# Production and Modulation of Fully Circular Ultrabroadband THz Radiation Using Two-Color Plasma Generation

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**Abstract:** We demonstrate near-perfect circularly polarized terahertz radiation from a two-color plasma source by optimizing crystal geometry, phase, and chirp. The method enables robust broadband circularity, reveals intrinsic ellipticity chirp, and supports ultrafast, high-depth THz polarization modulation for advanced spectroscopy and communication.

Controlling the polarization state of broadband terahertz (THz) radiation is a central challenge in advancing THz spectroscopy, imaging, and next-generation wireless communication [1-3]. Two-color laser-induced plasma, driven by a fundamental wave (FHW) and its second harmonic (SHW), is among the most powerful and broadband THz sources. Yet, achieving strong or fully circular polarization in this scheme has remained elusive: traditional single-arm configurations offer high stability but limited ellipticity, while two-arm systems enable tuning but suffer from phase and alignment instability. As a result, reported THz ellipticities rarely exceeded 0.75.

In this work [4], we combine numerical modeling with systematic experimental optimization to demonstrate, for the first time, **near-perfect circularly polarized THz radiation from a single-arm two-color plasma source**, achieving a record ellipticity of **0.99**, as shown in Fig. 1. We perform a full parametric investigation of the BBO crystal's rotation and tilt angles, the FHW–SHW phase delay, and the laser chirp, identifying the operating conditions that maximize ellipticity while retaining high stability and reproducibility.

A key result is the discovery and characterization of an **intrinsic frequency-dependent ellipticity ("ellipticity chirp")** in the generated THz field. Because higher-frequency components carry greater ellipticity than the DC contribution, circular polarization is only attainable when the THz spectrum extends sufficiently into the high-frequency regime (8–30+ THz). Experiments using silicon and Teflon filters confirm this monotonic dependence: removing high-frequency components dramatically reduces ellipticity, while maintaining full bandwidth preserves the circular state. These measurements agree quantitatively with simulations based on the local current model.

We further show that the circular polarization is **highly robust to laser chirp**, provided the SHW phase is adjusted accordingly. Even under large positive chirp, ellipticity remains

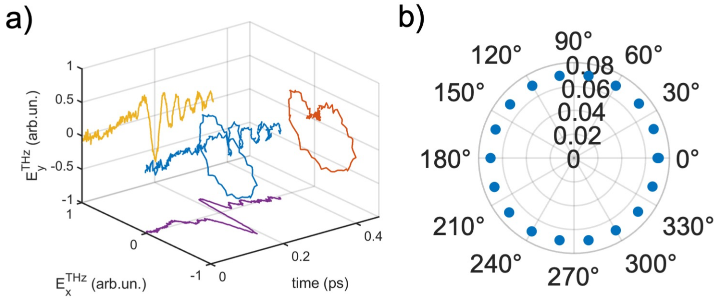


**Figure 1**. (a) THz electric field obtained via electro-optic sampling using a GaP detection crystal. The red curve represents the projection of the electric field trajectory on the xy plane. (b) Experimental polarimetric diagram measured using a Golay Cell.

above 0.95, enabling independent spectral shaping of the pump pulse—critical for targeting specific molecular, excitonic, or topological resonances—without sacrificing the THz polarization state.

Although operating at maximum ellipticity reduces THz energy by roughly 50%, the resulting pulses retain sufficient strength for nonlinear and time-resolved studies (~0.1 µJ and ~100 kV/cm).

Finally, we exploit the extreme sensitivity of THz polarization to BBO orientation to demonstrate that we may achieve **98% ellipticity modulation depth**, representing the most complete THz polarization control demonstrated to date. Based on this result, we propose two schemes for **high-speed THz polarization modulation**.

Together, these results establish the first clear route to generating and dynamically controlling fully circular, ultrabroadband THz fields from two-color plasma. This work provides both fundamental insight into polarization formation and practical tools for high-speed THz polarimetry, spectroscopy, imaging, and communication technologies.

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