Experimental Demonstration of Chromatic Angular Dispersion from Transmission Plasma Gratings

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Abstract: We present an experimental demonstration of chromatic angular dispersion of a probe beam incident on a transmission plasma grating. The results show a path towards a plasma compression grating for high intensity laser pulses. © 2025 The Author(s)

1. Introduction

The development of high-power laser systems utilizing chirped pulse amplification (CPA) are restricted to the damage threshold of solid-state optics at $\sim 10^{12}\ W/cm^2$ [1]. The final stage of the CPA system is especially susceptible to laser-induced damage because the compression grating is exposed to the full peak-power of the compressed laser pulse. Plasma optics have damage thresholds several orders-of-magnitude larger than conventional solid-state optics, making them an excellent candidate for use in systems that exceed the capabilities of solid-state optics. Additionally, plasma optics are versatile and can be used for applications such as temporal contrast cleaning [2], Bragg diffraction [3,4], and pulse compression [1]. The plasma grating is generated by temporally and spatially overlapping two pump beams within a gas cell. The intensities at regions of constructive interference are sufficient to ionize the neutral gas whereas regions of destructive interference do not, creating periodic regions of plasma and neutral gas and thus a modulation of refractive index. In this work, we experimentally measure chromatic angular dispersion introduced to a probe beam after diffraction from a plasma grating.

2. Experimental Setup

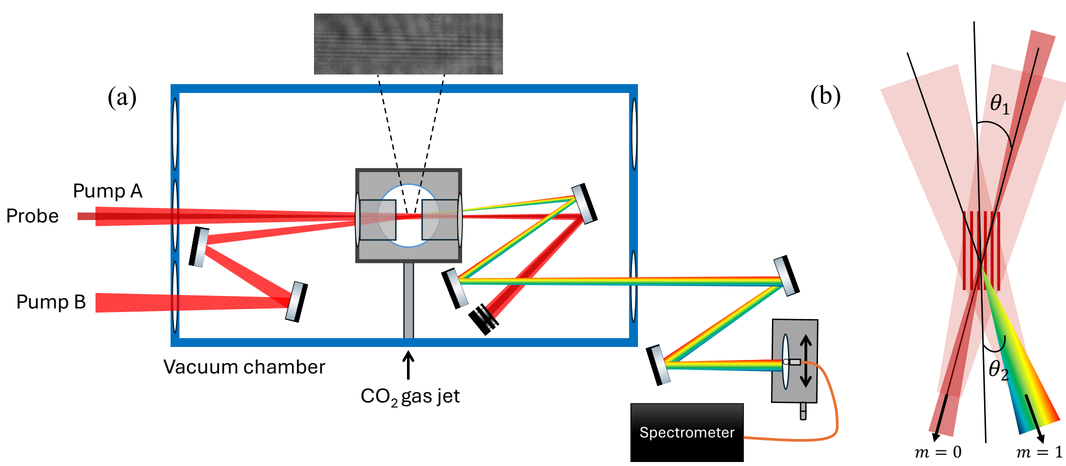

Fig 1. (a) Schematic of experimental setup for generation and measurement of angular dispersion from a transmission plasma grating. Pump A and pump B (lighter red) cross at $\theta = 4.45°$ at the center of the gas cell filled with CO_2 gas to generate the plasma grating (as seen by shadowgraph in inset). A probe beam (darker red) incident with azimuthal angle equal to the Bragg angle and colinear with pump A is diffracted and its 1st order diffraction is shown by the chromatically dispersed beam incident on a scanning spectrometer. (b) Schematic of beam geometry with probe angle of incidence θ_1 and angle of diffraction θ_2 for the $m = 1$ order.

The volume plasma grating is generated by temporally and spatially overlapping two pump beams (pump A and pump B) crossed at 4.45° inside a gas cell filled with CO_2 gas and used to diffract a subsequent probe beam of orthogonal polarization incident at the Bragg angle, propagating colinear with pump A, as shown in Fig. 1a. All beams originate from a Ti:Sapphire laser ($25\ fs$, $\lambda_0 = 800\ nm$, $20\ TW$, $10Hz$). Relative delays between beams are controlled using motorized delay stages. The generated plasma grating has a length of $1.65\ mm$ which was controlled by the size of the gas cell. The beams ablate through $50\ \mu m$ thick steel discs attached on both ends of the gas cell to create entrance and exit apertures to minimize CO_2 leakage into the vacuum chamber (residual chamber pressure ~ 8 mbar). Both pumps are *s*-polarized and each are focused with a plano-convex lens (f =1000 mm). The probe beam (*p*-polarized) is incident at the Bragg angle and is focused on the grating using a plano-convex lens (f = 1000 mm) with $\sim 120\ \mu m$ FWHM . To increase the transverse size of the grating, both pump beams are focused 2 cm after the center of the gas cell where the grating is formed ($\sim 400\ \mu m$ FWHM at the center of the gas cell), as shown in Fig. 1b. The on-target intensities for pump A, pump B, and probe are $\sim 1.0 \times 10^{13}\ W/cm^2$, $1.2 \times 10^{14}\ W/cm^2$, and $1.5 \times 10^{14}\ W/cm^2$, respectively. A plasma density on the order of $10^{17}\ cm^{-3}$ is estimated with Mach-Zehnder interferometry.

The pumps are crossed at a full angle of $\theta_1 = 4.45°$ to create a grating with period of $10.31\ \mu m$. To ensure that the chromatic angular dispersion is resolvable and exceeds the probe divergence from the focusing lens, we use an iris before the probe focusing lens to reduce the incident probe beam diameter to 6.5 mm to give a probe divergence of $0.37°$. To measure the angular dispersion, a spectrometer fiber coupled to a spectrometer (Ocean Optics HR2000+ES) was mounted on a translation stage and scanned 15 mm transversely across the diffracted probe beam in increments of 1 mm.

3. Results and Conclusion

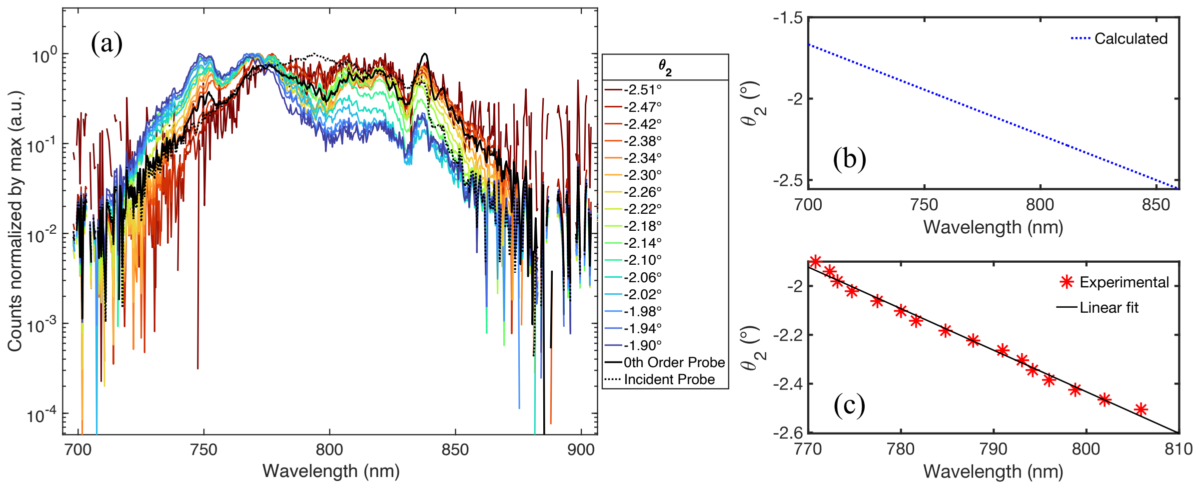

Fig 2. (a) Average of 2000 diffracted probe spectra taken at each diffracted angle θ_2. (b) Calculated diffraction angle and (c) average diffracted wavelength weighted by spectral intensity where θ_2 is the diffraction angle corresponding to spectrometer position.

The diffracted spectra at each spectrometer position corresponding to diffraction angle θ_2 along with the 0th order and incident probe spectra are shown in Fig. 2a. Using the grating equation, a calculated angular dispersion of $-0.0056\ °/\mathrm{nm}$ is shown in Fig. 2b. The average spectra from Fig. 2a at each θ_2 is weighted by its spectral intensity and gives an estimated angular dispersion of $-0.017\ °/\mathrm{nm}$ as shown in Fig. 2c.

As we scan the spectrometer fiber across the diffracted beam, we observe stronger blue frequencies for smaller angles of diffraction and stronger red frequencies for larger angles of diffraction. These results indicate the potential application of a plasma grating to be used as a dispersive optic for compressor gratings in CPA laser systems with the ability to diffract intensities two orders-of-magnitude greater than the solid-state damage threshold.

4. Acknowledgements

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5. References

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