Active-FDTD Module for CrystalWave/OmniSim   SPECIFICATION

❑ Brief description

The Active-FDTD add-on for CrystalWave and OmniSim provide additional capabilities to the FDTD engine to model semiconductor gain. It allows you to model the effect of population inversion to produce optical gain.

❑ Features

- Rate equation model of carriers including spontaneous recombination, stimulated recombination, injection current.
- Multiple-Lorentzian gain model, with automatic fitting to a set of gain curves (g(lambda) at a set of different carrier densities).
- Convergence Acceleration – normally the spontaneous lifetime is too long to model in fdtd (would require too many fdtd time-steps). Convergence Acceleration gets the device into the correct steady state more quickly.
- Fully integrated into the OmniSim and CrystalWave user-interfaces.
- Almost all features of the FDTD engine available (excluding clustering and sub-gridding – possibly available in a future version).
- Current injection is controlled by an Editor mask-layer, allowing you to readily inject current anywhere you want.
- All gain-material parameters are stored in a standard Photon Design material database file (.mat).
- Speed: in general the gain material is confined to a small layer – a fraction of the total simulation volume. Therefore the module does not significantly slow down the simulation speed.
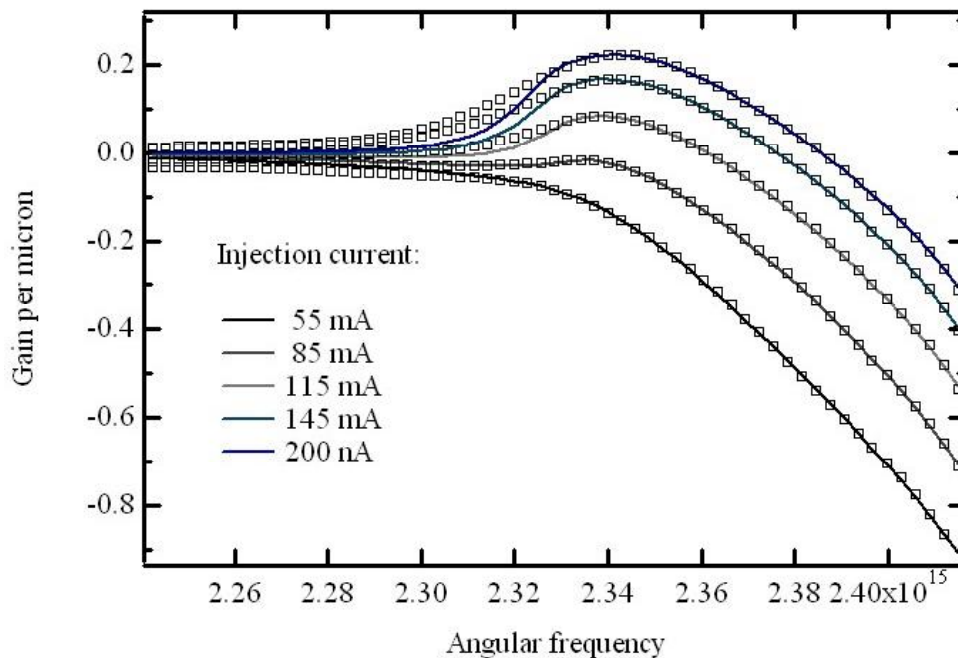- Applications include photonic crystal lasers and VCSELs.

Figure 1 (above). Showing the measured gain spectra (solid lines) at increasing injection current and the 4-Lorenzian automatically-fitted gain spectra (squares). The fitted spectra model well the gain peak, gain curvature and asymmetry and the fitting routines are supplied free with the Module.

❏ Dynamic Gain Model

The rate equation of carriers is given by:

$$\frac{dN}{dt} = -G(N).P - \frac{N}{\tau(N)} + \frac{J}{ed}$$

where N is carrier density, G(N) is the material gain, P is photon density, $\tau(N)$ is the carrier lifetime, J is the injection current density pumping a layer of thickness d.

❏ Static Gain Model

Where detailed carrier injection and a carrier rate equation is not required, one can use a static (fixed) gain, together with a strong gain non-linearity to reach the threshold condition. As the local optical intensity increases, the non-linear gain model causes the local gain to decrease in a manner proportional to 1/(1 + ε.P). While the details of the carrier density physics are lost, this can often produce a satisfactory initial laser simulation.

❏ Gain Fitting

We use a 4-Lorentizan model to match a set of real gain curves. The user inputs a set of gain spectra at increasing carrier densities. The algorithm then creates a 4-Lorentzian fit to each spectrum, creating a 12-parameter model. To re-generate the gain at an arbitrary carrier density these parameters are interpolated to the precise carrier density.

❏ Diffusion

An improved version of the Gain/Laser Model is in development which will add carrier diffusion.

❏ Example – Photonic Crystal Membrane Laser

We model a high-Q photonic crystal membrane with an InGaAsP active layer. We pump this electrically but it would usually be optically pumped in practise. The cavity mode of the crystal is shown below.
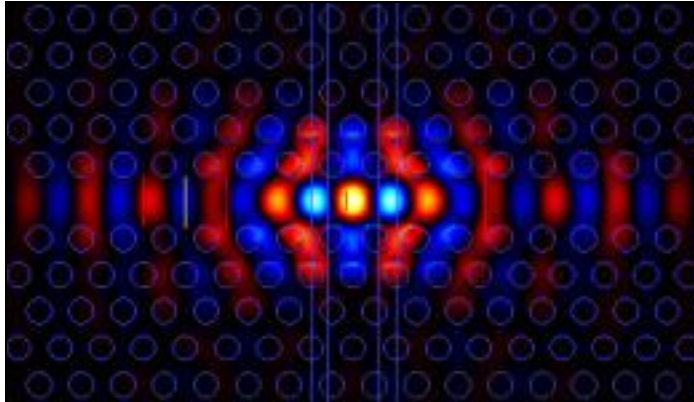

Figure 2 (above) lasing mode of a photonic crystal membrane laser, modelled with 3D-FDTD.
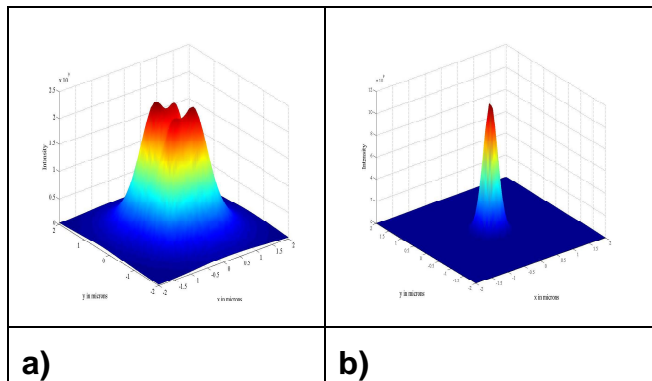

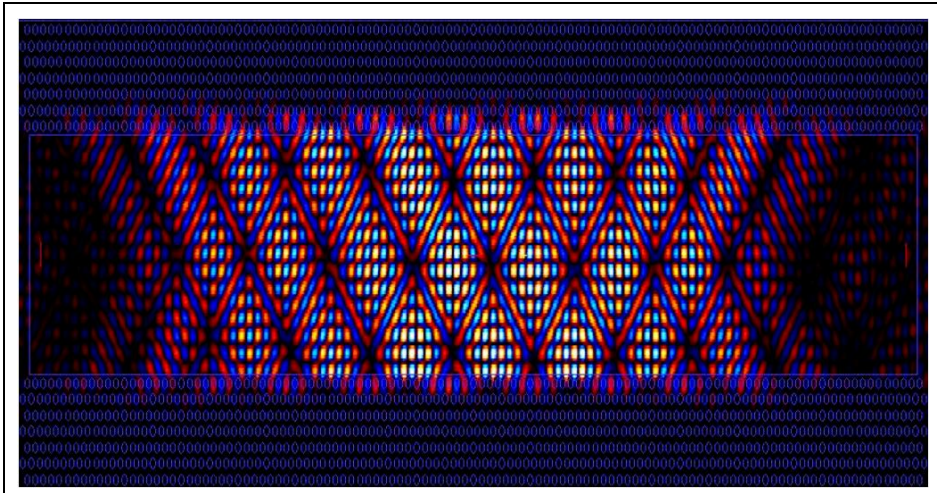Fig. 3 (above) a) Far field obtained for a single defect cavity. b) Far field for 7 coupled nanocavities.

Fig. 4 (above) Littrow lasing simulated in a W15 line defect constructed in an InGaAsP QW material and electrically pumped. The simulation includes a dynamic carrier model.
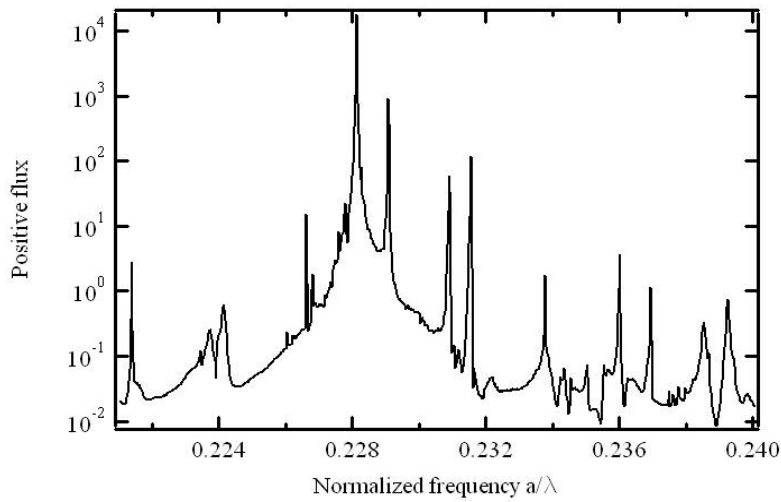

Fig. 5 (above) spectrum of the power flux inside the w15 cavity shown in Fig3. A clear strong dominant laser mode can be seen at least 12dB above the next strongest mode.