Validation Report

Name of Report	Simulation of a photonic crystal lens and demonstration of negative refraction with CrystalWave
Performance Date	09 November 2007
Performed By	Klearchos Chaloulos
Product Name	CrystalWave
Product Version & Compile Date	Version 4.2
References	[1] Photonic Crystal Lens: From Negative Refraction and Negative Index to Negative Permittivity and Permeability, PRL 97, 073905 (2006)
External Files	PhotonicCrystalLens.prj

Simulation of a photonic crystal lens and demonstration of negative refraction with CrystalWave

Outline

We will demonstrate the capability of CrystalWave to model negative refraction by using a photonic crystal. We will also show that this photonic crystal, as modeled by CrystalWave, can achieve focusing, therefore in can act as a photonic crystal lens. All the simulations reproduce results from [1].

Structure

The structure can be seen on Fig 1. It is a 2D hexagonal photonic crystal. The lattice period is 0.68um and the radius of the atoms is 0.294um. The holes are drilled in a material of permittivity 12. Around the photonic crystal is air. The spatial profile of the excitation is Gaussian with a width of 5um; the temporal profile is a pulse with duration of 500fs. This structure was modeled using the FDTD algorithm. The boundaries are absorbing (PMLs).
The top and bottom boundaries of the crystal are chosen right in the middle of successive rows of holes. The thickness of the photonic crystal is

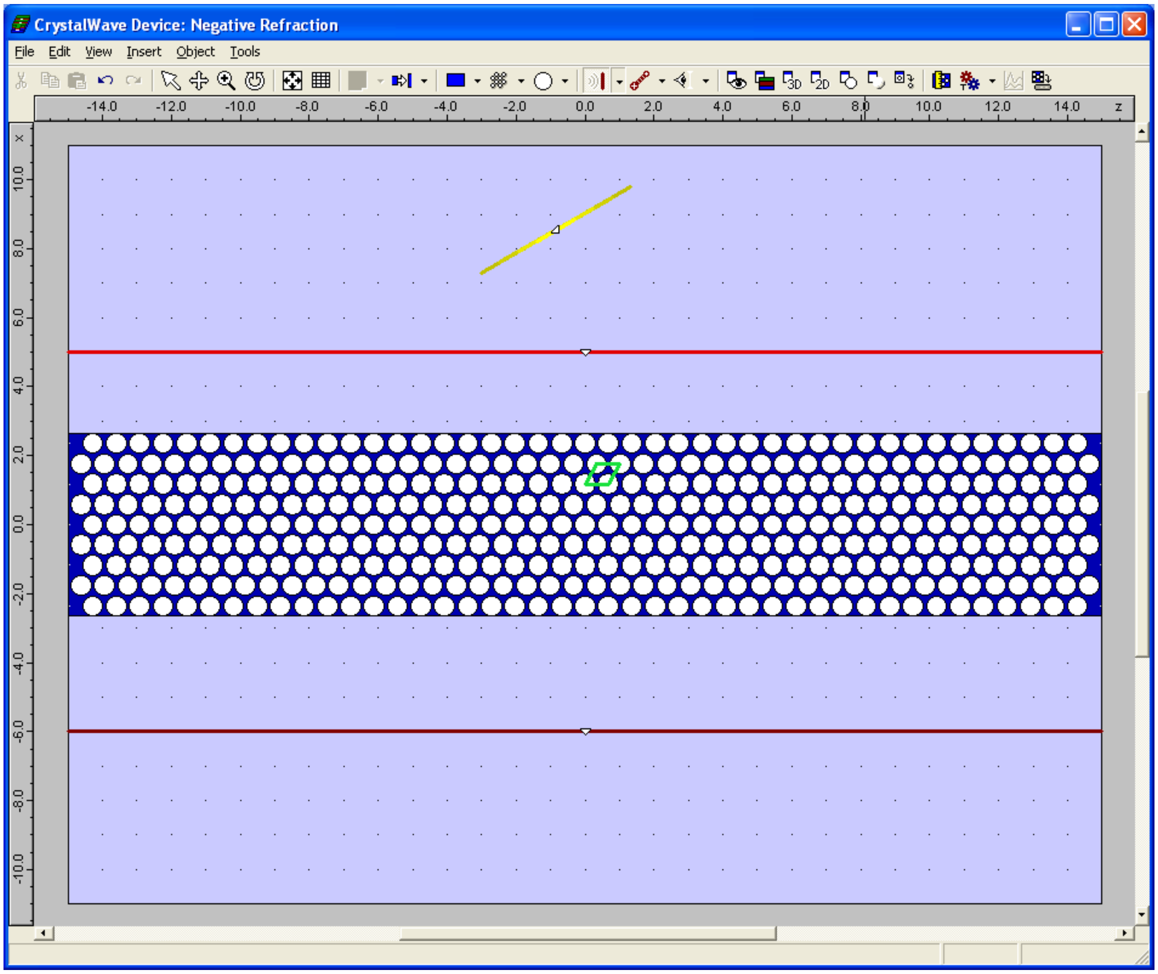

Figure 1: 2D photonic crystal that achieves negative refraction, showing negative permittivity and permeability. This structure was modelled with CrystalWave, using the FDTD algorithm. The yellow line is the Gaussian excitor and the red lines are the sensors.

Simulation

We simulate the above device with FDTD, using a grid of 0.68/10=0.068 um (10 points per lattice period). The duration of the simulation was 2500fs. In Fig 2 we can clearly see the negative refraction. The angle of incidence is 30deg.

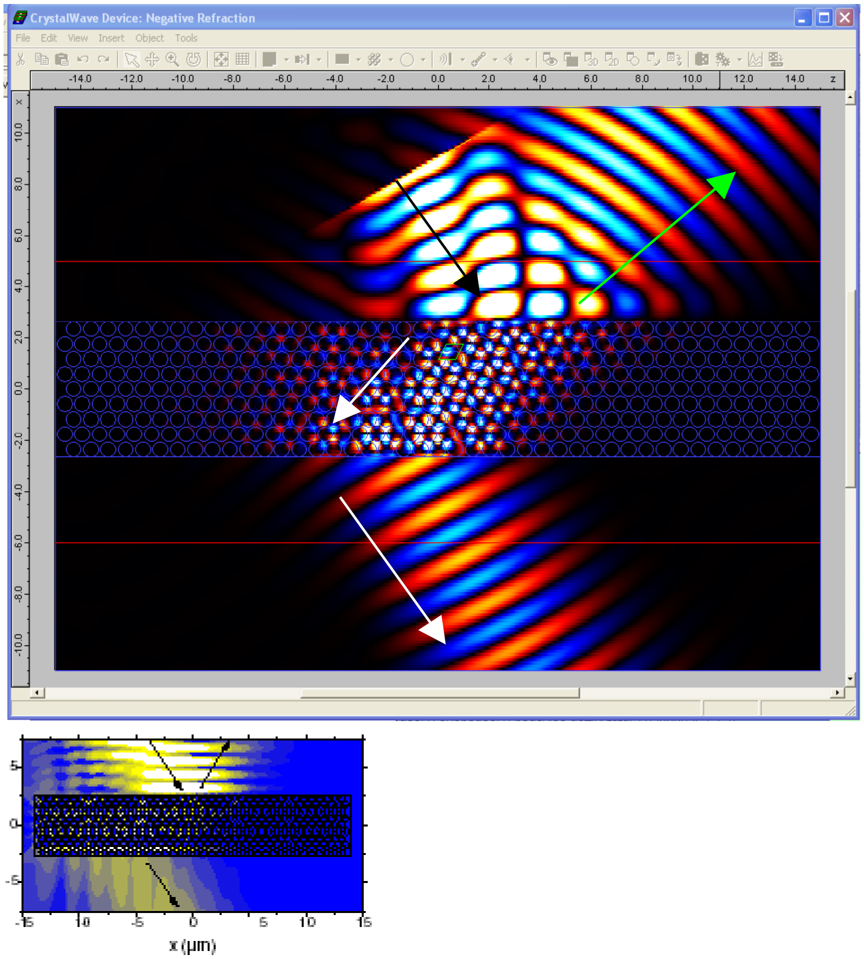

Figure 2: Plot of the Ey component of the field (parallel to the axis of the holes). We can clearly see the direction of the incident beam (black arrow), the reflected beam (green arrow) and the two negatively refracted beams (white arrows). The little plot is the corresponding picture from [1]. There is one difference between the two Figures. The top one (from CrystalWave) shows the instantaneous real value of Ey, while the bottom (from [1]) shows the modulus of the electric field. Apart from that, it is clear that the two figures show a very similar behaviour of the photonic crystal. Device Negative Refraction_PCInVacuum.

As we can see from Fig 1, the negative refraction is evident. The transmission through the crystal is rather low, as most of the power is reflected. In [1] the reflection is said to be 73%. From CrystalWave we get a transmission of 26.9%, which accounts for the same (Fig 3).

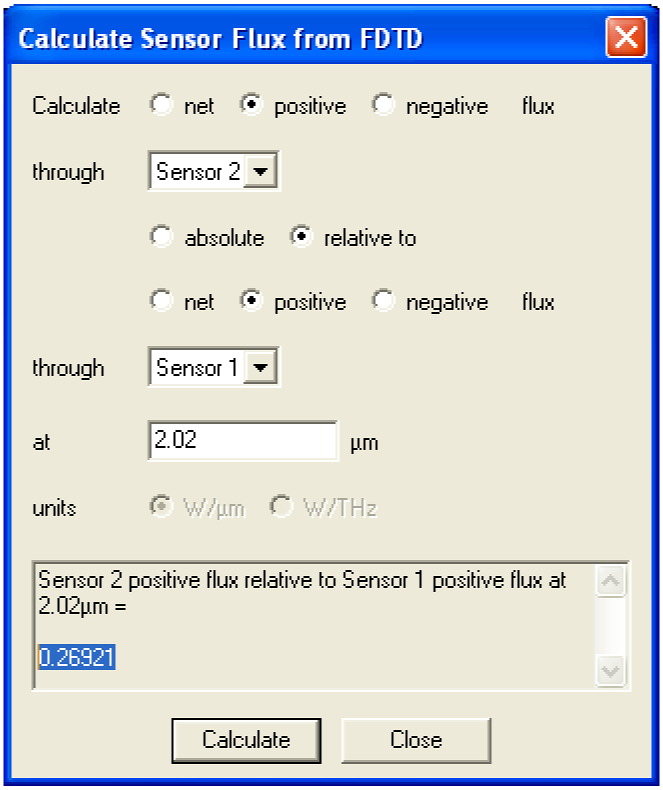

Figure 3: Transmission through the photonic crystal. 27% of the power is transmitted.

We then place the photonic crystal in a medium whose permittivity and permeability match those of the crystal. In fact, the permittivity and permeability of the medium have the opposite sign of those of the crystal. Therefore we should observe very low reflection (as there would be impedance matching), but negative refraction. This exactly what we observe in Fig. 4.

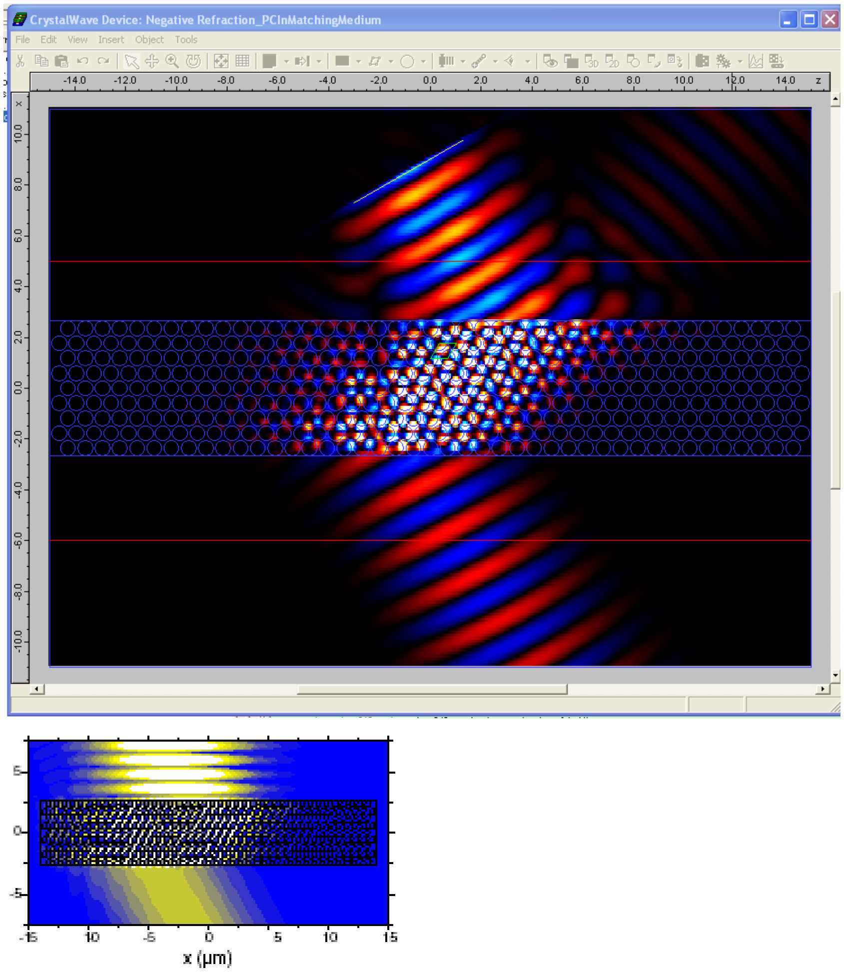

Figure 4: Top: Plot of Ey from CrystalWave. The photonic crystal is surrounded with a medium of epsilon=5.7 and mu=0.175. The fact that very little reflection is observed and that negative refraction occurs, shows that the effective epsilon and mu of the photonic crystal are –5.7 and –0.175 respectively. Bottom: The corresponding picture from [1]. Device Negative Refraction_PCInMatchingMedium.

<u>Photonic Crystal Lens</u>

Finally we will show that this layer of photonic crystal can achieve focusing, therefore can act as a lens. The device can be seen in Fig 5. The dipole source will be imaged by the photonic crystal.

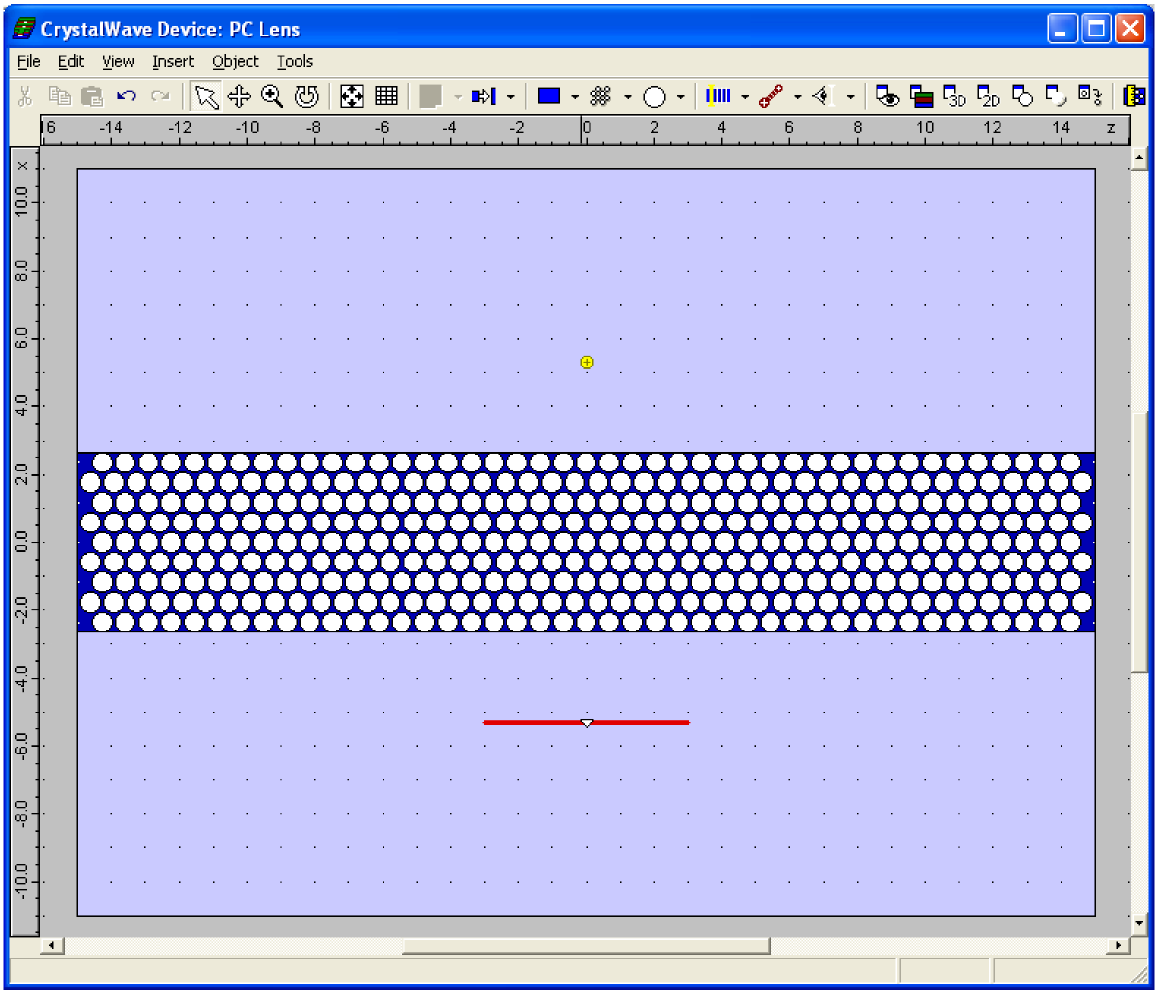

Figure 5: Structure of the photonic crystal lens. The dipole will be imaged by the photonic crystal. We will measure the size of the image with the sensor. The photonic crystal is surrounded by a medium with epsilon=5.7 and mu=0.175. Device PC Lens.

A screenshot from the simulation can be seen on Fig 6. We can clearly see the wavefront converging after the photonic crystal, towards a focus.

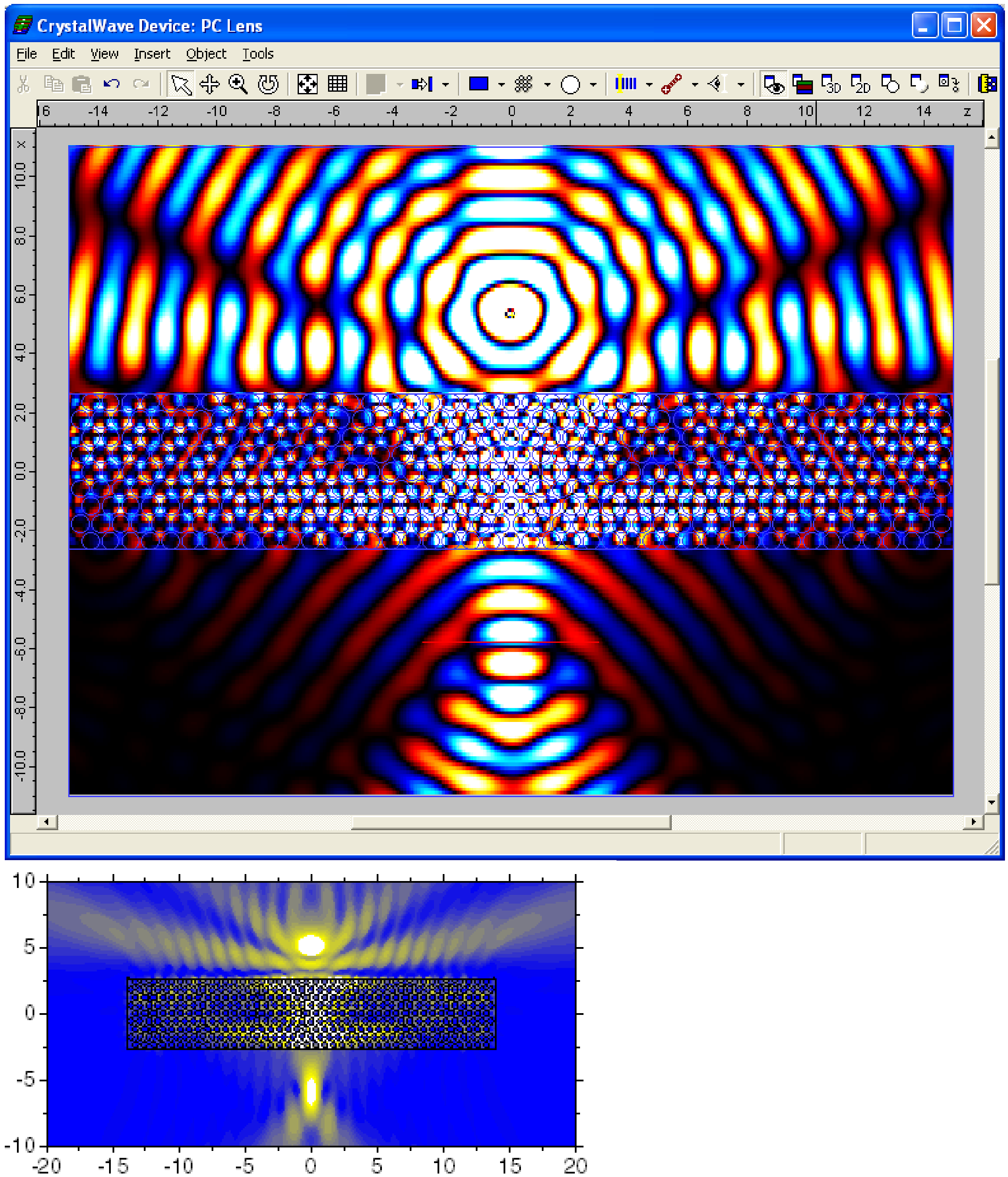

Figure 6: Top: Image of the photonic crystal imaging a source, therefore acting as a lens that works with negative refraction. Bottom: The corresponding picture from [1].

As a last test, we will measure the size of the image to see if we can achieve sub wavelength focusing. As we see on Fig.7, the FWHM of the image is FWHM (full width at half maximum) is ~0.65λ, very close to the value quoted in [1], 0.66λ.

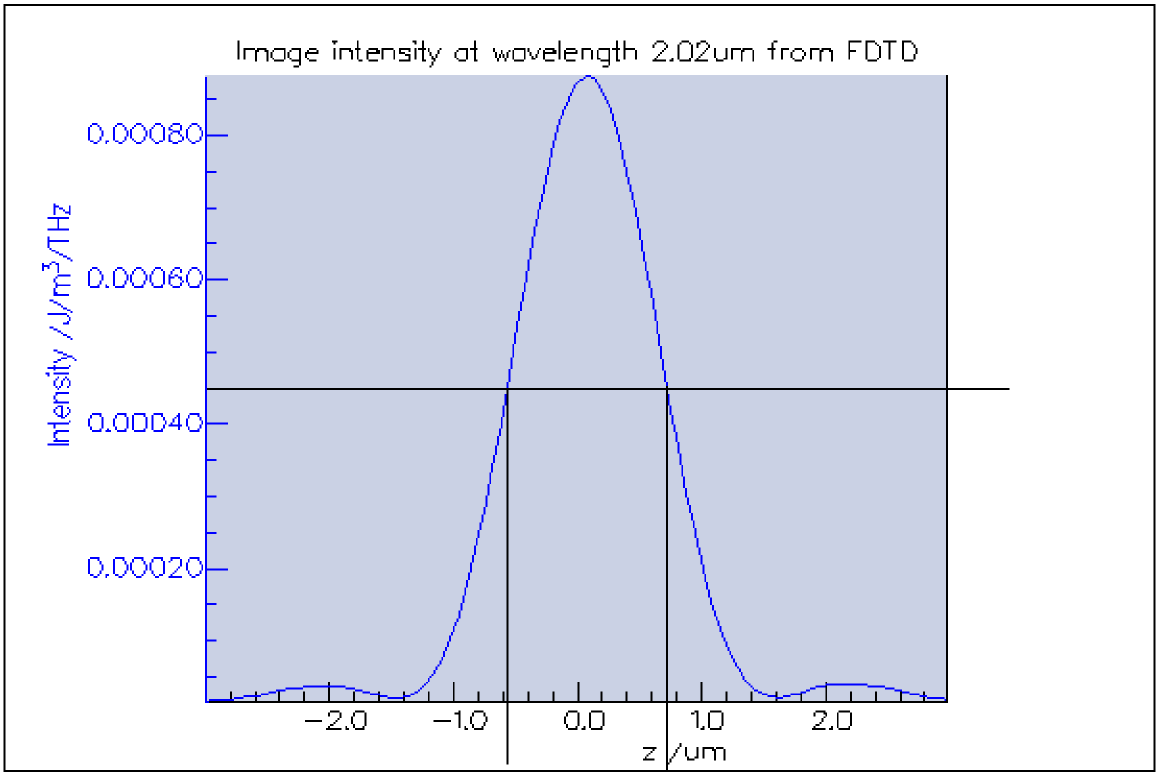

Figure 7: Intensity vs position on the image plane. We see that the FWHM is ~0.65λ, very close to the value quoted in [1], 0.66λ. A feature with size less that the wavelength is shown possible, and successfully modelled with CrystalWave.