FDTD Signal Processing Comparison

Torbjørn Bogen-Storø

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1 Introduction

This is a comparison of different approaches to convert from a time signal in FDTD, to an optical spectrum. The methods tested are:

- Mean Square: energy in a wave is directly proportional to the amplitude of teh E-field squared, the mean square is calculated both for a free space case, and a case with a material, with the detectors placed in the same position for both cases. The spectrum is found by taking the ratio between the means squared value with and without a material.
- Summed FFT: All time series signals for each case are summed, and the fast Fourier transform is taken, before these are divided by each other to get a spectrum
- Sum of individual FFT's. For each frequency in the simulation, the FFT is taken, and the ratio between the material case and the free space case is found, and multiplied by an exponential. These are in the end summed to obtain the spectrum.

$$T(\omega) = \frac{F(E_{material}(x_1, t))}{F(E_{free_space}(x_1, t))} \cdot e^{\gamma_2 - \gamma_1} \tag{1}$$

Here, γ is the propagation constant for the material in regard.

Three different signal types were also used. A continuous wave, a Hanning pulse and a Ricker wavelet. In this comparison, a signal from a 1 μm thick layer of TiO_2 is used, run for 50 different frequencies between 500 nm and 10 μm and run for 500 time steps in FDTD.

2 Experimental Ground Truth

To verify the spectrum's, they are compared to experimental results from a 380 nm thick TiO_2 layer, performed by Wojcieszak et. al. [1]. This spectrum is only the transmission spectrum, and ranges from wavelengths of 300 nm to 900 nm.

3 TRCWA results

When running the same case with TRCWA, this was the produced spectrum:

4 Results

5 Discussion

There seems to be no difference between a Hanning pulse and a continuous wave. The FFT approaches all cut of at 3 micrometers, which may be due to some wrong use of sampling frequencies etc. The Mean square approach seems to be the best match, as it is also easily transferable to the plot_spectrum function, as FFT has a frequency point for each time step, not for each frequency in the simulation. Personally, I also doubt the validness of the FFT approaches, from a physics perspective.

6 Gallium Arsenide: TRCWA vs FDTD RMS

7 Two layers: TRCWA vs FDTD

References

[1] Wojcieszak, D., Kaczmarek, D. and Domaradzki, J.. ”Analysis of surface properties of semiconducting (Ti,Pd,Eu)Ox thin films” Opto-Electronics Review, vol. 24, no. 1, 2016, pp. 15-19. https://doi.org/10.1515/oere-2016-0003

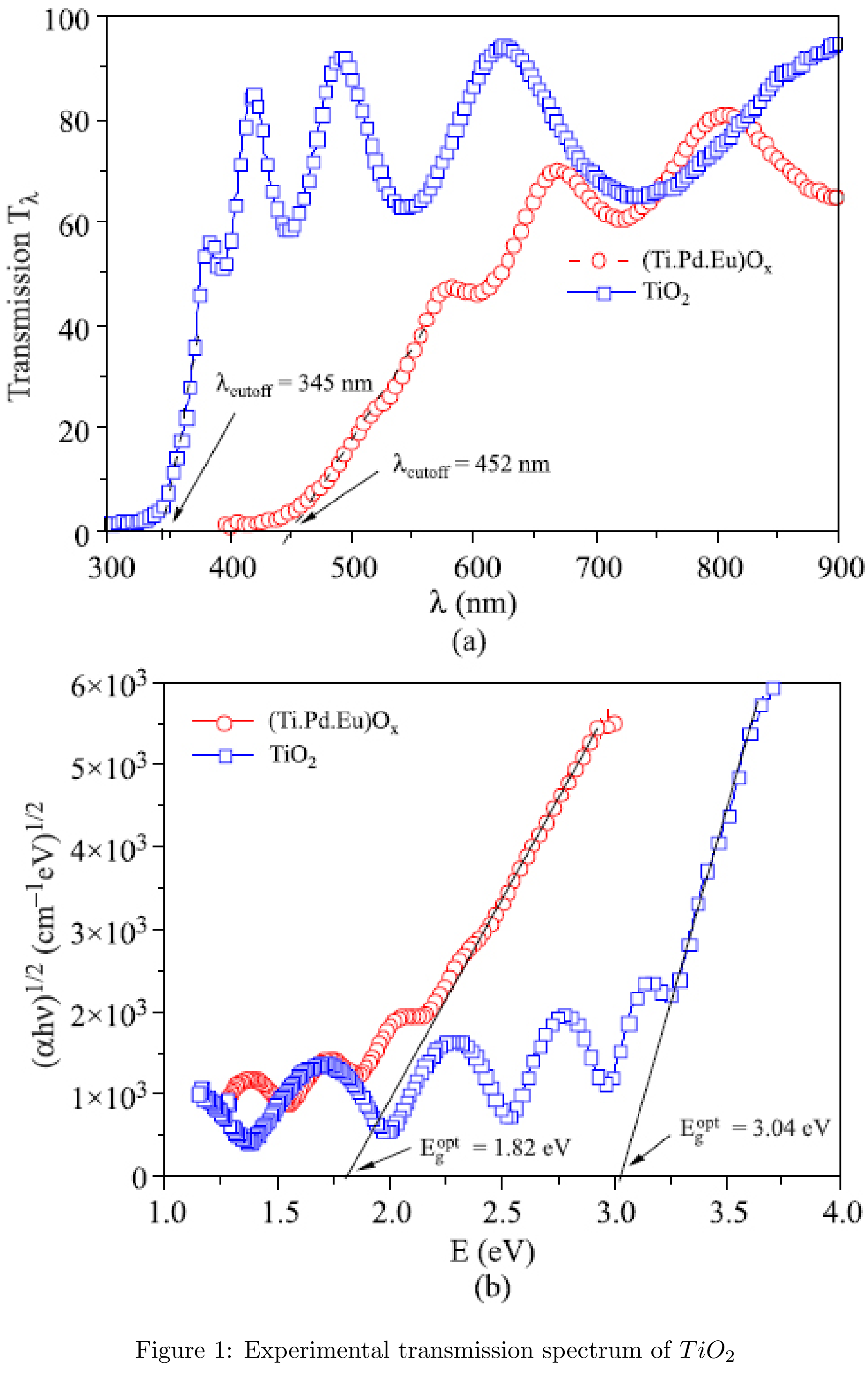

Figure 1: Experimental transmission spectrum of TiO_2

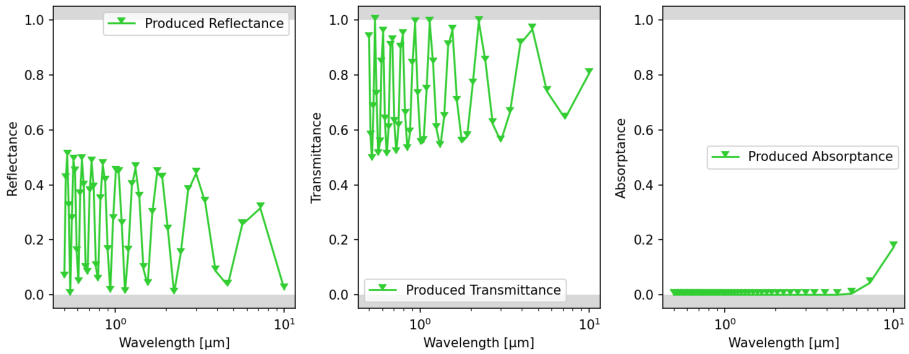

Figure 2: TRCWA spectrum

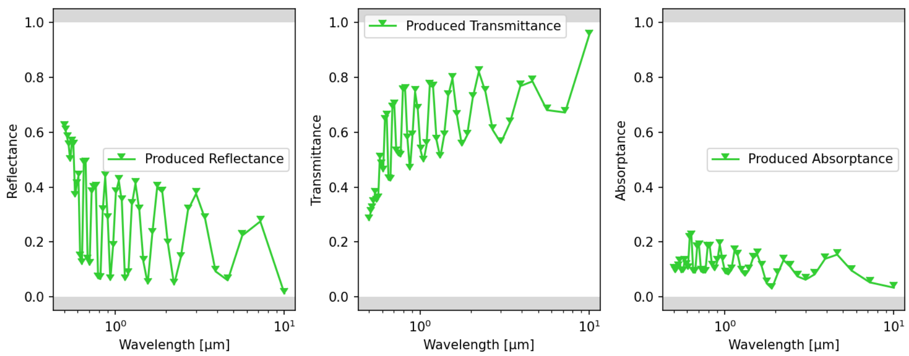

Figure 3: RMS, continuous wave

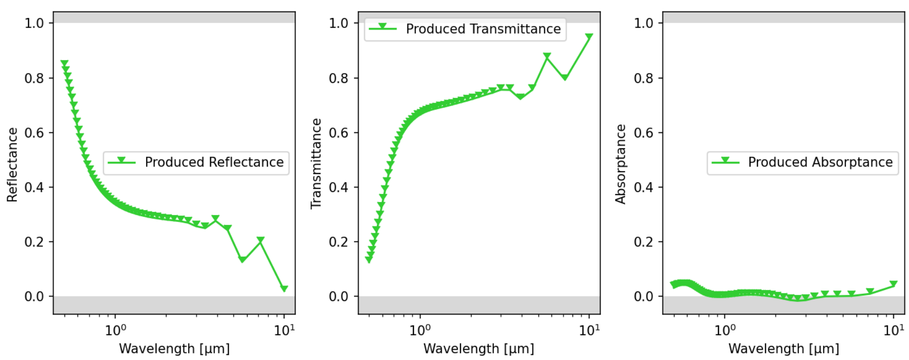

Figure 4: RMS, hanning pulse

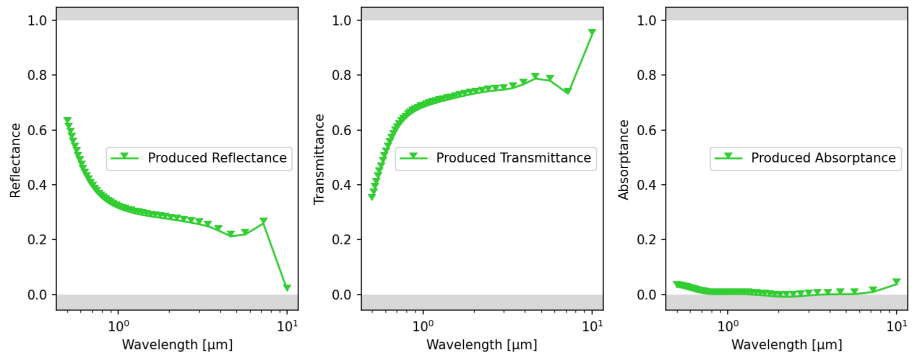

Figure 5: RMS, Ricker wavelet

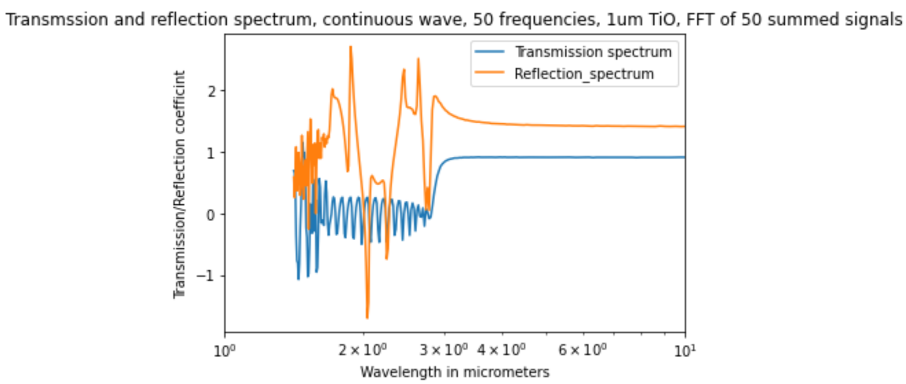

Figure 6: Summed FFT, continuous wave

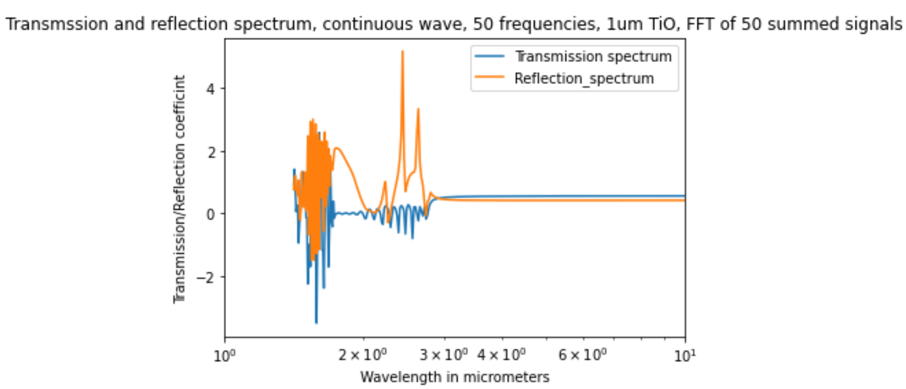

Figure 7: Summed FFT, hanning pulse

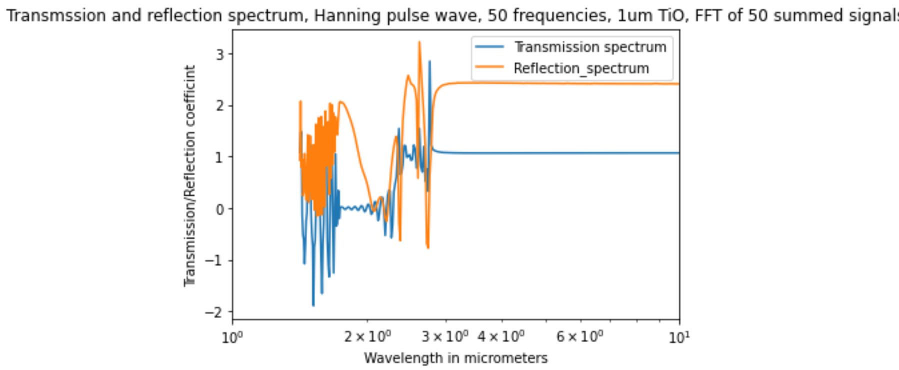

Figure 8: Summed FFT, Ricker wavelet

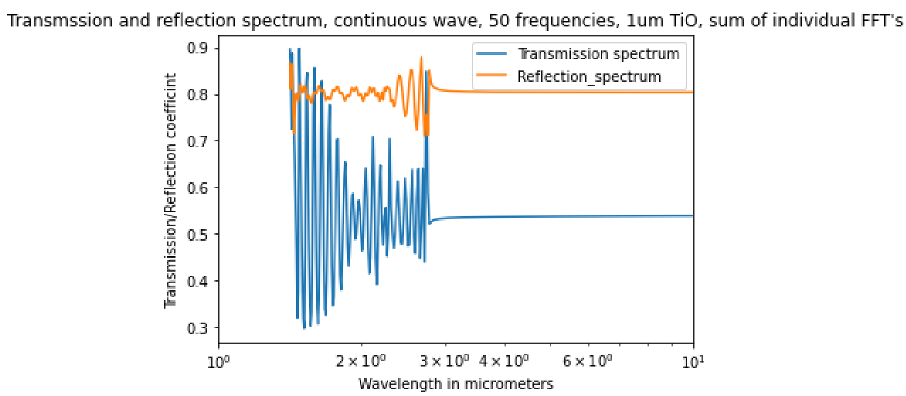

Figure 9: Sum of individual FFT's, continuous wave

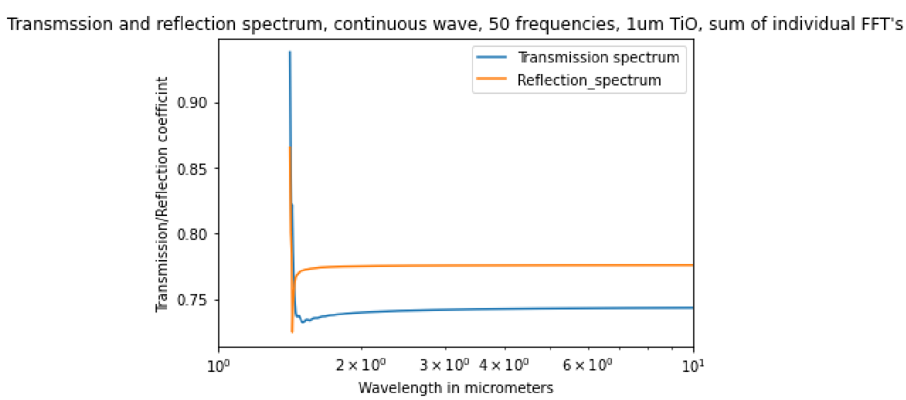

Figure 10: Sum of individual FFT's, Hanning pulse

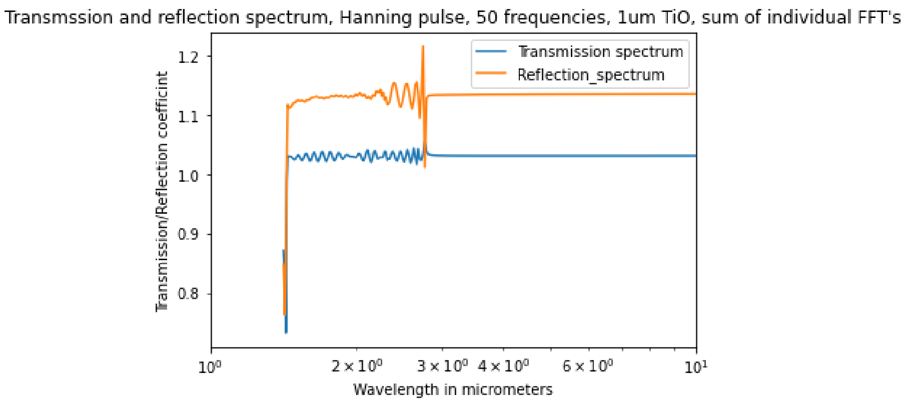

Figure 11: Sum of individual FFT's, Ricker wavelet

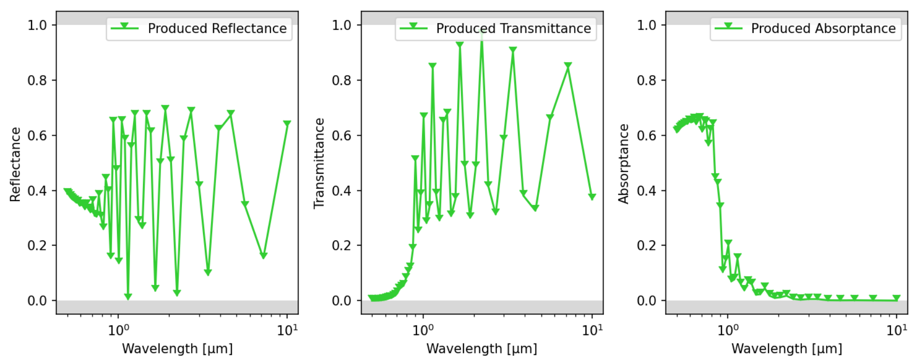

Figure 12: GaAs $1 \mu m$ TRCWA

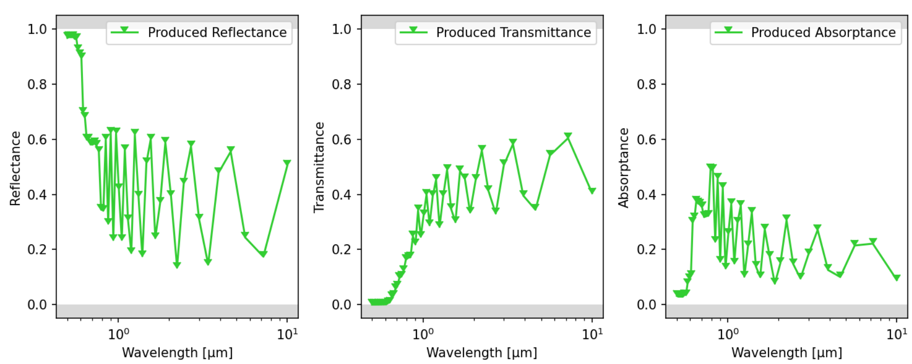

Figure 13: GaAs $1 \mu m$ FDTD RMS of continuous wave

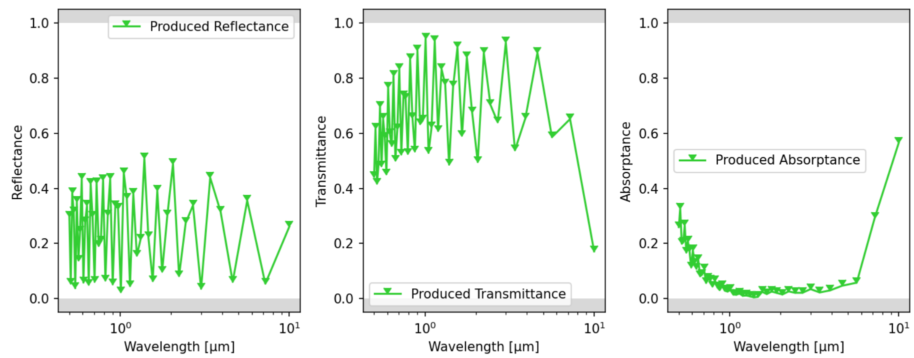

Figure 14: SiN/Ta205 $1\mu m$ / $1\mu m$TRCWA

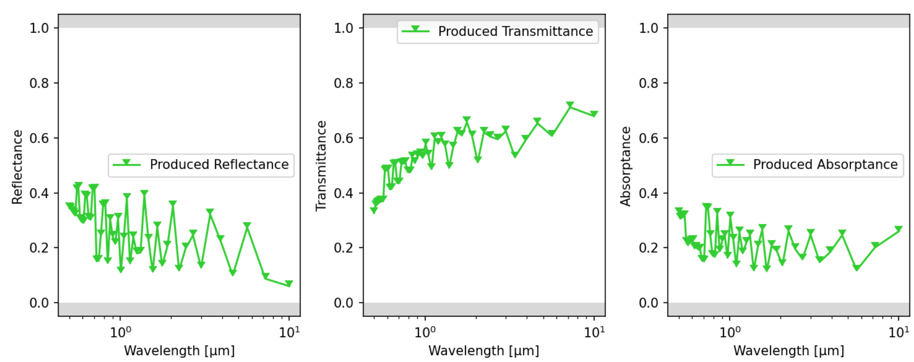

Figure 15: SiN/Ta205 $1\mu m$ / $1\mu m$ FDTD RMS of continuous wave