CrystalWave Examples

Modelling a Photonic Crystal Laser with Active FDTD

PCLaser_StaticGain.prj

Modelling a Photonic Crystal Laser
with Crystalwave's Active FDTD Module

Note: this example requires a license with the Active FDTD optional module.

The **Active FDTD** module of **CrystalWave** was used to model a photonic crystal laser cavity. This feature allows you to introduce realistic gain models in FDTD calculations, thus making it possible to model photonic crystal lasers and nano-cavity lasers.

The Active FDTD module supports two different gain models:

- The **Dynamic Gain** model in which the gain is a function of carrier density and depends on current injection, spontaneous and stimulated recombination rates
- The **Static Gain** model, which does not explicitly consider a carrier density in the device but rather uses a saturable gain. This is a much simpler model in which gain is only a function of intensity.

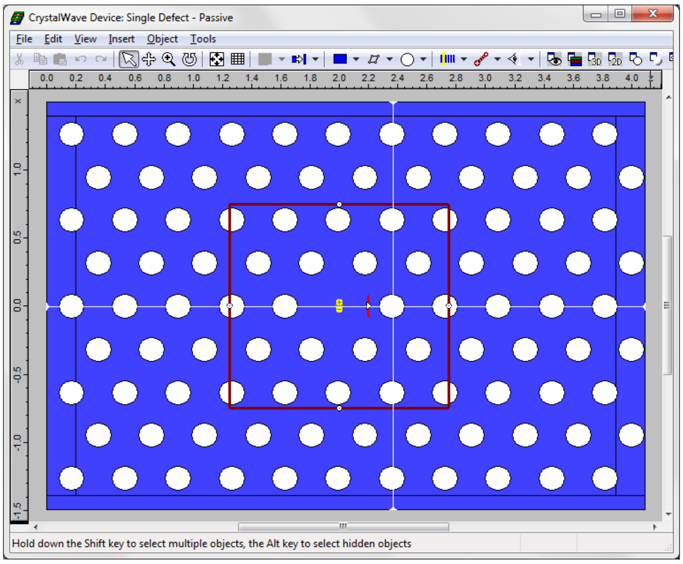
These two models are described in detail in the Active FDTD manual, which you can find in the "Documents" folder of your installation.

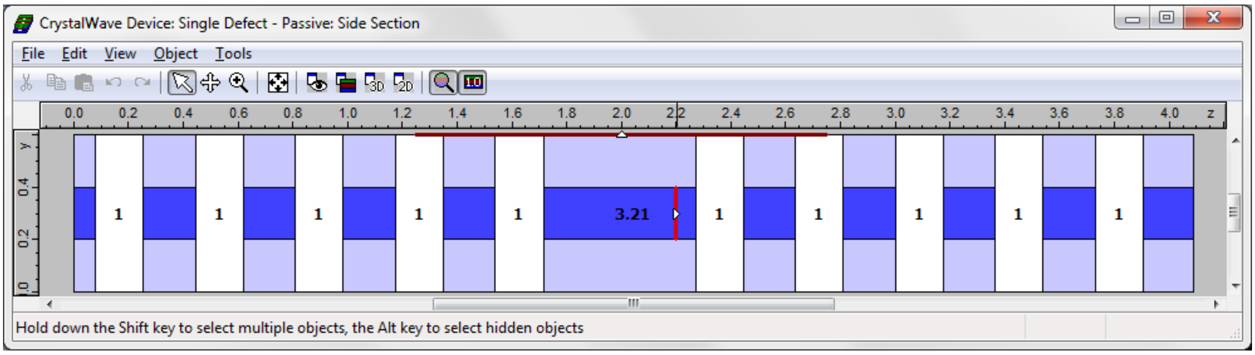
In this example we will use the Static Gain model to simulate a photonic crystal laser and reproduce the results given in [1]. A laser cavity is created by introducing defects in a 2D photonic crystal of air holes in a thin membrane of active InP material. The photonic crystal in the membrane has an hexagonal lattice with a lattice constant of 365 nm and a hole diameter of 175 nm; the membrane is 280nm thick and surrounded by air on both sides. We create resonant cavities in the membrane by removing single holes; the resonant frequency can be determined using a standard FDTD calculation without the gain present. We consider two laser designs, one with a single cavity and another one with an array of seven cavities.

First of all we will model the passive cavity and identify the resonant wavelength.

➢ Open the project PCLaser_StaticGain.prj in CrystalWave and double-click on "Single Defect - Passive".
You should see the following. This is a passive structure (no gain); you can inspect it via the cross-sections.

[1] W. H. P. Pernice, F. P. Payne and D. F. G. Gallagher, J. of Light. Tech., 25, 9, pp. 2306-2314 (2007)

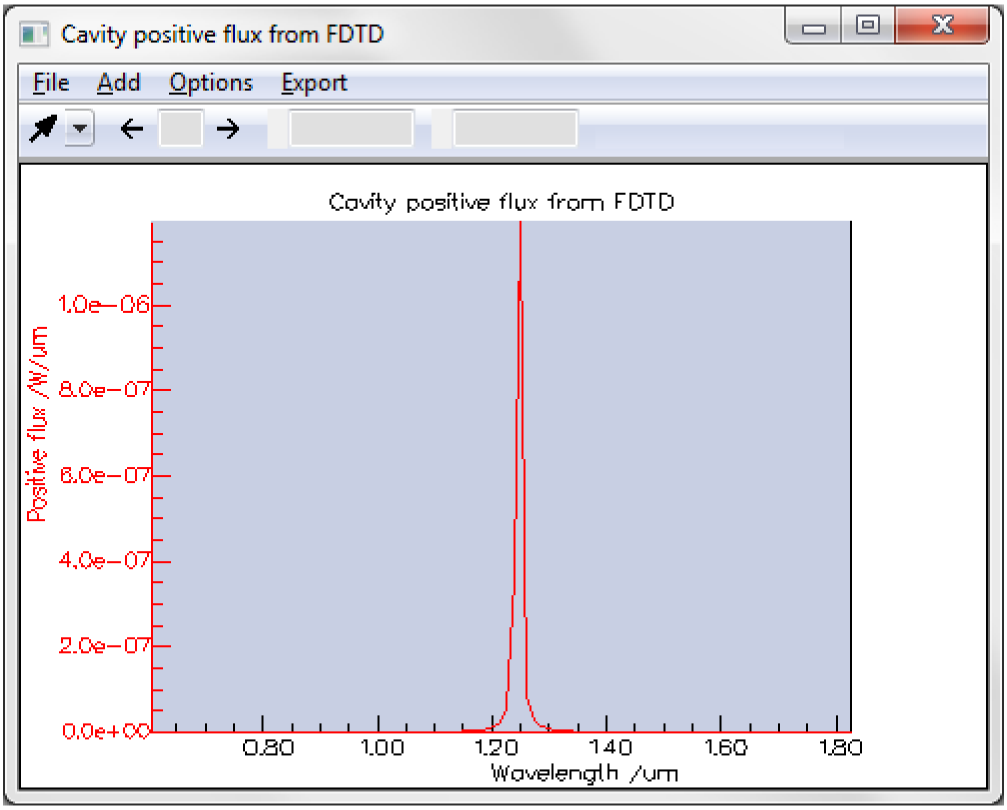




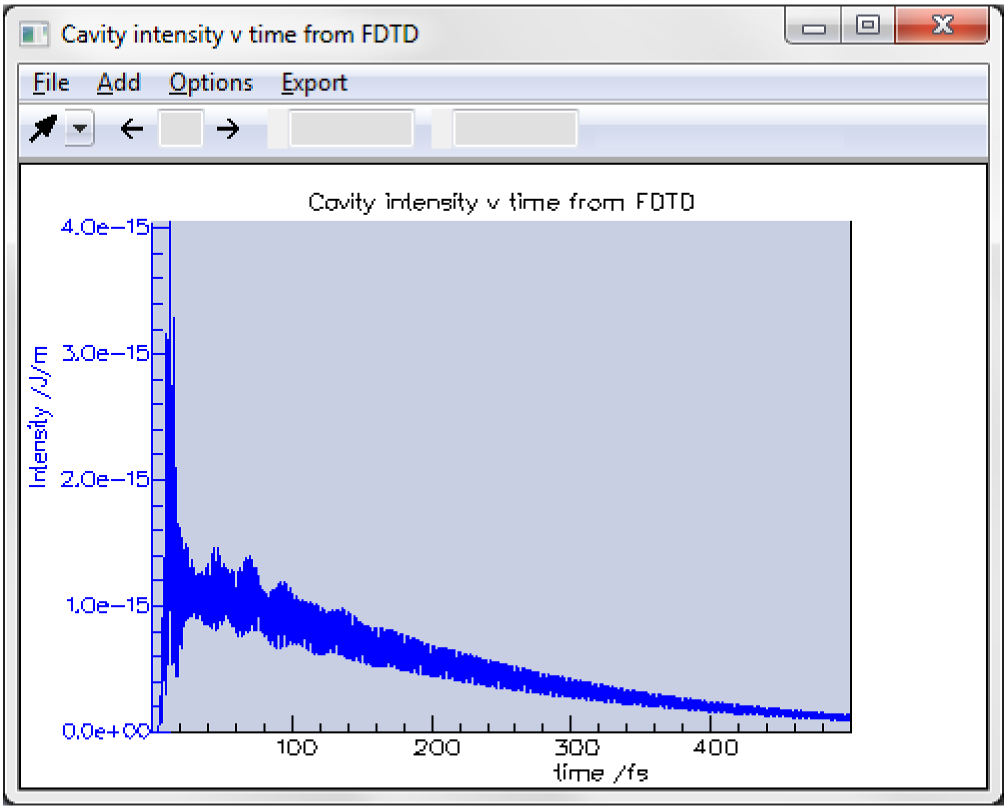
- Run the FDTD calculation and plot the positive flux versus wavelength for the sensor “Cavity”. The Fourier transform has been set up so as to ignore the first 50fs, which means that we should only measure light associated with the resonant mode.

Note: in this example, the calculations are performed with a grid of 0.02um, which could lead to non-negligible calculation times on modest computers. You can speed up calculations by increasing the grid to e.g. 0.05um.

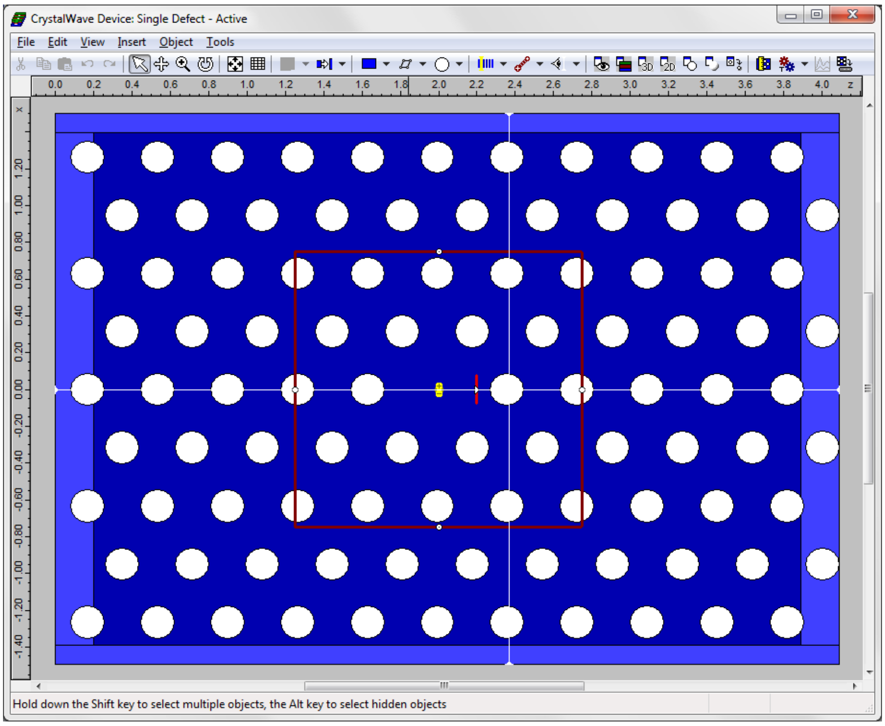
You should see the graph shown below. Using the SciGraph peak detection tool you should see that the resonant wavelength is 1.248um.



➢ Plot the intensity versus time in the sensor "Cavity", you will see that the light decays exponentially, as expected in absence of gain in the cavity.



➢ Close the CrystalWave Device and double-click on "Single Defect - Active". This time the membrane is associated with a material "InPGain", defined in the material database **refbase-membrane.mat**. The borders of the structure are defined with the same material as in the passive example (RIX = 3.21) as active materials cannot be put in contact with the PMLs.



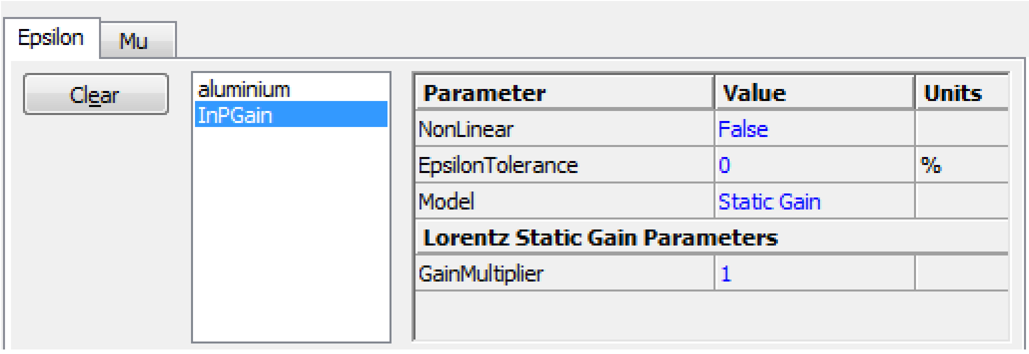
➢ You can inspect the material definition in the materials file. The lines used to define the material used with the Static Gain model are shown below.

```
GAIN_EPS   2.10496866e-15   // [cm3]
RIX_POLYL  1 3.21   // polylen
GAIN_STATICLORENTZ 1 0.1 // polyOrder confFactor
10000 1240 500 // peakGain [1/cm] peakPosn [nm] peakWidth [nm]
```

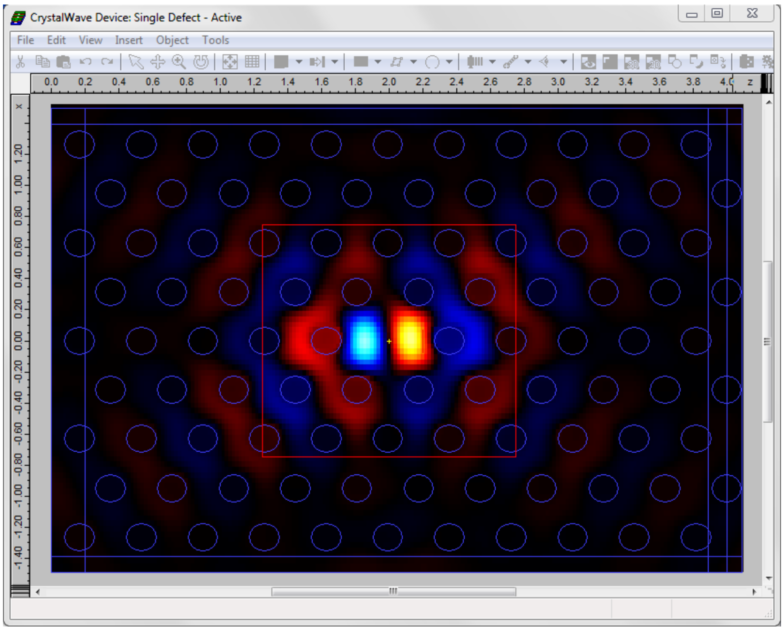
This means that the gain function is a Lorentzian curve centred on 1.24um, with a width of 500nm and an amplitude of 10000 cm^{-1}. The flag "GAIN_EPS" defines the gain saturation coefficient of 2.1e-15 cm^3. These flags are explained in the Active FDTD manual.

➢ If you inspect the properties of the excitor, you can see that we have chosen a very small input power of 1mW, which is below the saturation level.

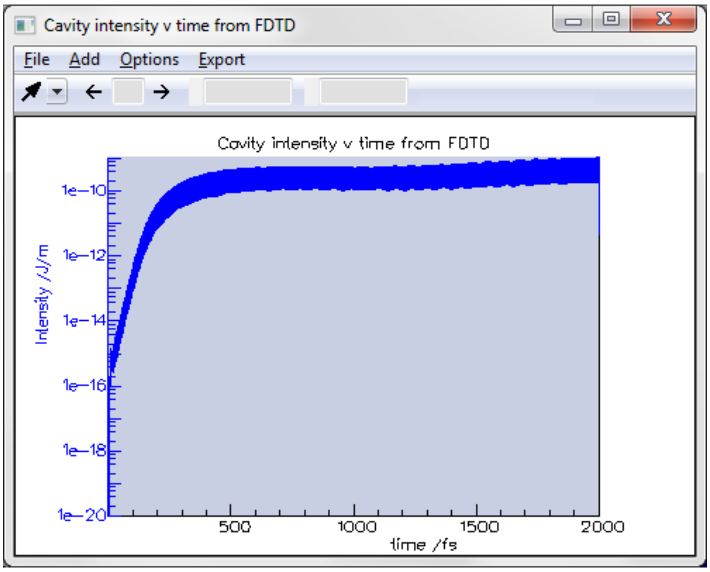
➢ In the *FDTD Calculator*, in the *Parameters* tab, if you double-click on the box next to "Materials", you will see that the "Static Gain" material model was selected for the material "InPGain".



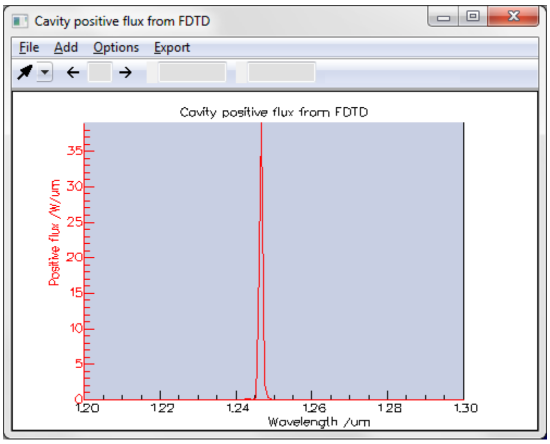
➢ Run the FDTD calculation. During the calculation you can visualise the fields; you can see below a screenshot of the Hy field for the resonant mode of the single cavity.

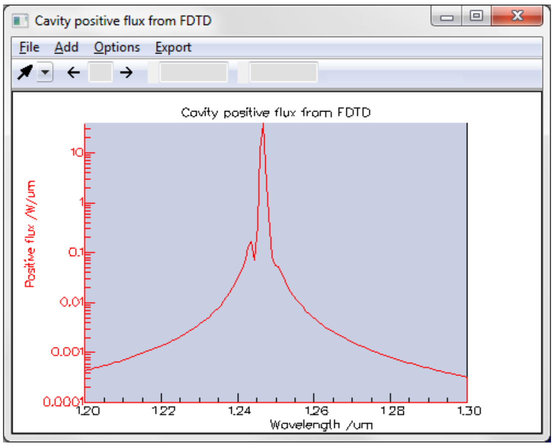


➢ Once the simulation is over, you can inspect the dynamics of your laser by plotting the intensity versus time in the "Cavity" sensor. It is shown below in log scale; the saturation of the power is quite clear and occurs from 500fs onwards.



- Plot the positive flux versus wavelength in order to visualise the spectrum of the cavity mode. The Fourier transform has been set up so as to ignore the first 500fs, so we will effectively be measuring the laser mode. The results are shown below in linear and log scale: they show a single peak at 1.246um with a very narrow linewidth of the order of 1nm.

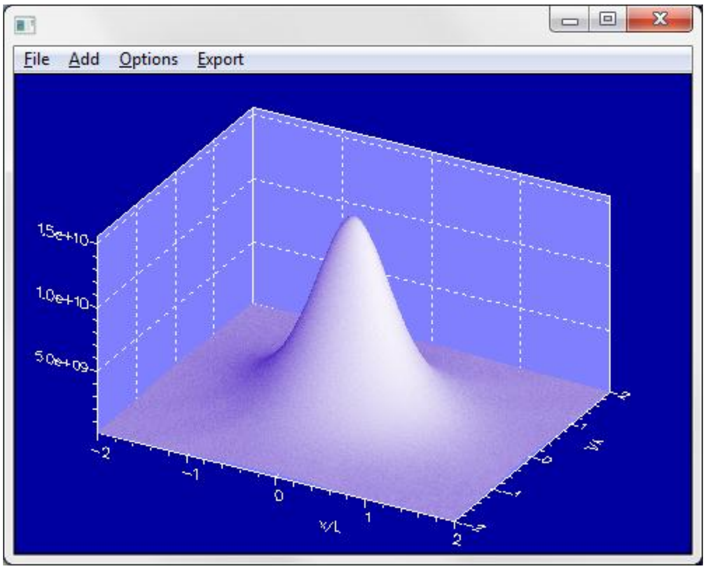




We placed a sensor on top of the cavity in order to calculate the farfield of the radiation emitted at the resonant wavelength.

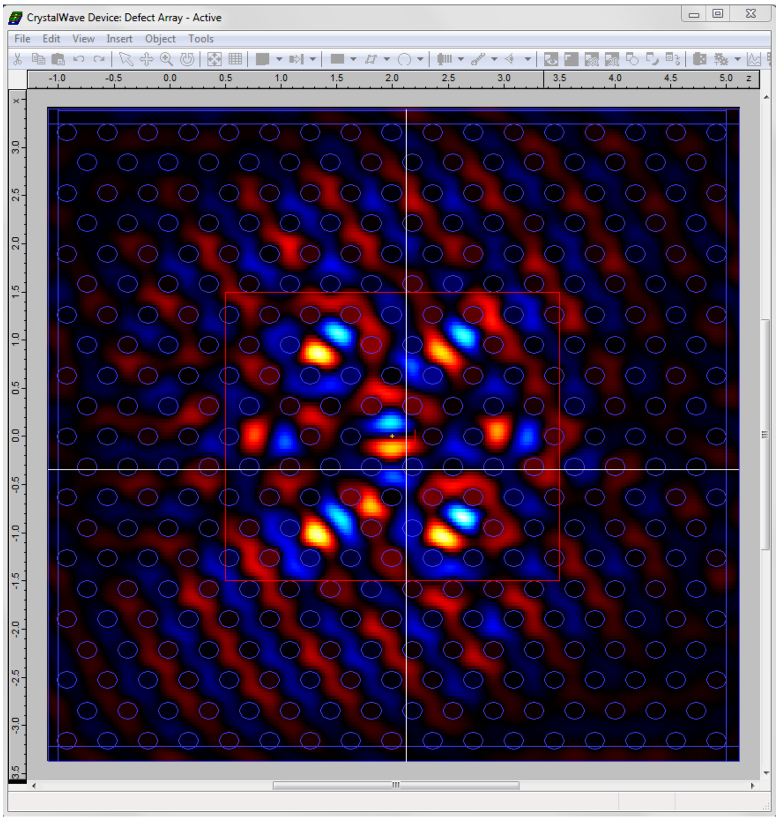
- Right-click on the area sensor and select **\Plot Farfield…**.
- Make sure that you have selected the "Top" sensor, set wavelength to 1.25um and click **Plot**.
- Click **Options** and set Grid to 1024x1024 and the **Projection** to *Planar* then click **OK**.
- Click on **Plot 3D**, then right-click on the Plot and select **\Display Options** and select 3D View, Gouraud, disabling both Contour Plot and Colour Map.

This will display the farfield of the emitted radiation, plotted versus lateral position. The plot is shown below. The farfield reveals that the single cavity does not provide a directional beam: measuring the FWHM of the profile reveals a horizontal half-angle of 55 degrees and a vertical half-angle of 27 degrees.

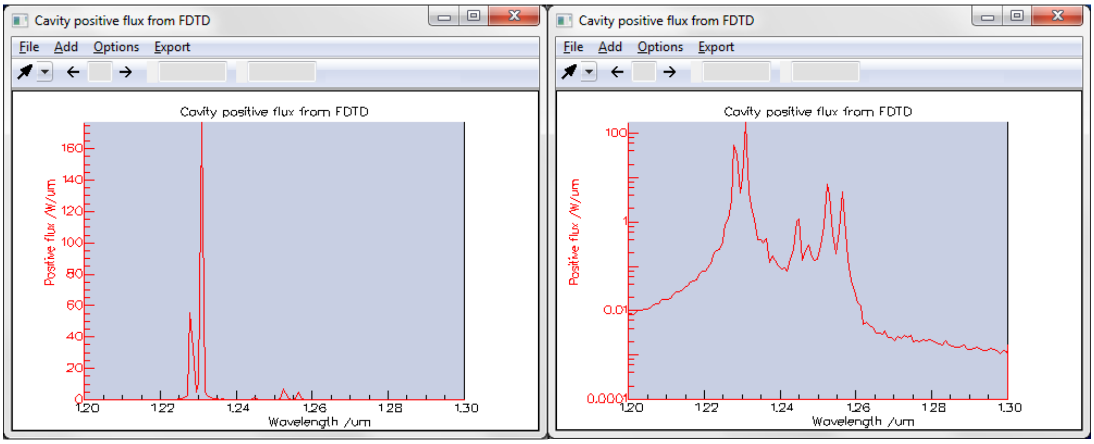


➢ Now perform the same calculations for the cavity array – the Device is "Defect Array - Active".

You can see a screenshot of the resonant supermode below.

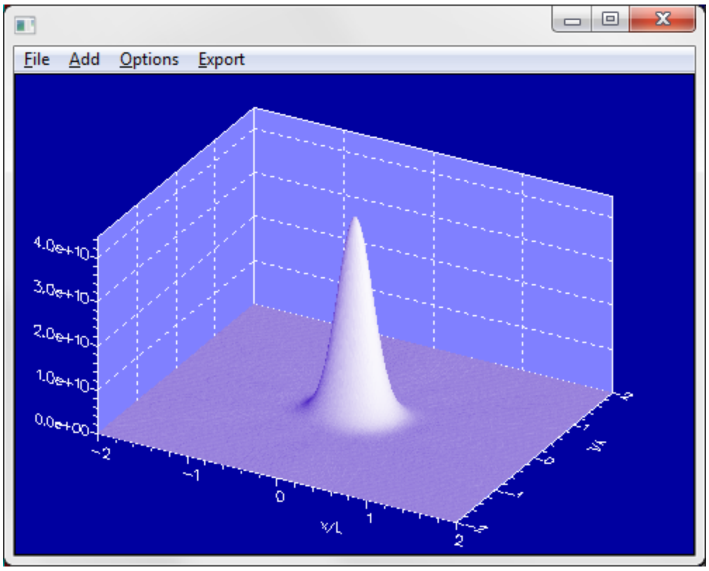


You can see below the spectrum of the resonance measured in the centre of the cavity array, plotted in linear (left) and log scale (right). The combination of the cavities leads to a splitting of the resonance peak, due to the presence of the cavity supermodes.

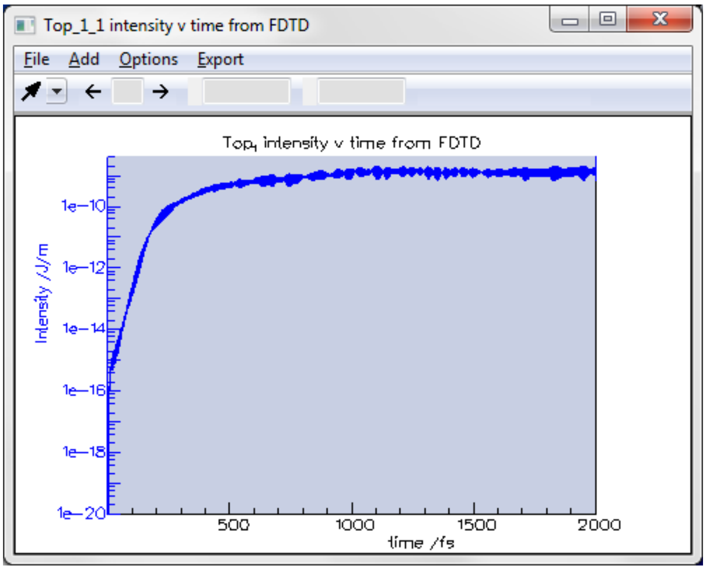


The dominant peak after 7ps is the resonance at 1.231um, which corresponds to the lasing mode. This resonance has a linewidth of the order of 0.3nm.

If you plot the farfield at 1.231um you will find a much narrower farfield profile than for the single cavity, with a horizontal half-angle of 22 degrees and a vertical half-angle of 12 degrees.



You can see below the evolution versus time of the intensity emitted by the cavity during the transitional regime, plotted in log scale.



In conclusion, the Static Gain model of OmniSim's Active FDTD module was used to simulate two different designs of photonic crystal lasers; we were able to characterise the field distribution and the farfield associated with each laser, as well as the spectrum of the light inside the nano-cavity.