

RicWaA User's Guide

Introduction.

RicWaA is a MATLAB based Rigorous coupled-Wave Analysis (RCWA) code. Built with the object-oriented programming of MATLAB, RicWaA provides a very simple and friendly user interface facilitating the easy implementation of RCWA to arbitrary 2D periodic multilayer photonic structures. For users who are familiar with MATLAB programming, RicWaA is definitely a good choice to learn and implement RCWA. With the powerful analysis and visualization tools of MATLAB one will find RicWaA a very flexible and intuitive tool.

Features.

RicWaA contains the following main features.

- 1, For 2D structure which is periodic along one dimension and which can be well described by a finite number of layers along the other dimension;
- 2, TE and TM polarization;
- 3, Dielectric and lossy materials;
- 4, Transmission and reflection computing;
- 5, Total/scattering field and index profile visualization tools;

Study with an example.

When start a project, one need to copy all the files contained in the RicWaA.zip into your MATLAB directory. Here is an example of how to use RicWaA to design a hybrid photonic crystal (HPC) micro-cavity. This example covers almost all the RicWaA operations one may need to use.

The hybrid PC cavity studied here is constructed by replacing the top DBR (distributed Bragg reflector) mirror of a conventional 2D DBR micro-cavity with a sub-wavelength high contrast grating layer. The Index profile of the structure is show in Figure 1.

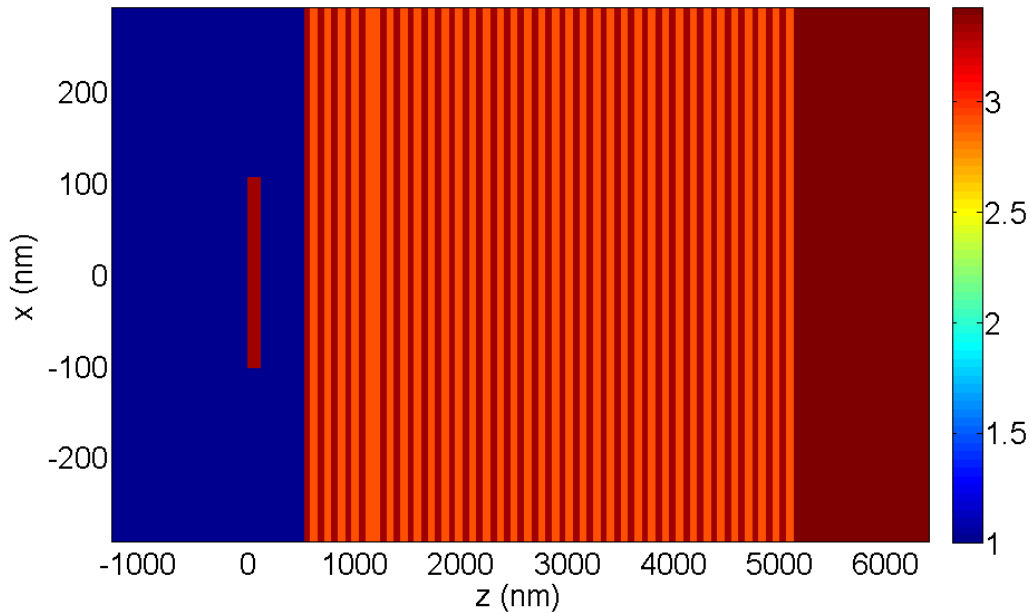


Figure 1 The index profile of one period of a HPC micro-cavity with a HCG combined with 4 pairs of top DBRs as the top cavity mirror and 30 pairs of bottom DBRs.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% hpccavity.m %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%      Step 1: Geometric and dielectric parameters definition      %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

wavelength=800;
% The wavelength of the light in the air
dbrwavelength=800;
% The wavelength used for DBR setting
incidentangle=0;
% The angle between the incident light and the normal direction of the
% layers, in degree
period=585;
% The grating period which is also the period of the whole structure
dutycycle=0.35;
% The duty-cycle of the grating structure, which is the ratio between
% the high index width and the period
gratingthickness=125;
% The thickness of the HCG layer
airgap=400;
% The air gap between the HCG and the top DBR
numtopdbr=4;
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% The number of the top DBR pairs
numbotdbr=30;
% The number of the bottom DBR pairs
nAlAs=2.9;
% Low index DBR layer, cavity
nGaAs=3.42;
cAlAs=0.2;
cGaAs=0.8;
nAlGaAs=(cGaAs*nGaAs+cAlAs*nAlAs);
% In this case nAlGaAs stands for the index of Al0.2Ga0.8As
gratingindex=nAlGaAs;
dbrhighindex=nAlGaAs;
dbrlowindex=nAlAs;
cavityindex=nAlAs;
substrateindex=nGaAs;
dbrhighthickness=dbrwavelength/dbrhighindex/4;
% DBR high index layer thickness, a quarter of the effective wavelength
dbrlowthickness=dbrwavelength/dbrlowindex/4;
% DBR low index layer thickness, a quarter of the effective wavelength
cavitythickness=dbrwavelength/cavityindex/2;
% Cavity thickness, one half of the effective wavelength
L=6+2*(numtopdbr+numbotdbr);
% Total number of the dielectric layers excluding the incident
% and out-going layers

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                               Step 2: RCWA object property assignment                               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

nmode=40;
rcwa=RCWA('period',period,'modenumber',nmode);
% mr=RCWA: creat a RCWA object mr
% mr=RCWA('PropertyName',propertyvalue,...): creat a RCWA object mr and
% specify the property values
% RCWA property list:
%   Name:          the name of the object
%   Polarization:  the polarization of the RCWA object
%   Period:        the period of the structure
%   ModeNumber:    the number of Bloch modes used to expand the field
%   LightSoure:    Source object that contains light source information
%   ModeNumber:    the Bloch mode number used to expand the field
%   LayerNumber:   the total number of layers including the incident
%                  and out-going layers
%   Layers:        the cell structure containing all the Layer objects
%   FieldDetectorNumber: the number of detectors in the RCWA object
%   FieldDetectors: the cell structure containing all the Detector
%                  objects
%   ComputingResults: Results object containing all the Bloch mode
%                  coefficients after running the RCWA object
%   Refelction:    the reflection rate
%   Transmission:  the transmission rate

rcwa.ApplyLightSource('poL','Te','wV',wavelength,'angle',incidentangle);

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% Apply a light source with Polarization='te', Wavelength=wavelength
% and IncidentAngle=incidentangle.
% Source property list:
%   Name:
%   Polarization:
%   Wavelength:
%   IncidentAngle:

% Immediately after creating the RCWA object with mr=RCWA(...), mr.Layers
% already contains two Layer objects; mr.Layers{1} is for the incident
% layer and mr.Layers{2} is for the out-going layer, so one do not need
% to add these two layers themselves. Notice the difference between
% Layers and Layer. Layers is a cell containing Layer objects.

rcwa.SetLayer(1, 'index', 1, 'name', 'In');
% Set the Layer objects properties using mr.SetLayer command, the first
% input argument specify which Layer ones wants to set. 1 is the index
% of this layer in the cell Layers. One can also sue the name of the
% layer to specify it.
% Layer object property list:
%   Name:          the name of the Layer object
%   Period:         the period
%   IndexProfile:  the index profile, the center of the period is
%                  defined as the original point (x=0,z=0);
%   IndexProfileResolution: the resolution of the index profile
%   LayerThickness: the thickness of this single layer
%   Thickness:     the distance between the lower boundary of this layer
%                  and the top line of the first dielectric layer (HCG surface)
rcwa.SetLayer(2, 'index', substrateindex, 'name', 'OUT');
% In property value is case insensitive, so 'OUT' is equivalent to 'out'

rcwa.AddLayer('lyt', gratingthickness, ...
    'profile', [-rcwa.Period/2*dutycycle, ...
    rcwa.Period/2*dutycycle...
    , gratingindex], 'name', 'hcg-grating');
% One can use the method mr.AddLayer of the RCWA object mr to add more
% layers while specifying the properties.
% ('profile', [x1,x2, gratingindex]) means change the index between x1
% and x2 to gratingindex.

rcwa.AddLayer('lyt', airgap, 'name', 'airgap');
rcwa.AddLayer('lyt', dbrhighthickness, 'index', dbrhighindex);

for icount=5:2:4+2*numtopdbr
    rcwa.AddLayer('lyt', dbrlowthickness, 'index', dbrlowindex);
    rcwa.AddLayer('lyt', dbrhighthickness, 'index', dbrhighindex);
end
% Build the top DBRs
rcwa.AddLayer('lyt', cavitythickness, 'index', cavityindex);
% Build the cavity
for icount=6+2*numtopdbr:2:L-1
    rcwa.AddLayer('lyt', dbrhighthickness, 'index', dbrhighindex);
    rcwa.AddLayer('lyt', dbrlowthickness, 'index', dbrlowindex);

```

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end
% Build the bottom DBRs

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                     Step 3: Run RCWA                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

rcwa.Run;
% Run rcwa. This will calculate all the reflection, transmission
% coefficients as well as all the Bloch mode expanding coefficients.
% All of these coefficients can be accessed by rcwa.ComputingResults.
% The reflection and transmission coefficients can also be accessed by
% rcwa.Reflection and rcwa.Transmission.

r=rcwa.Reflection;
t=rcwa.Transmission;
% Reflection and transmission coefficients

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% Notice %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% For a general RCWA application, r and t are all what one wants to
% know, other coefficients like diffraction efficiencies can be accessed
% by rcwa.ComputingResults.DER, rcwa.ComputingResults.DET standing for
% reflecting diffraction efficiencies and transmission diffraction
% efficiencies. RicWaA is very efficient to calculate all these results.
%
%
% However, if somehow one need to see the field profile, they can use
% the field detectors in RicWaA. But the calculation of the field will
% take much longer time than the coefficients computing. One can start
% with a lower resolution plot to estimate the time it will take to
% gain a fine resolution plot. The following are the steps to achieve
% this.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                     Step 4: Add and set field detectors                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

rcwa.AddFieldDetector;
rcwa.SetFieldDetector(1, 'x', linspace(-rcwa.Period, rcwa.Period, 100), ...
    'z', linspace(-rcwa.ComputingResults.StackThickness/4, ...
    rcwa.ComputingResults.StackThickness*5/4, 800), 'modal', 'scatter');
rcwa.AddFieldDetector('x', 0, 'z', linspace(...
    -rcwa.ComputingResults.StackThickness/4, ...
    rcwa.ComputingResults.StackThickness*5/4, 800));
% Add and set field detectors using rcwa.AddFieldDetector and
rcwa.SetFieldDetector.
% Field detectors are Detector objects contained in the cell named
% rcwa.FieldDetectors.
% Detector property list:
%     Name:          the name of the detector.
%     Status:        the status, 'on' or 'off'. If status is 'off',
%                    rcwa.FieldComputing will not compute the field of this
%                    detector.

```

```
%
X:      the x range of the field one wants to record.
Z:      the z range of the field one wants to record.
XResolution: the x resolution of the field
ZResolution: the z resolution of the field
Field:   the field matrix. For rcwa.Polarization='te', it
records Ey field; for rcwa.Polarization='tm', it records Hy
field.
One can use
pcolor(rcwa.FieldDetectors{1}.Z,rcwa.FieldDetectors{1}.X,...
real(rcwa.FieldDetectors{1}.Field));
to plot the field.
FieldModal: 'scatter' or 'total'. Specify whether total or
scattering field in the incident region one wants to record.
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                               Step 5: Field computing and plot      %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
rcwa.FieldComputing;
% Compute and record the fields of all the detector with status='on'.
```

```
subplot(2,1,1);rcwa.FieldPlot(1);
% Plot the field in rcwa.FieldDetectors{1}, see Figure 2.
subplot(2,1,2);rcwa.StructureIndexMap;
% Plot the index profile map of the whole structure. See Figure 2.
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% hpccavity.m %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

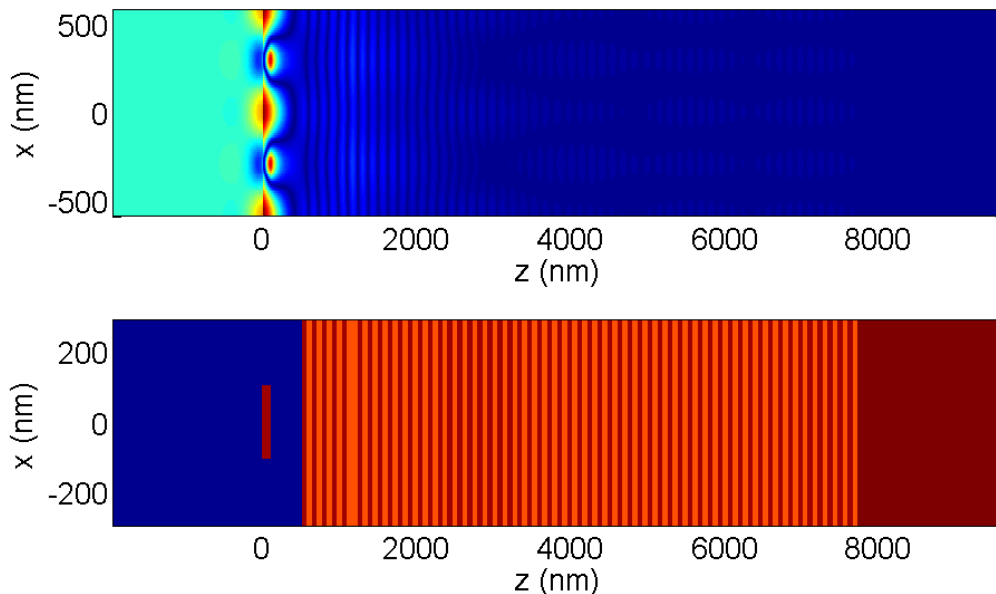


Figure 2. The field profile vs. the index profile. The upper plot contains two periods while the lower one only show one period.

References.

1. Moharam MG, Grann EB, Pommet DA, Gaylord TK. Formulation for stable and efficient implementation of the rigorous coupled-wave analysis of binary gratings. *J. Opt. Soc. Am. A*. 1995;12.
2. Lalanne P, Morris GM. Highly improved convergence of the coupled-wave method for TM polarization. *Journal of the Optical Society of America A*. 1996;13(4):779.
3. Moharam MG, Pommet Da, Grann EB, Gaylord TK. Stable implementation of the rigorous coupled-wave analysis for surface-relief gratings: enhanced transmittance matrix approach. *Journal of the Optical Society of America A*. 1995;12(5):1077.

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