Designing and Simulating THz Waveguide Devices using Finite Element Techniques

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Introduction: Terahertz frequency (10^{12} Hz) radiation has uses in bio-sensing, non-invasive package inspection, and for the next generation of electronic circuits. However, compact and portable methods to generate THz radiation are needed. Guided wave THz generators can address this need.

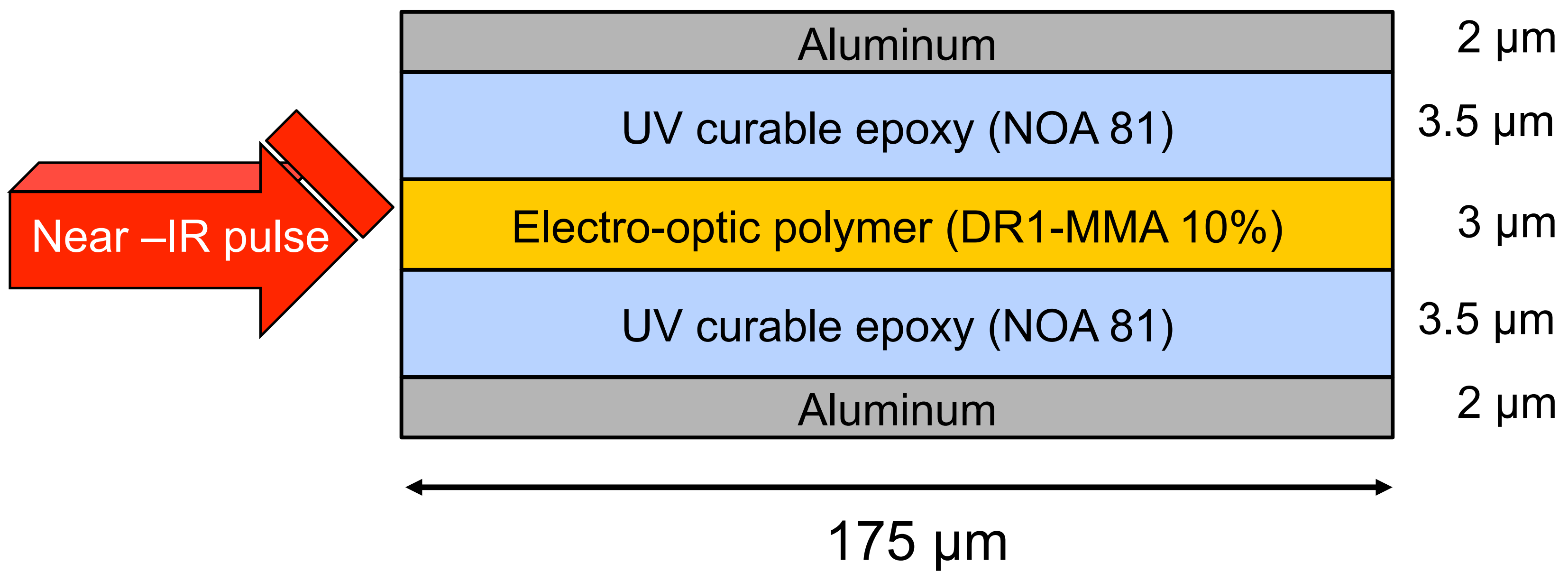

Figure 1. THz planar waveguide

Computational Methods: Optical wave propagation and nonlinear interactions in the device are modeled using the time-dependent transient solvers in the RF module, as governed by:

$$\nabla \times \frac{1}{\mu_r}\left(\nabla \times \mathbf{A}\right) + \mu_0 \sigma \frac{\partial \mathbf{A}}{\partial t} + \mu_0 \frac{\partial}{\partial t}\left(\varepsilon_0 \varepsilon_r \frac{\partial \mathbf{A}}{\partial t} - \mathbf{D}_r\right) = 0$$

where $\mathbf{D}_r = d_{33} E_y^2 \hat{y}$ accounts for the nonlinearity.

The input electric field is modeled as a Gaussian:

$$\mathbf{E}_{in}(y,t) = E_0 e^{-(y/w_0)^2} \cos(\omega_o t) e^{-t^2/(2\tau_0^2)} \hat{\mathbf{y}}$$

E_0 = peak amplitude = 30 kV/m
w_0 = minimum pulse radius = 1.5 µm
ω_0 = central frequency = 3.6×10^{15} s^{-1} (820 nm)
τ_0 = pulse duration = 10 fs
d_{33} = nonlinear coefficient = 1 x 10^{-17} F/V

Material	Relative Permittivity $\varepsilon_r = n^2$	Relative Permeability μ_r	Electrical Conductivity σ(S/m)
DR1-MMA 10%	$(1.56673)^2$	1	0
NOA 81	$(1.55700)^2$	1	0
Aluminum	$(2.77198)^2$	1	3.774×10^7

Table 1. Model parameters

Results: THz radiation is produced by optical rectification (OR) and collected at the right-hand output boundary of the waveguide.

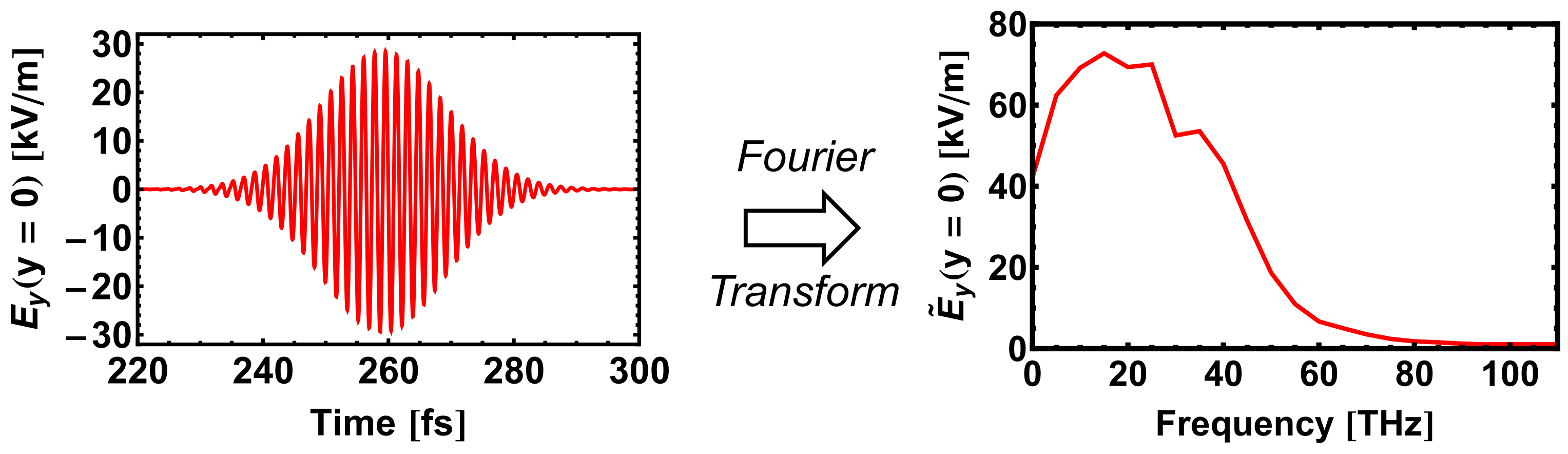

Figure 2. Time domain electric field at waveguide output (left) and its spectral amplitude (right).

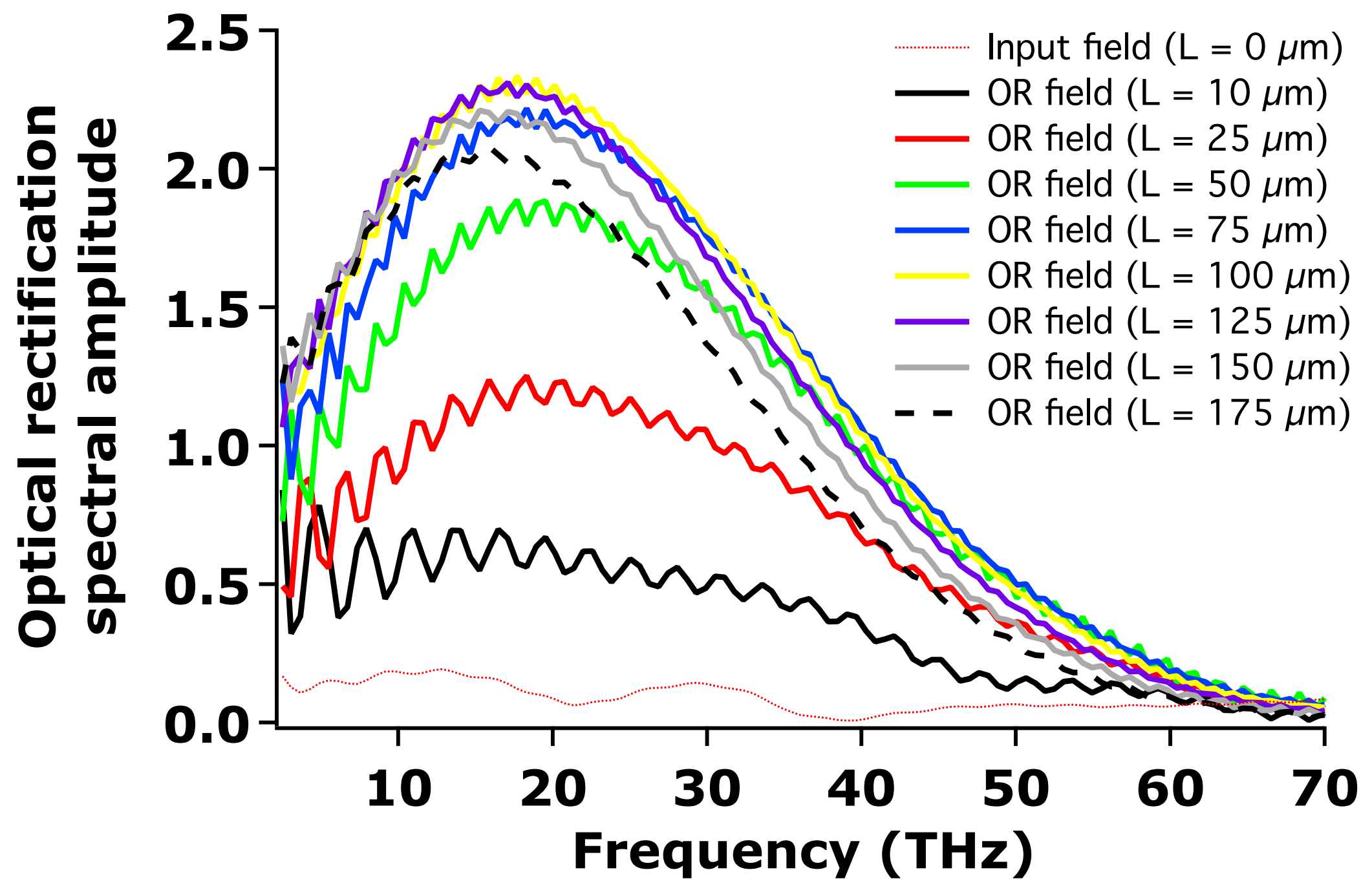

Figure 3. THz spectral amplitude for various propagation lengths.

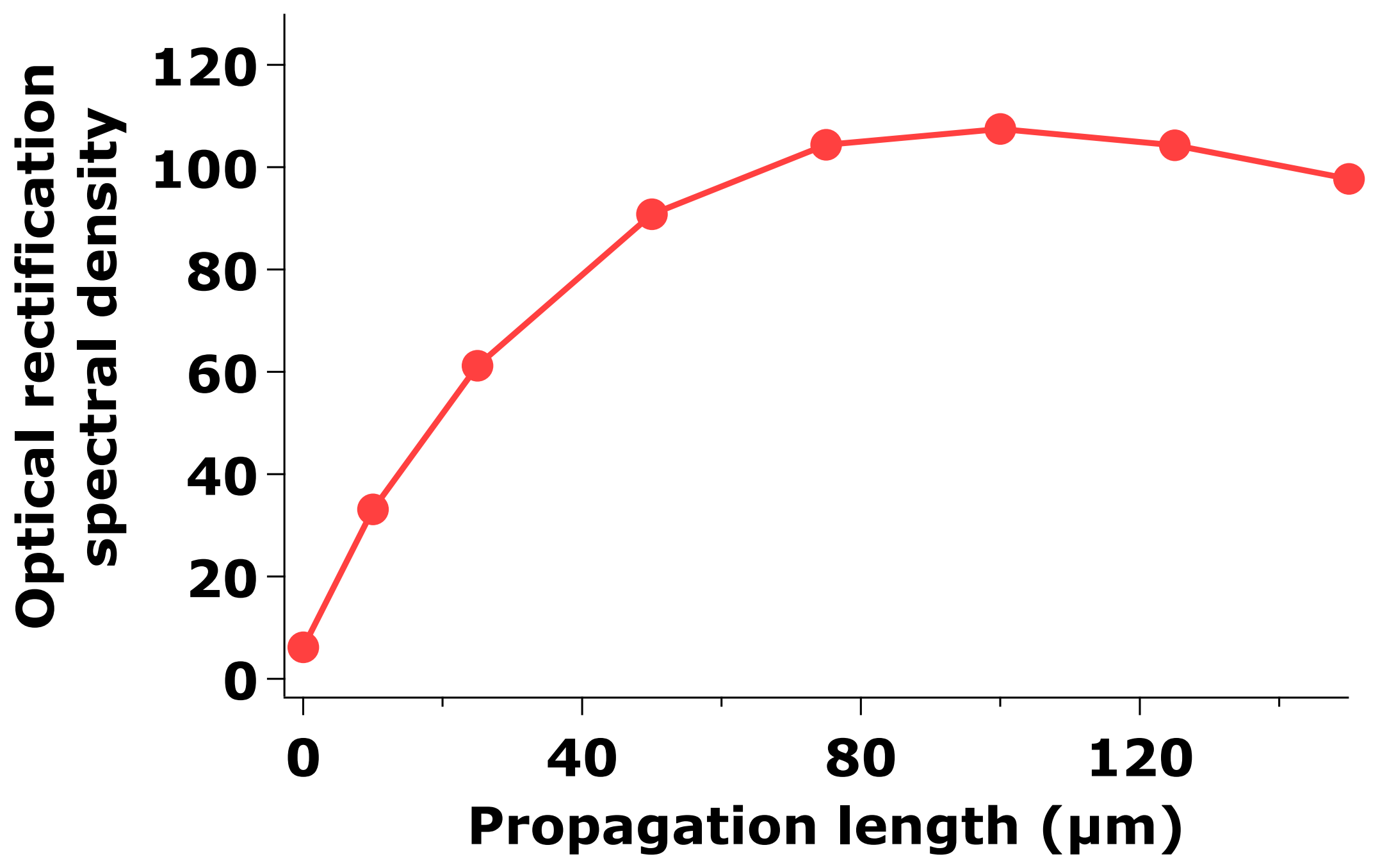

Figure 4. Total THz power created along the waveguide. At longer propagation lengths, THz absorption overcomes the generation.

Conclusions

- THz generation in a waveguide can be simulated in the time-domain, matching results predicted by the full coupled wave theory [1].
- Improvements need to be made in handling THz loss via complex indices of refraction, instead of electrical conductivity.

References

1. F. Vallejo and L. M. Hayden, "Design of ultra-broadband terahertz polymer waveguide emitters for telecom wavelengths using coupled mode theory," *Opt. Express* **21**, 5842-5858 (2013).

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