An Overview of Terahertz Spectroscopy

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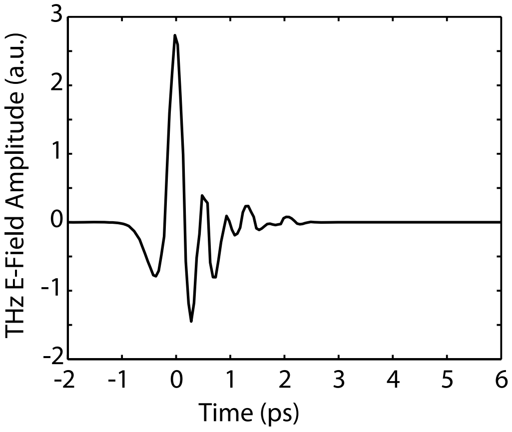
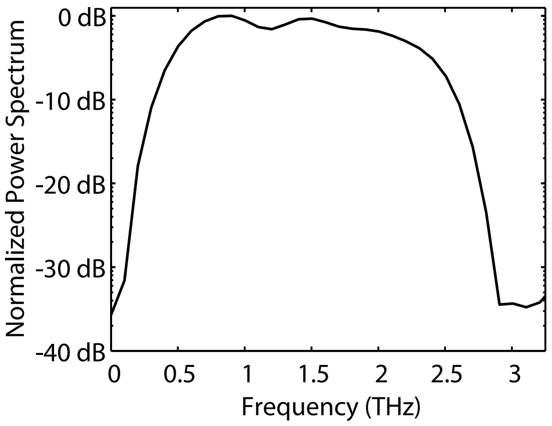
Electromagnetic radiation in the terahertz frequency range (0.1 THz – 5 THz) has many important potential applications in the areas of spectroscopy, detection, and security [1-3]. Many biological and chemical molecules exhibit vibrational modes corresponding to collective molecular oscillations, unfolding of molecular subdomains, and, for example, the twisting and deformation of the double-helix structure in DNA, that can be probed directly by THz radiation. Terahertz radiation can also be used to study carrier transport and relaxation dynamics in nanoscale physical systems such as carbon nanotubes, semiconductor quantum wells, and single-monolayer graphene sheets. Additionally, low energy THz photons are very suitable for screening for concealed weapons and explosives because they exhibit high transmission through many nonconductive materials, including concrete, clothing, and paper [1-3].

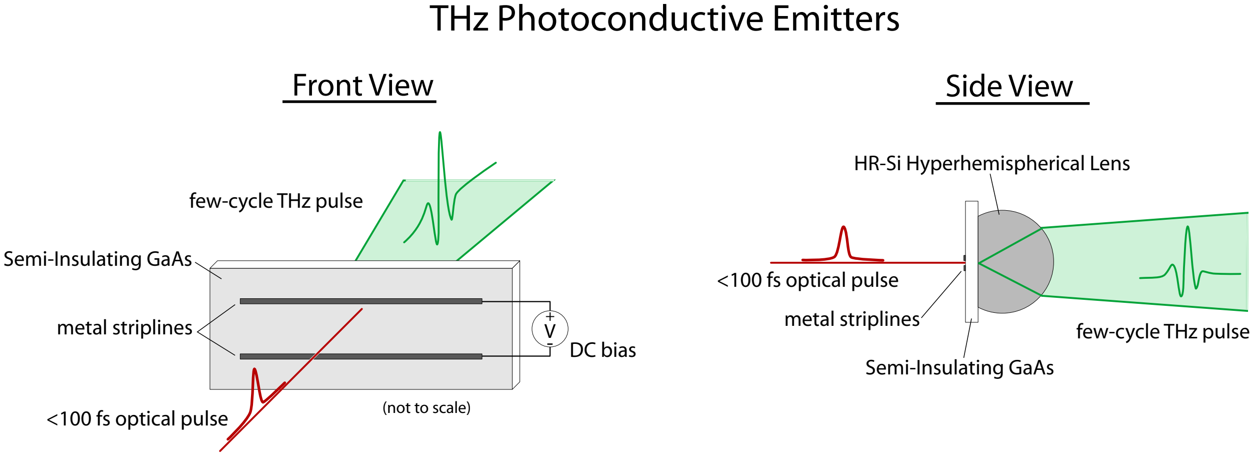
Although several different sources of coherent THz radiation currently exist, one of the most important and versatile tools found in many research labs to date is the THz Time-Domain Spectrometer. These tools are sources of ultra-broad-bandwidth THz radiation and can perform time-resolved spectroscopic measurements of the complex dielectric response of a medium by directly measuring the electric field of a few-cycle THz pulse [3,4]. The electric field and accompanying power spectrum a typical pulse is shown below.





Few-cycle THz pulses are commonly generated by exciting an electrically biased photoconductive dipole with an ultrafast laser pulse (<100 fs) [4]. The resulting photogenerated current responds on picosecond time-scales and couples to THz electromagnetic radiation. High-resistivity Si hyperhemispherical lenses are used to improve the coupling efficiency between THz radiation generated in the GaAs substrate of the photoconducting dipoles and free space [5]. Importantly, reflections from the lens-substrate interface are minimized because the index of refraction of Si (3.418) closely matches that of GaAs at THz frequencies [6]. The use of high resistivity >10 kΩ-cm Si is crucial for maintaining high dynamic range measurements because optical loss due to free carrier absorption increases dramatically at low frequencies. The THz absorption coefficient of high resistivity Si from 0.25 THz – 2 THz was measured to be < 0.5 cm^{-1} [6]. Using the above method along with a phase-sensitive lock-in-amplifier based detection scheme, THz pulses with spectral dynamic ranges exceeding 10^8 and bandwidths greater than 4 THz are readily achievable even with low optical excitation power (~10 mW) [7,8].

High-resistivity Si hyperhemispherical lenses are also important for the development of integrated THz photonics. They are can be used to focus broad-bandwidth THz pulses to a FWHM Gaussian focal spot of ~200 μm to achieve high coupling efficiency into and out of integrated single-mode microphotonic waveguides [8].


THz Photoconductive Emitters

The wide selection of high-resistivity Si optics and windows available from ISP Optics has enabled me to successfully and expeditiously meet my research goals. The optics are diamond-turned from >10 kΩ-cm Si to ensure extremely low free-carrier loss at THz wavelengths and are readily available in many dimensions. Additionally, the technicians at ISP Optics have been most helpful in modifying existing catalogues parts to accommodate the specific needs that I have had.

References

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