CAPR
Center for Advanced Photonics Research

Assessment of Threshold for Nonlinear Effects in Ibsen Transmission Gratings

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Purpose:

The purpose of this report is to measure the threshold power for nonlinear effects that limit the usefulness of fused silica transmission gratings produced by Ibsen Photonics. The threshold for nonlinear effects will be defined as the power at which either the grating is permanently damaged or the pulse characteristics have been compromised.

Criteria for threshold measurements

Damage Threshold of fused silica:

Much research has been done on laser-induced damage in fused silica. In the femtosecond regime the primary mechanism for permanent material damage has been determined to be photoionization-assisted avalanche ionization[1]. The damage thresholds reported in (1) are defined as the fluence at which the generated electron density exceeded the critical plasma density (1.6×10^{21} cm^{-3} in fused silica). For pulse durations close to those used in our experiment, a permanent damage threshold of ~3.5 J/cm^2 is reported for fused silica.

Nonlinear Threshold of fused silica:

Nonlinear effects induced by passage through fused silica can distort a pulse significantly. Self-phase modulation (SPM) and white-light (continuum) generation are the effects considered here as they serve as indications of thresholds for other related nonlinear effects which can lead to significant pulse effects (such as self-focusing, space-time focusing, self-steepening, etc.)[2]. The reported maximum fluence at the threshold for continuum generation in fused silica is 0.57 J/cm^2 (2). This value is smaller than the threshold for permanent material damage in the fused silica therefore we expect that the usefulness of the grating will be limited not by damage to the material but by nonlinear interactions with it. Peak power is a more important factor in nonlinear interactions than fluence[3].

Based on these considerations this experiment focuses on detecting changes in the pulse spectrum after it has passed through the grating.

Method for measuring the usability threshold

Laser Parameters:

Pulses were generated using a titanium:sapphire laser oscillator (KM Labs) and amplified through chirped-pulse amplification (Legend, Coherent) to 2.1 mJ with a pulse duration of 70 fs. The repetition rate of the laser is 1 kHz. Reference pulses were characterized using frequency-resolved optical gating (FROG).

Grating:

The grating tested was part number FSTG-PCG-1250-800 from Ibsen Photonics. It is ruled at 1250 lines per millimeter and AR coated for 800 nm.

Method:

The grating was position at the Littrow angle using the laser at low power. The laser power was varied by translating the grating various distances from a 1 meter focusing lens. After the lens, a glass slide is inserted which picks off a portion of the beam for power measurement and beam profiling. Once the beam has passed through the grating the spectrum is measured using a USB2000 spectrometer (Ocean Optics). The optical setup is shown below.

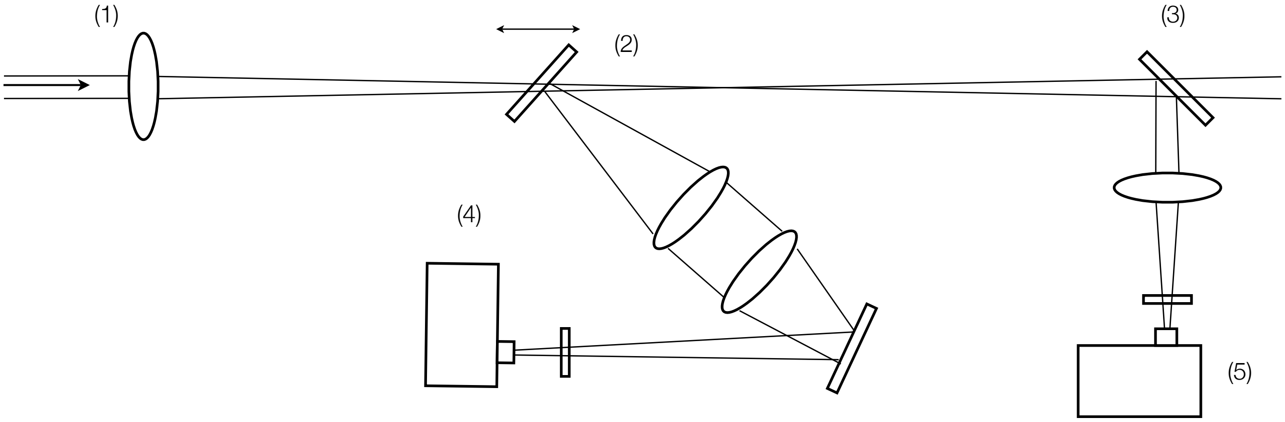

Figure 1. Experimental setup: (1) 1 meter lens, (2) diffraction grating, (3) beam sampler, and (4,5) Spectrometer/CCD camera.

Results and discussion

Observation of spectral broadening:

Spectral broadening was observed in the diffracted spectrum at high power. However, because of the high intensity of the fundamental spectrum, low intensity spectral features due to SPM and continuum generation were difficult to measure using the USB2000 spectrometers. Because the changes were directly visible in the diffracted spectrum, measurements were taken by observing the broadening of the diffracted spectrum on paper instead. Self-phase modulation was observed at 0.015 J/cm^2 and became significant at 0.028 J/cm^2. Significant SPM is defined as broadening of the base of the spectrum beyond the HWHM of the fundamental spectrum. While these values seem quite low, the corresponding intensities (2.1×10^{11} W/cm^2 and 4×10^{11} W/cm^2, respectively) show that the change in refractive index ($n_2 = 3.1\times10^{-16}$ for fused silica, corresponding to a change of 6.7×10^{-5} and 1.3×10^{-4} in the refractive index, respectively) is actually quite significant for both of these fluences[3].

Small spectral broadening can be tolerated in a few applications, especially if the pulse duration and profile is not significantly changed by the process. Continuum generation is a much more dramatic effect and represents a stronger manifestation of several nonlinear effects, as mentioned above. The threshold for continuum generation was measured to be 0.11 J/cm^2. Because this threshold value is a factor of five lower than the value reported in ref. 2 further investigation into the mechanism of continuum generation in our experiment was necessary. Continuum generation occurred at point sources on the back (grooved) surface of the grating and also changed as the beam was translated vertically on the grating. After prolonged exposure to the laser beam, the grating was studied under a microscope. From these observations it was concluded that continuum generation occurred because of dust induced hot-spots in the beam on the surface of the grating. Investigation with the microscope showed that dust particles were burned onto the surface, but that the surface itself was not damaged by the beam. Small burns from previous investigations also could have been sources of hot spots in the beam.

Conclusion:

Because nonlinear effects are the limiting factor on the usefulness of the grating for pulse compression, laser power is a more important factor than laser fluence. In a very clean environment the usability threshold could potentially be extended, but for average lab conditions an intensity of ~1.5×10^{11} W/cm^2 was determined to be a safe operating intensity for the grating under investigation. In the experiment the peak laser power was 14 times the critical power for self-focusing in air and beam collimation to diameters smaller than 0.5 cm resulted in collapse of the beam. In lab conditions beams are usually kept at larger diameters to prevent this from occurring. For a beam fitting fully on the grating (~0.8 cm), the maximum beam energy corresponding to the safe limit is 15 mJ (for a 50 fs pulse duration).

[1] Mourou *et al.* Phys. Rev. Lett. **82**, 3883 (1999)

[2] Brodeur and Chin, J. Opt. Soc. Am. B **16**, 637 (1999)

[3] R.W. Boyd. *Nonlinear Optics*. 2nd ed. Academic Press, London. 2003