# Contents



# A perfect absorber using an all-dielectric metasurface

Metasurfaces, which may modify the amplitude, phase, and polarisation of incident light, are the two-dimensional counterpart of bulk metamaterials. They are optically tiny scatterers (known as meta-atoms) arranged in periodic or aperiodic two-dimensional (2D) configurations that are typically seen on a thin substrate (around a few hundred micrometer).

In this article, OptiFDTD is used to model an all-dielectric metasurface composed of crystalline silicon ($c - Si$) meta-atoms on a silica ($SiO_2$) substrate to exhibit perfect absorption at a specified wavelength (0.46 $\mu$m) as reported in [1].

## Labels

Dielectric metasurface; Metasurface; Metamaterial; Periodic structure; Perfect absorber; Reflection; Transmission; Journal confirmation.

## Design

The 3D design of the metasurface is modelled by a unit cell consisting of one meta-atom. The meta-atom is an elliptic cylinder with major, minor axis and thickness equal to 0.190 $\mu$m, 0.176 $\mu$m and 0.108 $\mu$m, respectively. The periodicity of the metasurface is 0.280 $\mu$m along the x and y axes. Figure 1 shows the 3D editor image (left) and the schematic (right) of the unit cell with corresponding dimensions. Figure 2 shows the structure in the OptiFDTD layout view.

The wafer dimensions in the simulation region are chosen as length = 1 $\mu$m and width = 0.28 $\mu$m. The boundary conditions at z = 0. $\mu$m and z = 1.0 $\mu$m are chosen as absorbing perfectly matched layer (APML), while the boundary conditions in x and y directions are periodic boundary condition (PBC) positioned at x (y) = -0.140 $\mu$m and x (y) = 0.140 $\mu$m. The substrate is created using a linear waveguide set to a channel waveguide profile (WG_channel_example) from z = 0.5 to 1.0 $\mu$m. The elliptic cylinder is a linear waveguide set to a fiber profile (WG_fiber_example) with Rx = 0.095 $\mu$m and Ry = 0.088 $\mu$m.

The optical source was configured using the input plane (positioned at z = 0.3 $\mu$m) with a rectangular distribution, see table 1 for further details.

Table 1: Details of the optical source employed in the simulation

| Optical source features | Value |
|---|---|
| Wavelength ( $\mu$m ) | 0.60 |
| Half Width ( $\mu$m ) | 0.28 |
| Polarization | X |
| Time domain shape | Sine-Modulated Gaussian Pulse |

The absorption (A) is calculated through observation areas recording the reflection ($R$) and transmission ($T$) and

$$A = 1 - R - T. \tag{1}$$

The observation areas (XY) used were located at z = 0.2 $\mu$m and z = 0.8 $\mu$m for reflection and transmission respectively.

The c-Si is represented as a dispersive material based on the experimental data taken from [2-3] shown in Figure 3. The material fit is achieved using a Lorentz-Drude material with 3 resonances shown in table 2.

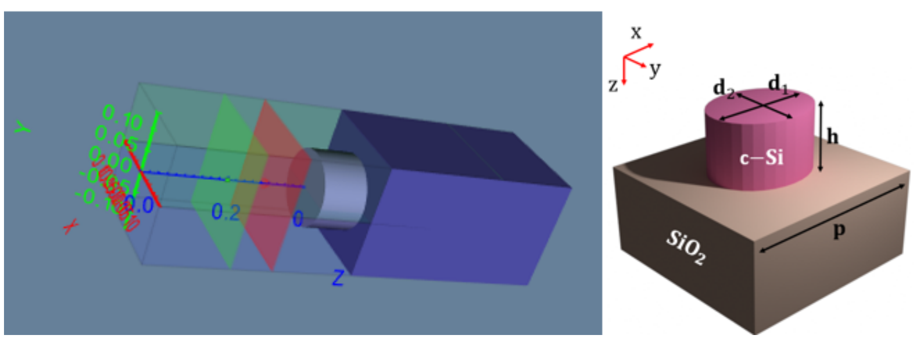


Figure 1: The 3D editor image of the unit cell in OptiFDTD (left). The schematic of the unit cell with corresponding dimensions (right). $d_1$ = 0.190 $\mu$m, $d_2$ = 0.176 $\mu$m, $h$ = 0.108 $\mu$m and $p$ = 0.280 $\mu$m.

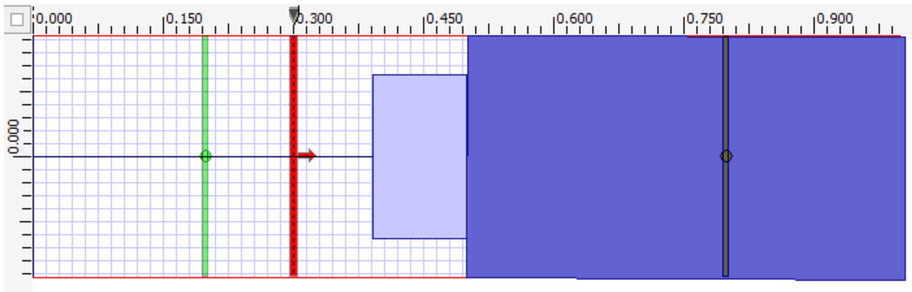


Figure 2: The layout for the simulation of the metasurface with the input plane (red line) and two XY observation areas for calculating reflection and transmission.

Table 2: Lorentz-Drude fit data for c-Si

| Strength | Plasma Frequency ( rad/s ) | Resonant Frequency ( rad/s ) | Damping ( rad/s ) |
|---|---|---|---|
| 7.140530 | 7.057110e+15 | 7.057110e+15 | 2.643950e+12 |
| 3.702920 | 5.280530e+15 | 5.280530e+15 | 3.106500e+14 |
| 1.000000 | 4.557600e+14 | 0.000000e+00 | 1.102740e+11 |

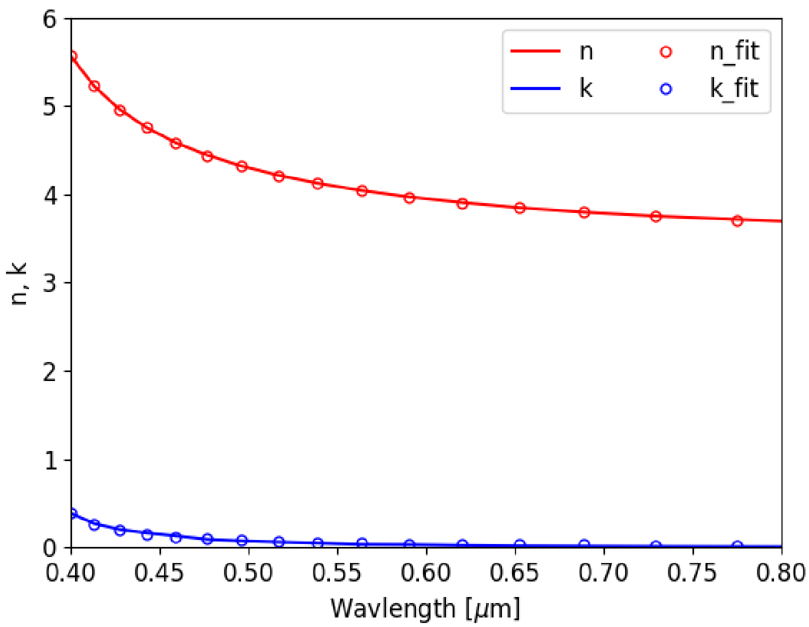


Figure 3: The n and k terms the refractive index for both the experimental data taken from [2-3] as well as the fit shown as the hollow circles.

After convergence testing, the spatial mesh parameters ($\Delta$x, $\Delta$y and $\Delta$z) were chosen as 1.5 nm. Testing also confirmed that 35e3 time-steps are required for accurate results.

## Results

The normalized reflection and transmission spectra obtained from the simulation of the metasurface are shown in Fig. 4. At 0.467 $\mu$m, it can be observed that both the transmission and reflection vanish and perfect absorption (A = 1) is achieved. Physically, it is originated by the interference of induced electric and magnetic quadrupoles inside the mata-atoms around $\lambda = 0.46\ \mu$m [1].

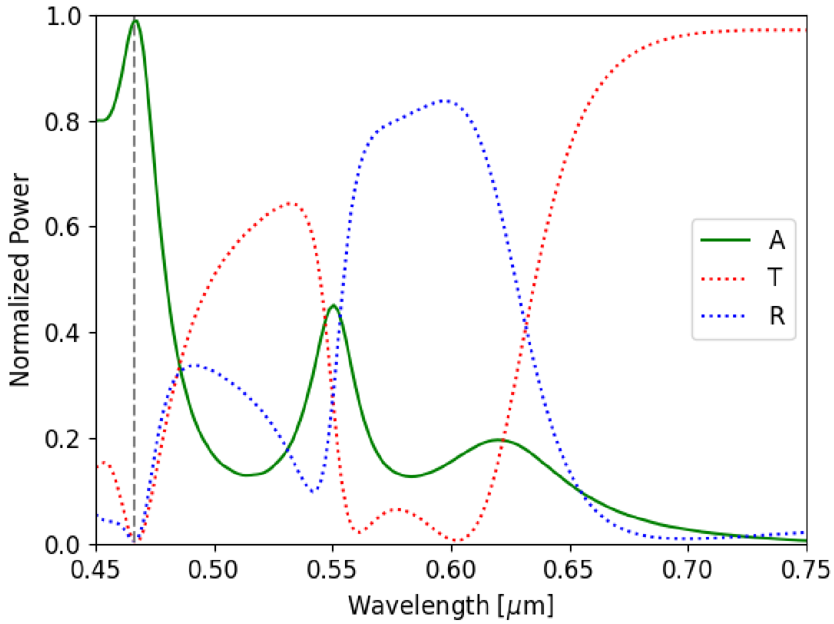


Figure 4: The absorption, reflection, and transmission spectra for the metasurface illuminated by an x-polarized plane wave. The grey dashed line corresponds to 0.467 $\mu$m, the wavelength at which perfect absorption occurs.

## References

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