Note :
     /*Empty*/
------------------------------------------------------------------------------

>>> findkzE 520   -2.0:0.01:2.5   -2.5:0.01:2.5

>>> plotkvskxky

>>> plotkzvskxky

>>> plotEvskxky
```

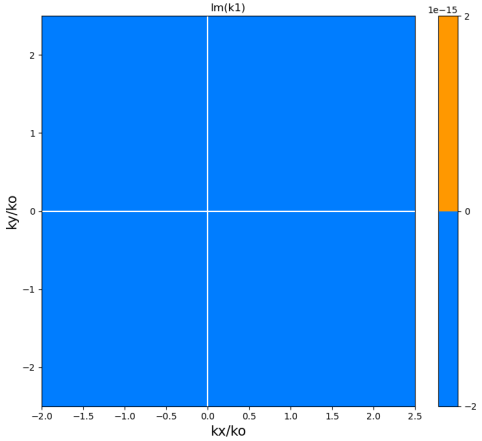
Plot the data (Uniaxial)

```
>>> plotkvskxky
```

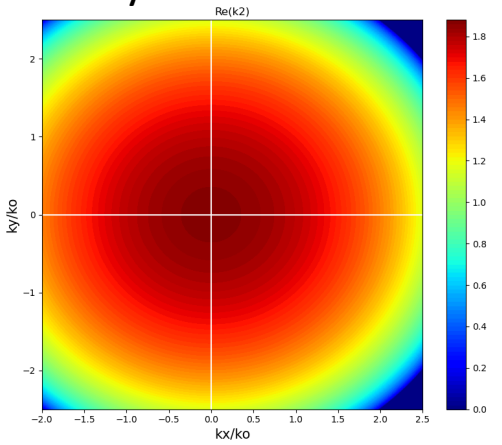
Ordinary wave



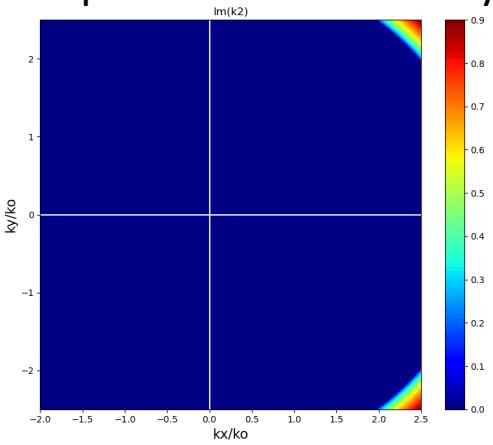
Independent on kx and ky



Extraordinary wave



Dependent on kx and ky

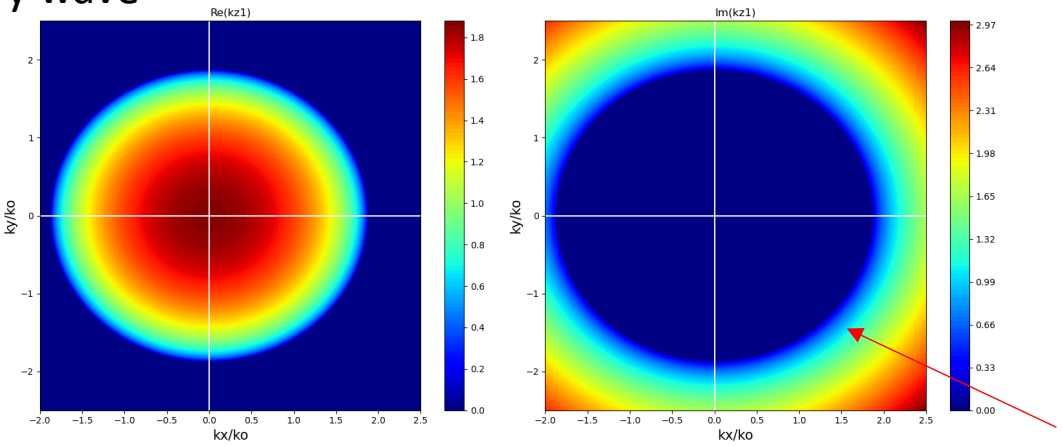


Plot the data (Uniaxial)

```
>>> plotkzvskxky
```

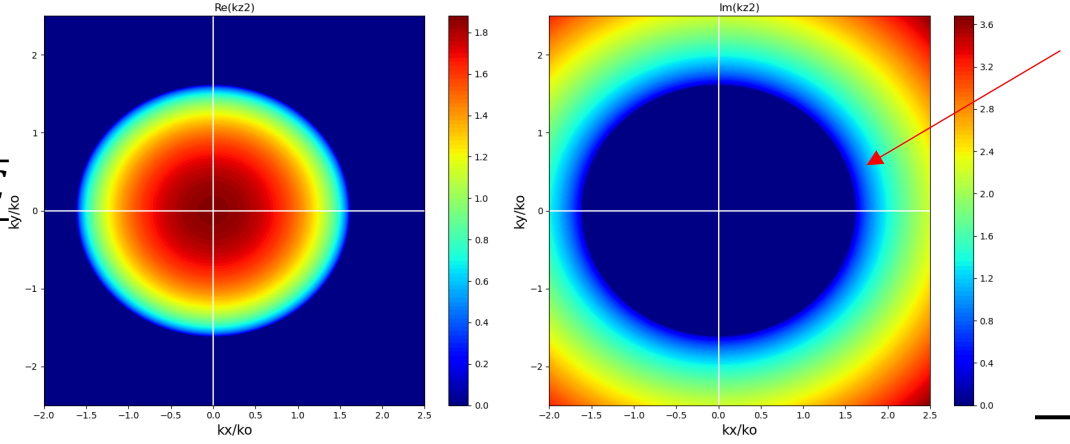
Ordinary wave

$$k'_{z,1} = \sqrt{k_o^2 \epsilon_{11} - k'^2_t}$$



Extraordinary wave

$$k'_{z,2,4} = \frac{B + \sqrt{B^2 - AC}}{A}$$

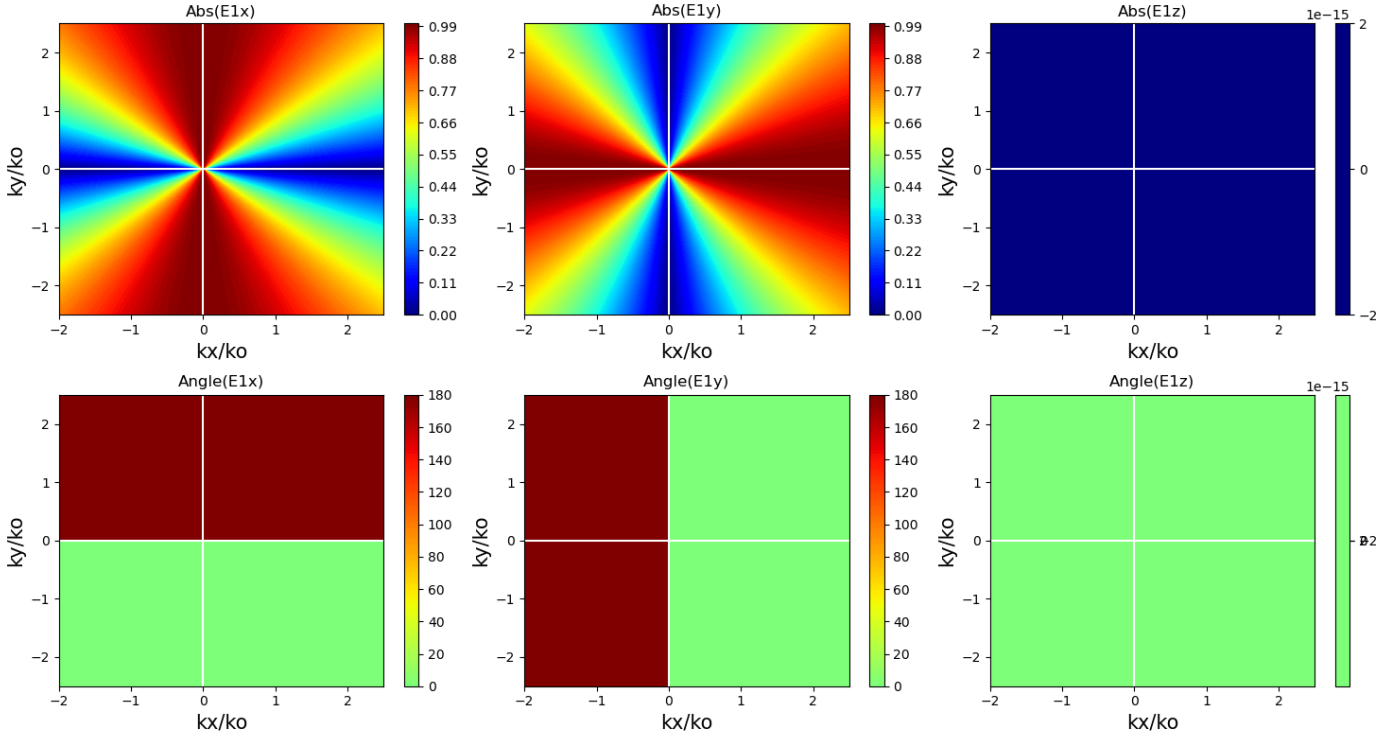


Different size

Plot the data (Uniaxial)

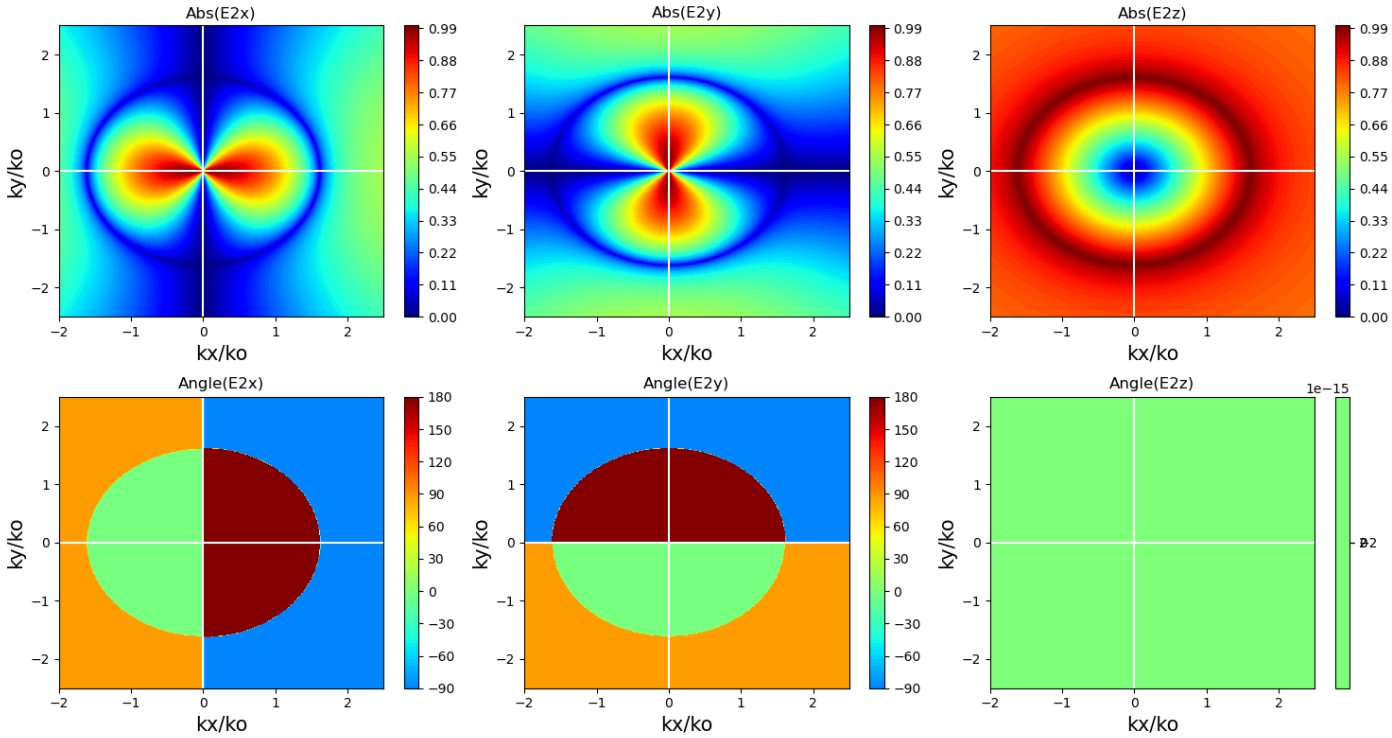
```
>>> plotEvskxky
```

$$\boldsymbol{e_1'} = \begin{bmatrix} -\dfrac{k'_y}{k'_t} \\ \dfrac{k'_x}{k_t} \\ 0 \end{bmatrix}$$



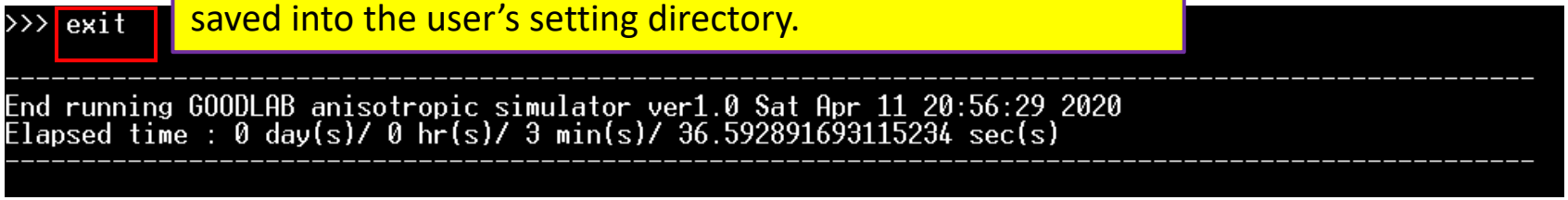
Plot the data (Uniaxial)

$$\boldsymbol{e'_{2,4}} \parallel \overline{\overline{\mathrm{R}}} \begin{bmatrix} -\dfrac{k_x k_{z,2,4}}{k_t k} \\ -\dfrac{k_y k_{z,2,4}}{k_t k} \\ \dfrac{\epsilon_{11} k_t}{\epsilon_{33} k} \end{bmatrix}$$



Exit the material manager system

Exit the material manager system.
*** The material manager system would be automatically saved into the user's setting directory.



Command Structure File

One can type the command lists in a file. The file can be executed by the execution file.

materialOpticsCmd-Example-1.txt

```
1  ?
2  printSettingInfo
3  SaveFileName B3PYMPM_isotropic
4  SaveFilePath ../../Example/materialOpticsCmd/B3PYMPM/Isotropic/Test_vs_WV
5  changefigshowBool F
6  setNK B3PYMPM_isotropic
7  setFluo cbp_irppy3
8  setMaterialName B3PYMPM_isotropic
9  printSettingInfo
10 generateMaterial
11 printSettingInfo
12 printMaterial
```

Execution file

Command file

```
\LegendDesign\ori_src\Execution>python materialOpticsCmd.py ./Example/materialOpticsCmd-Example-1.txt
```