

Dielectric THz Metalens Design

Using RSoft DiffractMOD RCWA and MetaOptic Designer

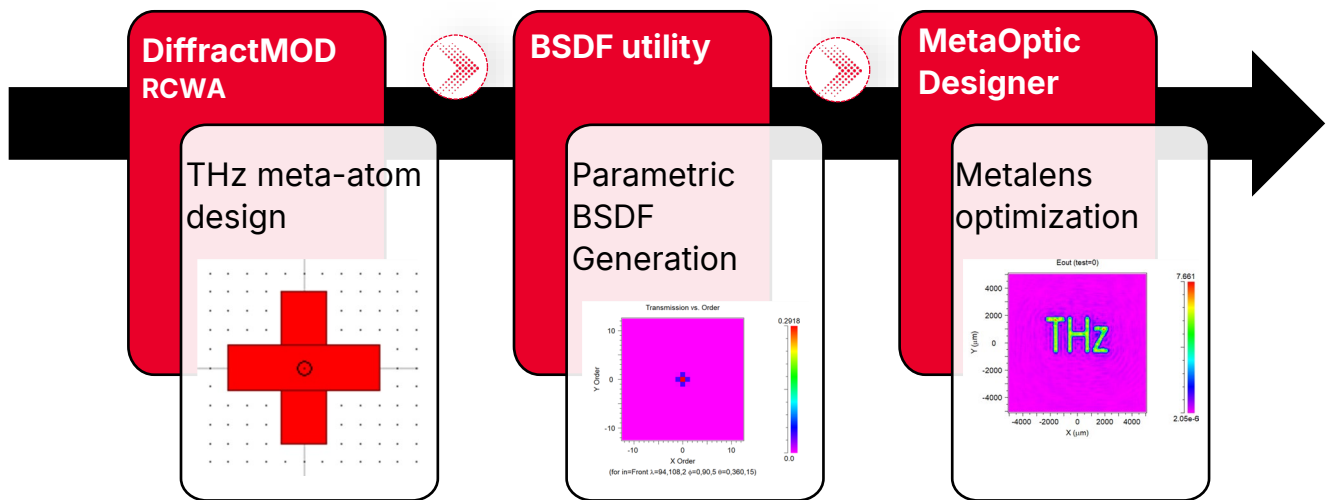
Introduction

Terahertz (THz) waves fall between microwaves and far infrared (100 GHz-10 THz). These waves present some unique characteristics which makes them useful in many applications such as astronomy, telecommunication, imaging, and sensing.

The manipulation of the THz waves requires the development of low loss and compact lens. For this purpose, metalenses could be a good candidate.

This example presents the steps toward designing a dielectric THz metalens. The design is reproduced from the work presented by Jia et al. [1].

Flow Description



Step 1: THz Meta-Atom Design using RSoft DiffractMOD RCWA

As a first step we need to build the meta-atom in RSoft CAD and calculate its transmission coefficient. The meta-atom has a cross shape and a constant refractive index $n=3.4$, that represents the Silicon refractive index at 3.11 THz ($\lambda = 96.46 \mu\text{m}$). The cross arms width (W) and height (H) are respectively set to 12 and 20 μm , while the length (L) is set to 48 μm . The pitch (P) size is set to 80 μm . The figure 1 below shows the geometry and refractive index profile of the Si THz metaatom.

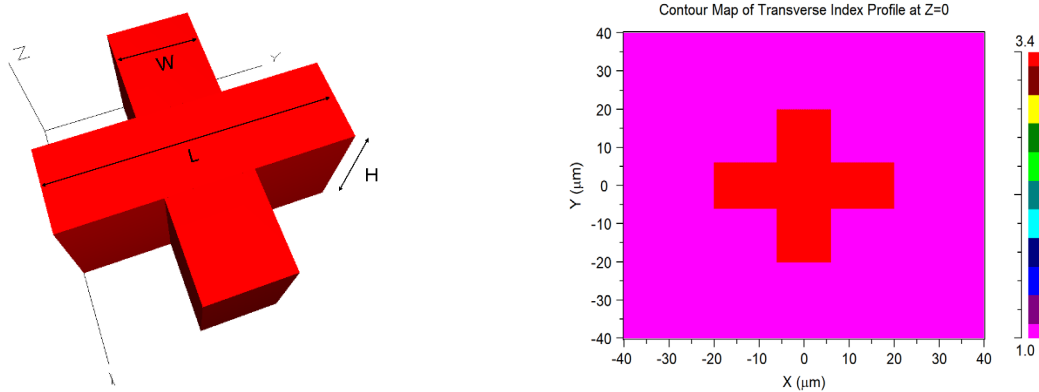


Figure 1. Metaatom geometry on the left and index profile on the right

The polarization angle is set to 0 for an electric field along X axis. A convergence test is done using MOST to determine the optimal number of harmonics to be used. The number of harmonics is then set to 9 in X and Y. Figure 2 below shows the calculated transmission coefficient for a frequency range between 2.7 (~110 μm) and 3.5 (~85 μm) THz.

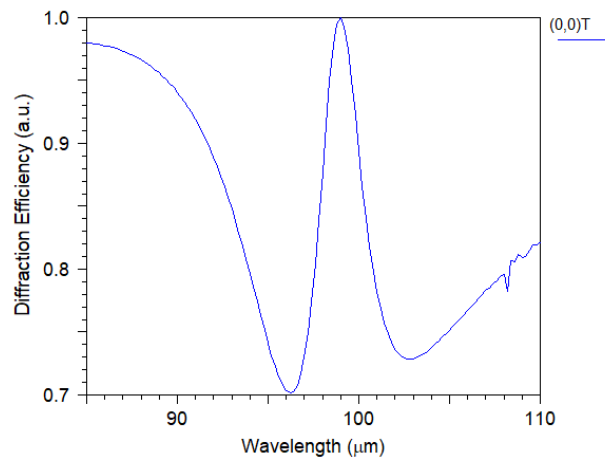


Figure 1. Transmission diffraction coefficient magnitude as function of the wavelength

The designed metaatom presents a relatively high transmission at a broad spectral range. In the next step the BSDF utility will be used to generate the necessary THz metaatom library.

Step 2: BSDF Calculation using the BSDF Utility

As mentioned previously in step 1, the different geometrical parameters of the metaatom were fixed to some constant values. To achieve a full phase control, a variation of the length (L) of the metaatom cross arms is required. In this step the BSDF utility is used to generate a parametric BSDF with a variation of the length L between 15 and 65 μm and a step of 1 μm . The calculations are done for a frequency range between 2.6 ($\sim 115 \mu\text{m}$) and 3.6 ($\sim 83 \mu\text{m}$) THz. A normal incidence is used in this example. A more complete BSDF can be generated by adding angular variation (theta and phi), and or additional variable parameters.

After multiple RCWA calculations, the utility provides a full BSDF with the amplitude and phase response at different polarization and propagation direction. The generated library will be used as a database input for the MetaOptic Designer in step 3.

Step 3: Metalens Design using MetaOptic Designer

In this step, we start by building the optical system which consist of a metalens with a focal length $f = 30 \text{ mm}$ and a diameter of 10 mm. The previously generated BSDF will be used as a database input.

As a first test case, we use a planewave input at a $\lambda = 96.5 \mu\text{m}$ ($\sim 3.11 \text{ THz}$) and we chose an airy spot target. The metric tolerance is set to $1\text{e-}05$ for a 1000 maximum iteration.

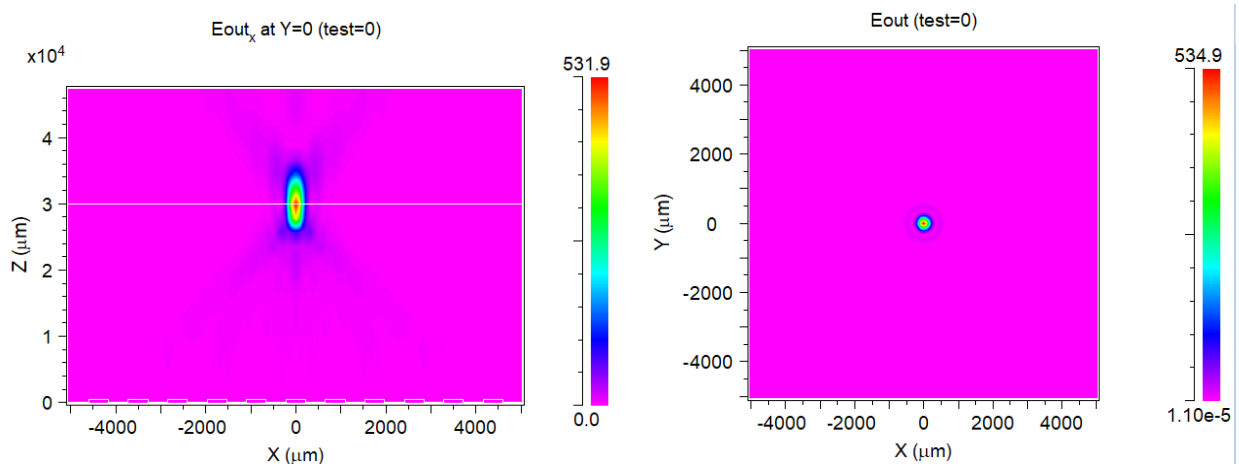


Figure 2. On the left the XZ view showing the focused beam at 30 mm. On the right the magnitude of the output beam

Figure 3 shows the output result of the designed metalens focusing the spot at a 30 mm focal distance with an absolute focusing efficiency of 76 % and an intensity match of 94%. A GDS and ind files for the metalens design are also generated by MetaOptic Designer. The GDS file can be used for fabrication while the ind file can be used to run FDTD simulation using RSoft FullWAVE tool. However, this large design might require high computational power and long simulation time with FDTD.

A second test case is done by using the same conditions and replacing the airy spot target by the THz logo. Below the output THz logo image projected by the designed metalens is shown.

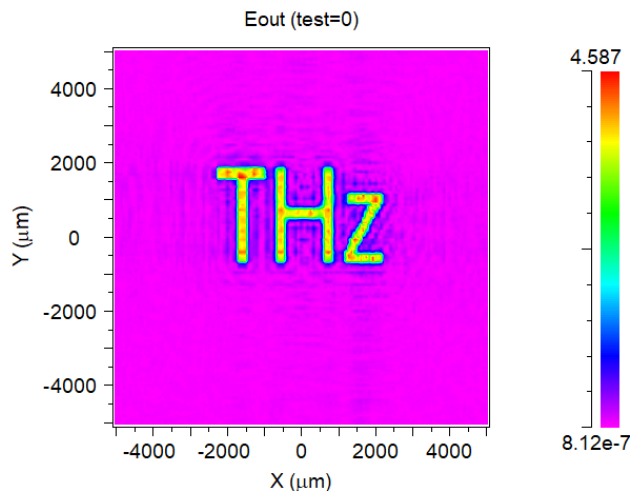


Figure 3. THz logo image created by the designed metalens

Conclusion

In this application note we presented the workflow toward designing and optimizing a THz metalens using High Resistivity Silicon wafer.

References

- [1] Delin Jia, Yuan Tian, Wei Ma, Xiaofeng Gong, Jiayi Yu, Guozhong Zhao, and Xiaomei Yu, "Transmissive terahertz metalens with full phase control based on a dielectric metasurface," Opt. Lett. 42, 4494-4497 (2017)
- [2] Chenglin Xu, Evan Heller, Jan Bos, Robert Scarmozzino, Mayank Bahl, Li-Ce Hu, Nicholas Achuthan, "Fully automated inverse design solution for metalenses/metasurfaces," Proc. SPIE 12428, Photonic Instrumentation Engineering X, 1242802 (8 March 2023); <https://doi.org/10.1117/12.2657443>

Design files

Supporting Files for RSoft Application Note: "Dielectric THz metalens design"

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