Designing and Simulating THz Guided Wave Devices Using Finite Element Techniques

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Abstract

Introduction: The generation of terahertz (THz) frequency radiation (0.1-10 THz) is becoming an important technological goal due to the use of this non-ionizing radiation to penetrate a wide range of non-conducting materials giving rise to applications ranging from biological imaging to detect tumors [1], to non-destructive identification of illicit drugs hidden in mail envelopes [2], to the identification of electrical faults in integrated circuits [3].

One outstanding problem has been the propagation of THz radiation in guided wave devices. Conventional metal and dielectric waveguides that are typically used do not function well at THz frequencies. This is due to high loss and high absorption in such waveguides. The development of novel THz waveguide structures is crucial to the commercialization of THz applications. Despite this fact, few studies on the construction of efficient THz waveguide devices have been performed. Here we begin with a simple structure, with hopes to create better ones in the future.

Numerical simulation: Before fabricating a device, it is advantageous to simulate the propagation of THz radiation through a waveguide (Figure 1). Optical wave propagation and nonlinear interactions in the device are modeled using the finite element solvers of the RF Module in COMSOL Multiphysics®.

We designed and simulated a metal-insulator-metal (MIM) slab THz waveguide device. Initially, we determined the propagation modes for the IR pump beam and generated THz beam using the RF mode solver, then we simulated THz generation for a laser pulse traveling through the waveguide using the time dependent RF solver.

Results: Since we want to include the effect of the metal layers on the propagation loss, the metal layers cannot be modeled by a perfect electrical conductor, but rather by a real metal. The thickness of the metal layers in the model must be large enough so that the electric field is essentially zero by the outer boundary. By simulating different metal layer thicknesses for different THz frequencies (Figure 2) we concluded that 2 μm thick metal layers were sufficient for our modeling purposes. These results were in perfect agreement with a simple model for the metal skin depth. We found that the effective index and mode attenuation determined by COMSOL for our structure agreed very well with those values obtained using coupled mode theory [4] (Figure 3). The mode profiles were also identical.

To simulate the generation of a THz pulse, we injected a Gaussian pulse into the core that was modeled with a remnant electric polarization proportional to the square of the incident electric field. This remnant polarization produces all second order nonlinear effects like SHG as well as DFG, but we focus only on the difference frequency generation. The DFG output is shown in Figure 4.

Conclusions: The waveguide model in COMSOL Multiphysics has been able to reproduce the mode constants in the literature and to simulate THz generation for a laser pulse via optical rectification. The model that we have developed will be able to determine the optimal structural and material properties via parameter sweeps for such devices.

Reference

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

Figures used in the abstract

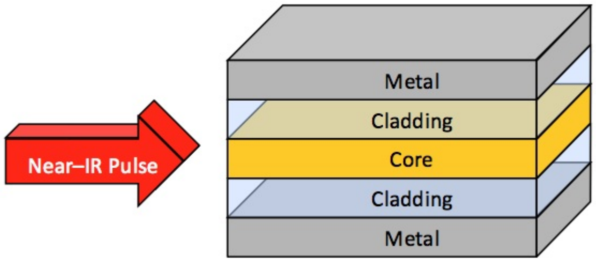

Figure 1: Schematic of a symmetric, five-layer THz waveguide device. The near-infrared pulse generates THz radiation, via optical rectification.

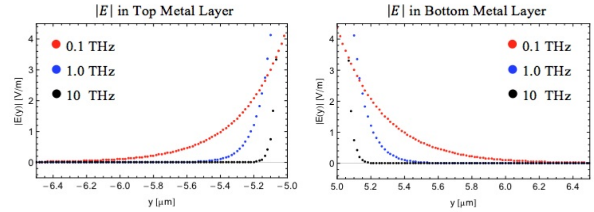

Figure 2: The magnitude of the electric field inside the top and the bottom metal layers at 0.1 THz, 1.0 THz, and 10 THz.

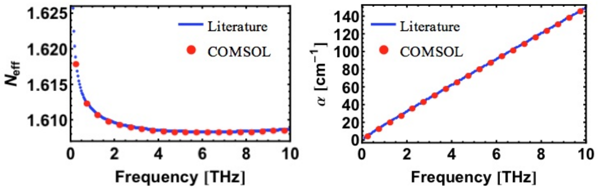

Figure 3: The effective index and the attenuation determined by using the transverse modes simulation (COMSOL) and by using coupled mode theory [4].

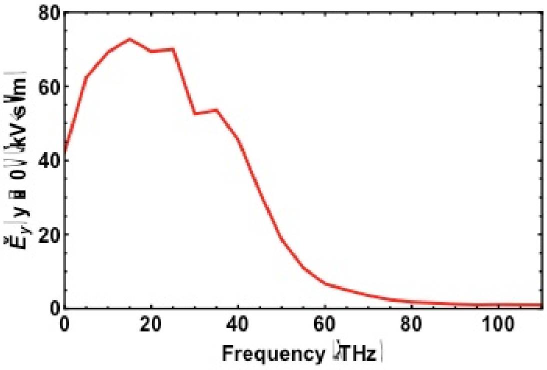

Figure 4: The low frequency portion of the spectrum for the output pulse which shows the difference frequency generation process. Input pulse width was 10 fs, wavelength was 820 nm.