Tutorial SimPhotonics_FMM

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SimPhotonics_FMM is a useful and powerful Matlab toolbox for the simulation of nanophotonic structures. It is based on the Modal Fourier Method (well known as RCWA) which can be used to model multilayer structure, 1D and 2D periodic metamaterials.

SimPhotonics_FMM includes a specific feature that allows the design of nanoparticles by the use of the Gielis's SuperFormula.

This toolbox is the result of research works developed in the Charles Fabry laboratory and in particular the contributions of J.P. Hugonin.

With its advanced features, SimPhotonics_FMM is a valuable resource for researchers and engineers working in the field of nanophotonics.

Features

- ✓ Reflection and transmission of incident light
- ✓ Dispersive materials
- ✓ Reduced CPU time with y-axis symmetry
- ✓ Quick calculation of a Bragg mirror
- ✓ Intuitive field visualization
- ✓ Parallel computation
- ✓ User-friendly examples

https://github.com/SimPhotonicsFMM/Sources

Main functions

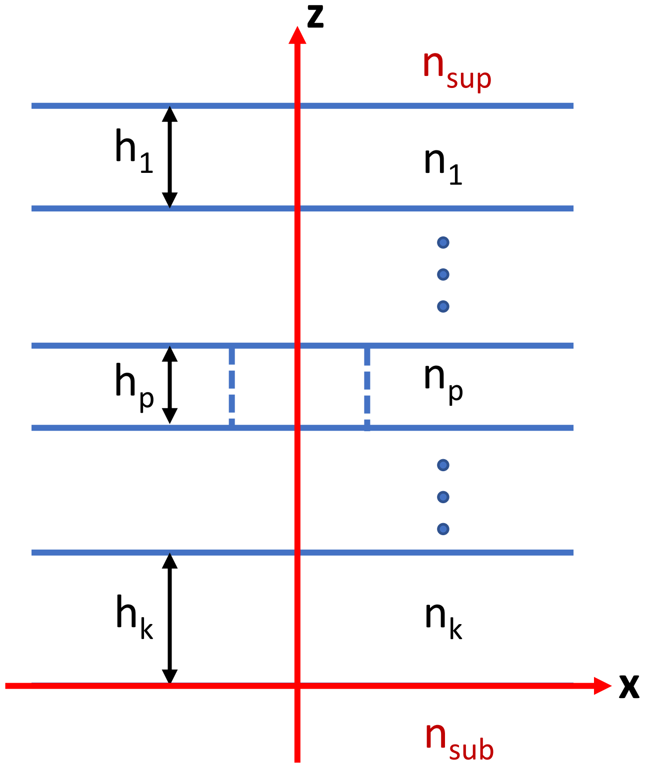
- **SetGeom** : define geometric parameters of the structure
- IndexVal : refractive index library
- **Spectrum** : compute S-matrices and the spectrum of reflectivity-transmittivity

- **Field** : compute S-matrices and field distribution
- CalculFieldFMM : calculate the field distribution
- VisuFieldFMM : plot the distribution of the electromagnetic field

- MeshLayer : discretize different layers of the structure
- VisuMesh : plot the discretization of the structure

Geometrical and optical properties

geom : Layer width (µm)
index : Refractive index



- Homogenous multilayer

  geom = [h_1 … h_p … h_k];
  index = [n_{sup} n_1 … n_p … n_k n_{sub}]; % constant refractive indices

  for dispersive material (use handle function)
  index = {n_{sup} n_1 … @n_p … n_k n_{sub} }; % cell array
  index = {n_{sup} n_1 … **IndexVal**('Material') … n_k n_{sub} };

- Grating + multilayer : use [Gielis's SuperFormula]

  geom = **SetGeom**('Param1',Val1,'Param2',Val2,...);

  index = {n_{sup} n_1 … [n_{p1} n_{p2} …] … n_k n_{sub} }; % Constant value
  `{supstrat, layers, {grating}, layers, substrat}`
  index = {n_{sup} n_1 … {@n_{p1} n_{p2} … }… n_k n_{sub} };

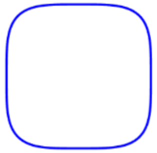
Gielis's SuperFormula

$$r(\varphi) = \left(\left| \frac{\cos\left(\frac{m\varphi}{4}\right)}{a} \right|^{n_2} + \left| \frac{\sin\left(\frac{m\varphi}{4}\right)}{b} \right|^{n_3} \right)^{-\frac{1}{n_1}}$$

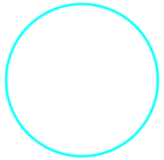
Optional parameters

geom = SetGeom('dx',...,'dy',...,'hc',...,'mn',[m n1 n2 n3],'ab',[a b],'Angle',...,'Dep',...,'Num',...,'npx',...,'npy',...,'Plot', ...)

mn : 4



mn : [4 4 4 4]

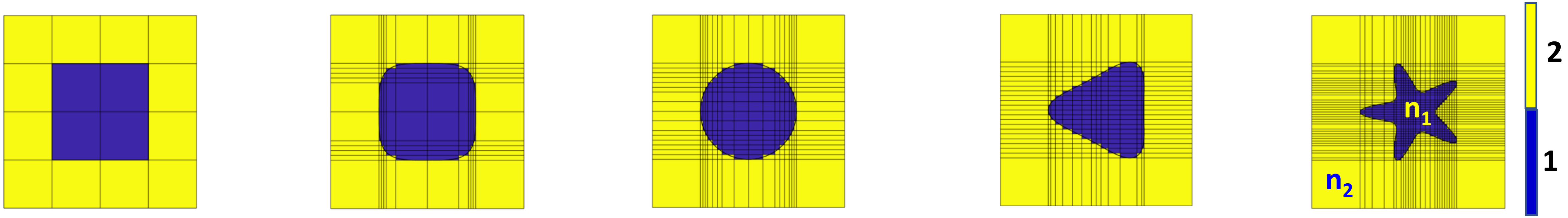


mn : [4 2 2 2]

mn : [3 6 6 6]

mn : [5 2 7 7]

```
mesh = MeshLayer(geom);  % discretization of the structure according to the choice of npx and npy value
figure, VisuMesh(mesh)     % plot mesh
```



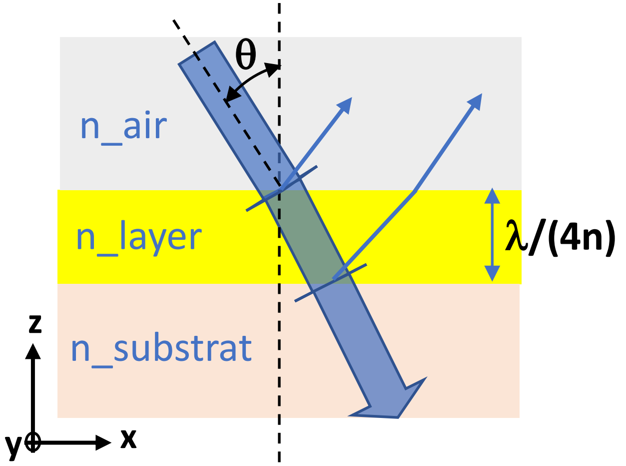
Reference number of subdomains is used to establish refractive index table: index = { nsup ...[n_1 n_2]...nsub}

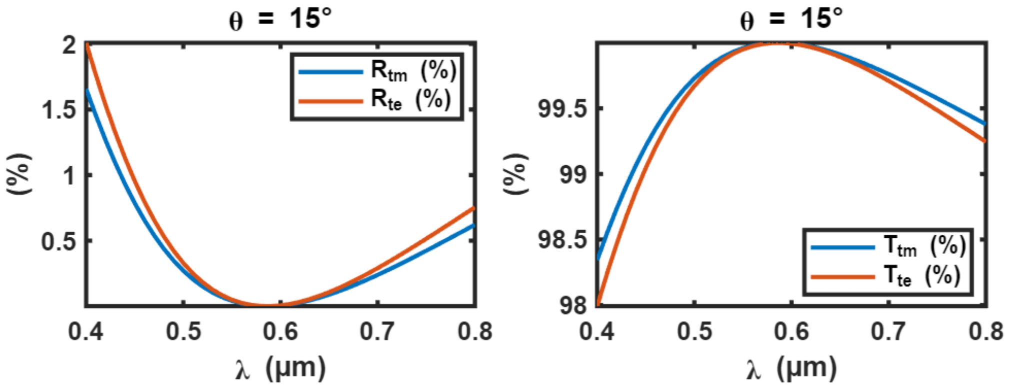
Tutorials & Examples

- TutoStepByStep.mlx: Discover step by step the different stages of a simulation with SimPhotonics_FMM
- TutoSuperFormula.mlx: Interactive generation of different shapes of nanoparticles with Gielis's Superformula
- TutoGeomMesh.mlx: Some examples of geometry generation and the associated mesh
- TutoSpectrum.mlx: How to use '*Spectrum.m*' with different examples

  - ✓ AntiReflectionCoating.mlx
  - ✓ BlazedGrating1D.mlx
  - ✓ SPRBioSensor.mlx
  - ✓ SPRBioSensorGrating1D.mlx
  - ✓ SPRBioSensorGrating2D.mlx

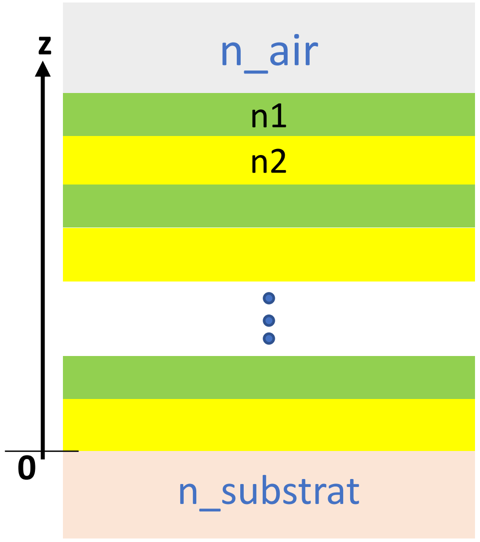
Anti-reflection coating

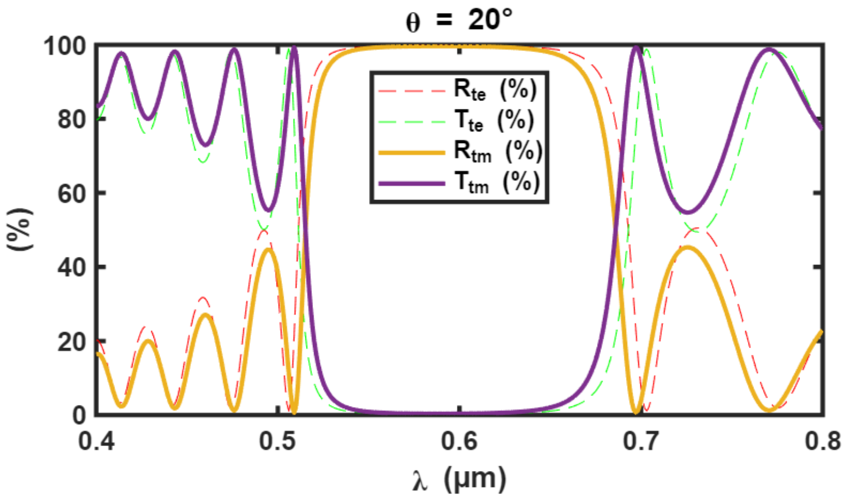





```
%
% Refractive index
n_air = 1;  n_subtrat = 1.5;  n_layer = sqrt(n_air*n_subtrat);
index = [n_air n_layer n_subtrat];
%
% Geometry
wl = .6;                        % Wavelength reference (µm)
geom = wl/(4*n_layer);          % Width of anti-reflection layer (µm)
%
% Incident plane wave
lambda = 0.4:0.01:0.8;          % Wavelength (µm)
theta = 15*pi/180;   % Angle of incidence (rd)
inc = +1;                       % Incidence from top =+1, from down =-1
%
% Spectrum calculation for TM and TE polarization
[R_tm,T_tm,R_te,T_te] = Spectrum(index,geom,lambda,theta,inc);
%
% Plot results (with PlotCoefRTA or simply with matlab function plot)
figure
subplot(121), PlotCoefRTA(lambda,theta,R_tm,R_te),
              legend('R_{tm} (%)','R_{te} (%)'), axis tight
subplot(122), PlotCoefRTA(lambda,theta,T_tm,T_te),
              legend('T_{tm} (%)','T_{te} (%)'), axis tight
```

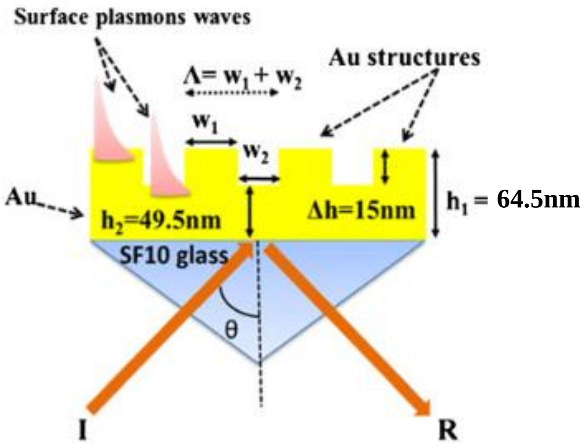
Bragg mirror

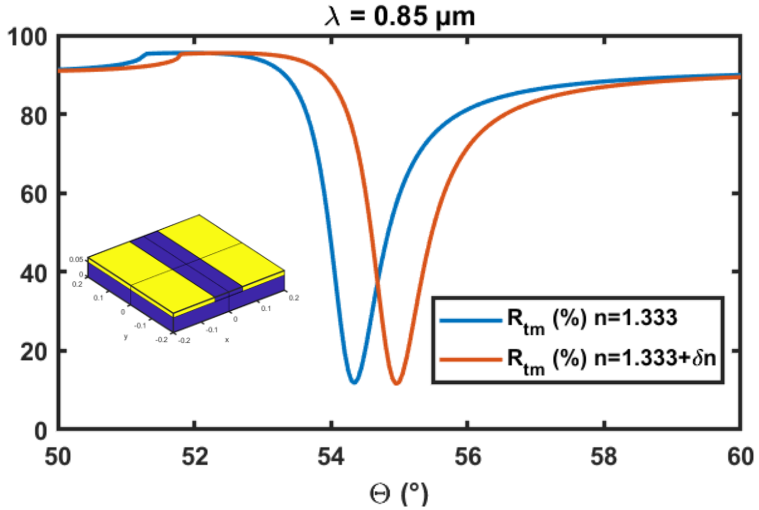





```
% Calculation with the optional parameter 'Nper' Number of periods to
% reduce CPU time

Np = 10; % Number of periods
%
n_air =1; n_subtrat = 1.5; n1 = 1.5; n2 = 2.2;
index = [n_air n1 n2 n_subtrat];
% index = [n_air repmat([n1 n2],1,Np) n_subtrat]; % Second method (slow)
%
wl0 = .6; % Wavelength reference
geom = [wl0/4/n1, wl0/4/n2]; % Width of different layers from top to down
% geom = repmat([wl0/4/n1 ,  wl0/4/n2],1,Np); % Second method
%
lambda = .4:.001:.8;
theta = 20*pi/180;
inc = +1;
%
[R_tm,T_tm,R_te,T_te] = Spectrum(index,geom,lambda,theta,inc,'Nper',Np);
% [R_tm,T_tm,R_te,T_te] = Spectrum(index,geom,lambda,theta,inc);
%
figure, hold on
    plot(lambda,R_te*100,'--r',lambda,T_te*100,'--g'),
    PlotCoefRTA(lambda,theta,R_tm,T_tm),
    legend('R_{te} (%)','T_{te} (%)','R_{tm} (%)','T_{tm} (%)')
```

SPR Biosensor

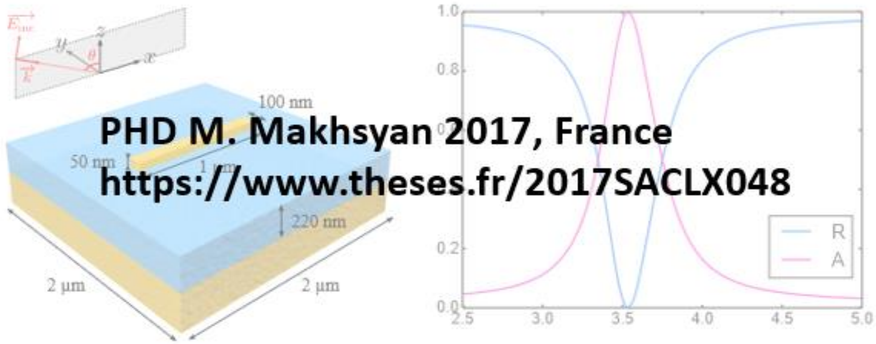




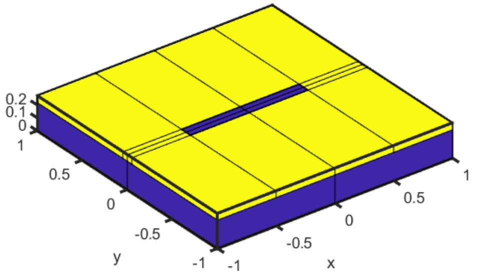
[Enhanced SPR sensitivity with nano-micro-ribbon grating - an exhaustive simulation mapping]
M. Chamtouri, A. Dhawan, M. Besbes, J. Moreau, H. Ghalila, T. Vo-Dinh, M. Canva
Plasmonics, 2013, pp.10.1007/s11468-013-9600-4. ⟨10.1007/s11468-013-9600-4⟩

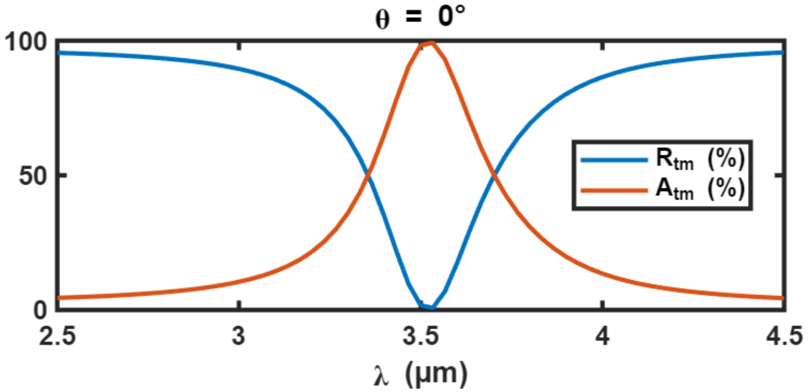
```
% Geometry (µm)
h1 = 0.0645; % Au thickness (layer+grating)
h2 = 0.0495; % Gold layer thickness
dx = 0.4;    % Period x-axis
w1 = dx/4;   % Grating width
%
geom = SetGeom('dx',dx,'mn',{4 []},'ab',{[w1/2 inf] []},'hc',[h1-h2, h2]);
%
% Refractive indices
n_H2O = 1.333;
%        {supstrat   ,   {grating}   ,    layers     ,    substrat}
index1 = {n_H2O , {IndexVal('Au') n_H2O}, IndexVal('Au'), IndexVal('SF10')};
%
% Incident Plane Wave
lambda = .85;                            % Wavelength(µm)
theta = linspace(50,60,201)*pi/180; % Incident angle (rd)
inc = -1;
%
% Spectrum Computation versus incident angle for a defined wavelength
R_tem1 = Spectrum(index1,geom,lambda,theta,inc,'mx',20);
%
% n_H2O + Dn : reflectivity variation
index2 = index1;
index2{1} = n_H2O + 1e-2; index2{2}{2} = n_H2O + 1e-2;
R_tem2 = Spectrum(index2,geom,lambda,theta,inc,'mx',20);
%
% Plot Reflection versus incident angle in TM polarisation
figure,
PlotCoefRTA(lambda,theta,R_tem1(:,1),R_tem2(:,1)),
legend('R_{tm} (%) n=1.333','R_{tm} (%) n=1.333+\deltan ')
```

MIM plasmonic nanoantenna



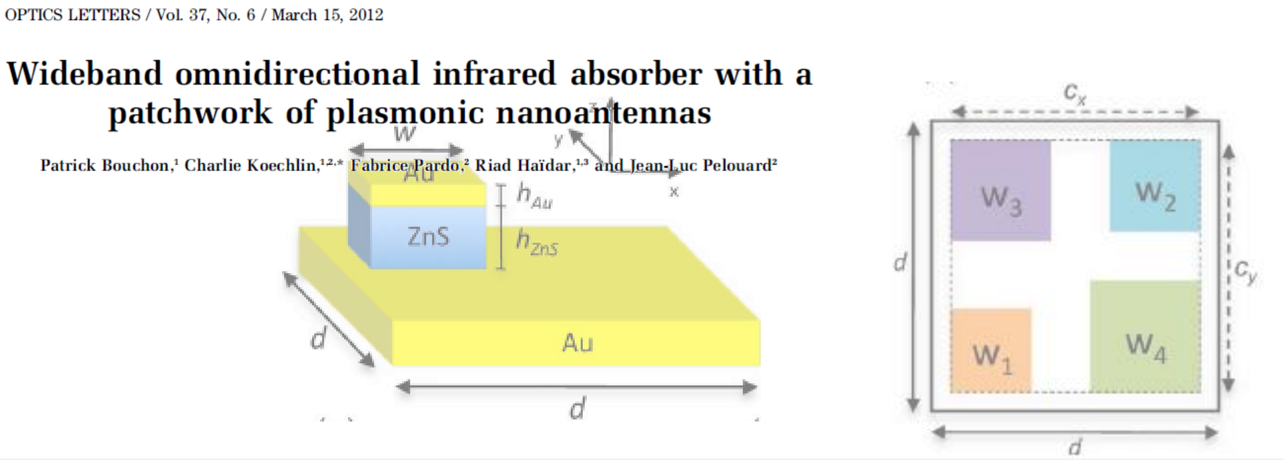
PHD M. Makhsyan 2017, France
https://www.theses.fr/2017SACLX048

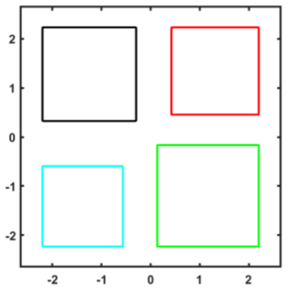


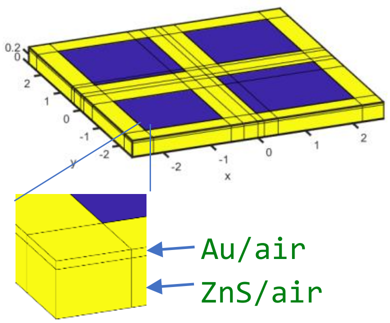


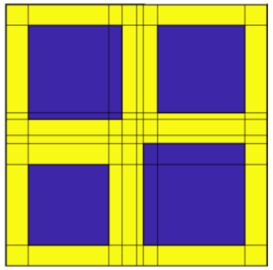

```
% Geometry (µm)
dx = 2;
dy = 2;
L = 1;
w = 0.1;
h =[0.05 0.22];
%
% With Superformula
geom = SetGeom('dx',dx,'dy',dy,'hc',h,'mn',{4 , []},'ab',{[L/2 w/2] , []});
%
% Drude model for Au
xr = 0.159; g = 0.0077;
nAu = @(x) sqrt(1-1./(xr./x.*(xr./x+1i*g)));
%
index = {1 , {nAu 1} , IndexVal('SiO2'), nAu};
%
lambda = linspace(2.5,4.5,61);
theta = 0;
inc = +1;
%
% With symmetry in y-axis (0: TM – 1: TE)
[R,T] = Spectrum(index,geom,lambda,theta,inc,'mx',15,'my',15,'SymY',0);
% Without Symmetry
%[R_tm,T_tm,R_te,T_te] = Spectrum(index,geom,lambda,theta,inc,'mx',15,'my',15);
%
% Plot Reflection and absorption versus wavelength in TM polarisation (SymY=0)
Figure, PlotCoefRTA(lambda,theta,R,1-R-T), legend('R_{tm} (%)','A_{tm} (%)')
```

```
% Geometric data
d = 5.3;
h_ZnS = 0.29; h_Au = 0.05;
w1 = 1.64; w2 = 1.78; w3 = 1.91; w4 = 2.07;
cx = 4.41; cy = 4.47;
%
Tab_mn = repmat([4],4,1); % 4 squared particles
TabR = 0.5*[w1 w1; w2 w2; w3 w3; w4 w4];
Dep_XY = 0.5*[-cx+w1 -cy+w1; cx-w2 cy-w2; -cx+w3 cy-w3; cx-w4 -cy+w4];
%
% Use cell array for multi-layers (2 layers: Au/air + ZnS/Air)
%
geom = SetGeom('dx',d,'dy',d,'hc',[h_Au h_ZnS],'mn',{Tab_mn , Tab_mn},...
               'ab',{TabR , TabR},'Dep',{Dep_XY , Dep_XY},'Plot',1);
```



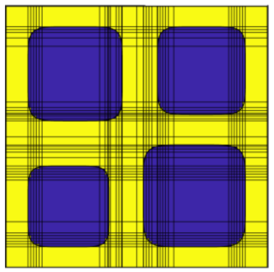


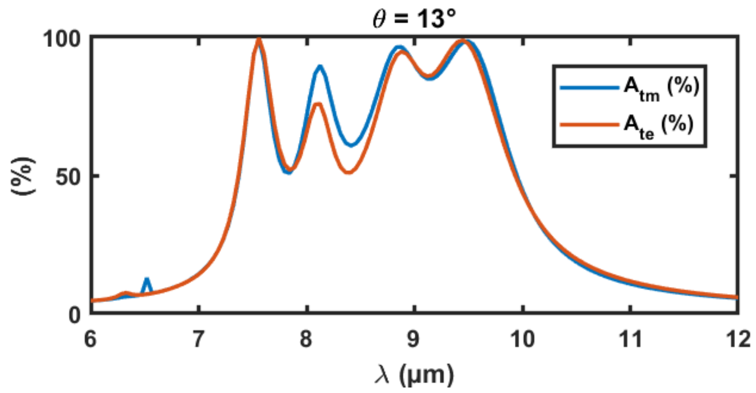




```
% Drude model for Au
xr = 0.159; g = 0.0048; nAu = @(x) sqrt(1-1./(xr./x.*(xr./x+1i*g)));
n_ZnS = 2.2; n_air = 1;
%
index = {n_air , {nAu n_air } ,{n_ZnS n_air } , nAu};
%
lambda = linspace(6,12,128);
theta = 13*pi/180;
inc = +1;
%
% Spectrum calculation
[R_tm,T_tm,R_te,T_te] = Spectrum(index,geom,lambda,theta,inc,'mx',15,'my',15);
%
figure, PlotCoefRTA(lambda,theta, 1-R_tm-T_tm, 1-R_te-T_te)
legend('A_{tm} (%)','A_{te} (%)')
```

```
% With rounded squared shape
Tab_mn1 = repmat([4 6 6 6],4,1);
geom1 = SetGeom(geom,'mn',{Tab_mn1 , Tab_mn1}, ...
               'npx',80, ‘npy',80);
%
mesh = MeshLayer(geom1);
figure, VisuMesh(mesh),
```



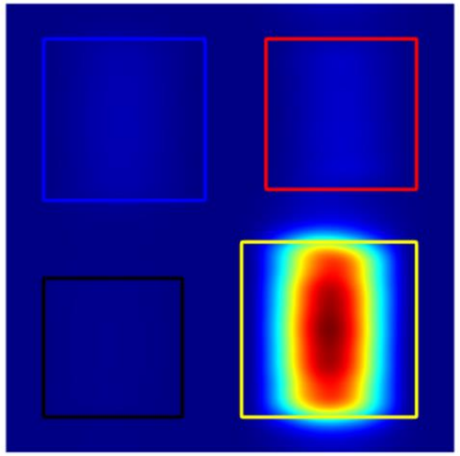


Field calculation

```
lambda = 9.5;
% S-Matrix calculation
s = Spectrum(index,geom,lambda,theta,inc,'mx',15,'my',15);

% Field calculation at (xy) plan
geom = SetGeom(geom,'z',h_ZnS/2,'x',linspace(-d/2,d/2,100),'y',linspace(-d/2,d/2,110));
[E,H] = CalculFieldFMM(s,geom.x,geom.y,geom.z);

% Second method
[E,H] = Field(index,geom,lambda,theta,inc,'mx',15,'my',15);

% Plot field (E:[Etm,Ete]  H:[Htm,The])
figure, VisuFieldFMM(abs(H(:,2)).^2,geom.x,geom.y,geom.z) % TM
figure, VisuFieldFMM(abs(H(:,4)).^2,geom.x,geom.y,geom.z) % TE
```

```
geom = SetGeom(geom,'z',linspace(-.1,2,100),'x',0,'y',0);

% Field calculation along z-axis
[E_tm,H_tm,E_te,H_te] = Field(index,geom,lambda,theta,inc,'mx',15,'my',15);

% Plot field
figure, VisuFieldFMM(abs(E_tm(:,1)).^2,geom.x,geom.y,geom.z)
```

$|H_y|^2$ - TM



$|H_x|^2$ - TE