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High power terahertz generation from laser-plasma interactions

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Sandwiched between the optical and microwave regimes, the far infrared or terahertz (THz) frequency range has recently drawn special attention due to its ubiquitous nature and broad applications. The physics of THz generation is also compelling, raising fundamental questions about the interaction of strong electromagnetic fields with atoms and molecules. THz radiation (or T-rays) can easily pass through non-polar materials such as clothing, paper, plastics, wood and ceramics. This property allows many applications in molecular sensing, biomedical imaging and spectroscopy, security scanners, and plasma diagnostics. These applications provide strong motivation to advance the state of the art in THz source development. In particular, high-energy THz generation is vital for application in nonlinear THz optics and spectroscopy.

Recently, THz generation by two-color laser mixing in air plasma has attracted a considerable amount of interest owing to its capability of producing ultra-broadband and high-power THz pulses [1-7]. In this scheme, an ultrashort laser pulse (ω) is focused with its second harmonic (2ω) in a gas (or air) to generate gaseous plasma, and this can emit intense, single-cycle THz radiation in the forward direction (see Fig. 1). In this process, the bound electrons of atoms or molecules tunnel out under the laser field. With the right phase between ω and 2ω, the symmetry of charge separation can be broken. This microscopic asymmetric charge separation can cause a current surge arising over the laser pulse duration, simultaneously emitting THz radiation in the far field [1-3].

Macroscopically, phase matching naturally occurs due to off-axis constructive interference between locally generated terahertz waves, and this determines the far-field terahertz radiation profiles and yields [4]. For a plasma length longer than 10 mm, it emits conical THz radiation in the off-axis direction, peaked at 4~7° depending on the radiation frequencies. Here the total terahertz yield continuously increases with the plasma filament length, providing a simple method for scalable THz generation in elongated plasmas.

In practice, we have demonstrated strong-field (>8 MV/cm), high-peak-power (12 MW) THz generation with a bandwidth of >20 THz via two-color laser mixing in air [5]. Moderate average power (1.4 mW) is also achieved by using a cryogenically cooled Ti:sapphire amplifier operating at a 1 kHz repetition rate with a typical laser-to-THz conversion efficiency of ~0.01%.

Recently, we have studied pressure-dependent THz generation in various gases [6]. Contrary to short-focusing geometry, we find that long filamentation yields higher THz energy at lower gas pressures in most gases. This counter-intuitive phenomenon occurs due to multiple peculiar properties associated with laser filamentation. In practice, filamentation in low-pressure argon provides a maximum conversion efficiency of ~0.1%, about 10 times higher than in atmospheric air.

In another recent experiment, we have used a femtosecond mid-infrared laser (3.9 μm) to greatly enhance the laser-induced plasma current, a microscopic source for THz radiation [7]. By using a long-wavelength driver, we have achieved ~1% conversion efficiency, about 10~100 times larger than conventional values obtained with 0.8 μm lasers. The efficiency can be enhanced further with more efficient second harmonic generation (SHG) and/or by using an even longer wavelength driver such as CO_2 lasers. This type of THz source can potentially produce single-cycle, broadband, millijoule-level THz radiation, useful for studying THz-driven extreme phenomena and nonlinearities.

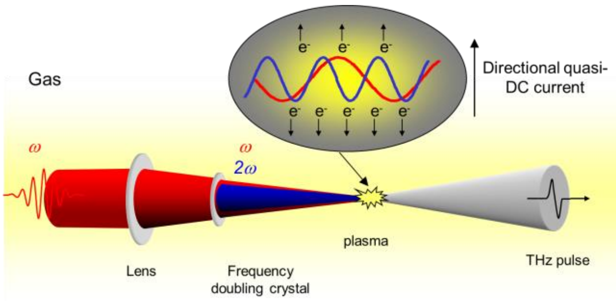

Figure 1. Schematic of strong THz pulse generation from two-color laser-produced gaseous plasma.

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