# Design and Fabrication of Efficient Reflection Grisms for Pulse Compression and Dispersion Compensation

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**Abstract.** Efficient reflection grisms for pulse compression and material-dispersion compensation have been designed and demonstrated in a CPA system. Designs for 800-nm and 1030-nm ultrafast applications are characterized using off-the-shelf diffraction gratings.

## 1. Introduction

In the earliest demonstrations of chirped pulse amplification (CPA), the compressed pulse duration was limited by dispersion mismatch between the fiber stretcher and the Treacy grating-pair compressor. Specifically, the fiber dispersion was nearly linear, with positive GVD and positive TOD, while the grating-pair compressor dispersion provided negative GVD and also a significant amount of positive TOD. With the introduction of the grating-pair stretcher, the dispersion mismatch between optical-material stretchers and grating-pair compressors was no longer an issue for high-power CPA systems.

There are, however, many applications which would benefit from the ability to compensate for large amounts of material dispersion. Short pulses are often delivered through large amounts of optical fiber (requiring large prism sequences to partially compensate for excess TOD), and a host of very simple CPA lasers for low-energy applications could be realized by replacing the grating-pair stretcher with intracavity material.

In this work we present a practical solution to compensating large amounts of material dispersion – pulse-compression grisms with high efficiency using off-the-shelf gratings – which are successfully demonstrated in a novel 40-fs CPA laser system.

## 2. Grism Design and Testing

Tournois showed that a conventional grating pair compressor could never be designed with pure GVD and zero TOD; however, a compressor made from grisms (gratings in optical contact with a prism) could easily satisfy the condition for zero-TOD operation [1]. Kane and Squier expanded upon this design, showing that grisms could exhibit negative GVD and negative TOD [2], and a 600 lines/mm grism was fabricated to compress an 800-nm, 135-fs pulse which had propagated through over 100m of optical fiber, in the first demonstration of a grism compressor design.

The early demonstration was not of great practical significance, because the grism was very inefficient (25% or less per pass). For a grism to be most efficient (80-90%), the grating should satisfy the Littrow condition; i.e., the angle between the incident beam and diffracted beam should be nearly zero. In order to satisfy the zero- or negative-TOD requirement of the compressor, the grism as described by Tournois must have an extremely large deviation angle – on the order of 90 degrees – and therefore is not a good candidate for a high-efficiency component. The goal of this new study was to design a grism which would satisfy the negative-TOD requirement and operate near Littrow to provide high efficiency.

The designs of the new grisms are shown in Figure 1. The beam is incident on the prism, diffracts off the grating inside the prism material, but unlike the Tournois grism, the beam is then refracted at a surface which is not parallel to the grating surface. At this prism surface, the angular dispersion is given by

$$\sin\theta_d = n \sin[\theta_p + \arcsin(\sin(\theta_i - \lambda/nd))] \quad (1)$$

where $\theta_p$ is the angle between the prism entrance face and the grating.

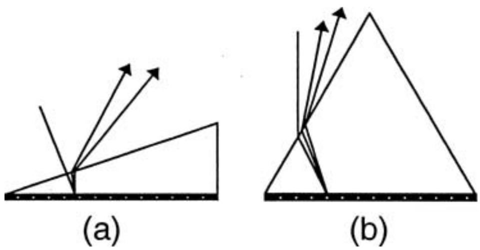


Figure 1. Schematic of the new near-Littrow reflection grisms for (a) 800-nm and (b) 1030-nm CPA systems

This slight modification to the grism geometry results in a new degree of design freedom: by properly choosing the right combination of grating groove density and prism angle $\theta_p$, it is now possible to specify a Littrow-use grating which is highly efficient at the grism's design wavelength and simultaneously satisfies the negative-TOD condition.

We designed and fabricated two reflection grisms, the first with 600 lines/mm using a 26-degree prism and a stock gold-coated grating (50x140 mm dimension) from Horiba Jobin Yvon. For this design, the prism required an AR coating, but other designs can utilize all-Brewster-angle refractions to maximize transmission.

The stock grating was not optimized for pulse compression, but rather for spectroscopic applications where efficiency was not critical, so the grism was expected to have good efficiency but not to approach theoretical values. The grism was better than $\lambda/4$ over the full aperture and was cosmetically pristine. For negative-TOD operation, the deviation angle of the grism was approximately 30 degrees, which was sufficiently close to Littrow to provide high efficiency.

The grism efficiency was calculated using commercial design software (PC-Grate 6.1) which predicted >85% efficiency at the design wavelength. The grating efficiency was measured at ~80%, in good agreement with the model. While this stock grating's efficiency is adequate for many ultrafast applications, higher efficiency (>90%) can be achieved with an optimized grating.

The second grism was fabricated for 1030-nm fiber laser applications, with a Jobin Yvon holographic pulse compression grating (1480 lines/mm, gold coated, replica of JY p/n 524.28) and an off-the-shelf BK7 equilateral prism. This grism is used near the Brewster angle, so no AR coatings were needed. PC-Grate calculations predict 88% efficiency for this grism, and measurements using a 1030-nm laser show 85% efficiency at the correct incidence angle for SOD/TOD compensation. The agreement with calculation is excellent in this case.

**Table 1.** Grism efficiency (absolute) vs. incidence angle. TOD/GVD compensation is achieved at 43 degrees.

| Incidence angle (deg) | Absolute efficiency |
|---|---|
| 27.5 | 79.3 |
| 41.53 | 85.3 |
| 42.6 | 84.9 |
| 43.5 | 86.2 |
| 50.52 | 85.3 |
| 53.7 | 84.4 |
| 56. 7 | 82.3 |
| 69.0 | 79.3 |

To demonstrate negative-TOD operation, the 800-nm grisms were used in a multi-kilohertz CPA system to produce 40-fs amplified pulses. The results of this experiment are described elsewhere [3]. The grisms provided optimal dispersion compensation at exactly the incidence angle for which they were designed, validating the calculations for GVD and TOD of the grism. Phase measurements indicated uncompensated $4^{th}$-order dispersion, which is also in agreement with calculations.

## References


1 P. Tournois, Electron. Lett. **29**, pp. 1414-1415 (1993).

2 S. Kane and J. Squier, IEEE J. Quantum Electron. **31**, no.11,pp 2052-2057 (1995).

3 E. Gibson et al., accepted for publication in Opt. Lett. (2006).