DIFFRACTIVE OPTICS

Fiber Bragg Gratings in the Ultrashort Pulse Regime

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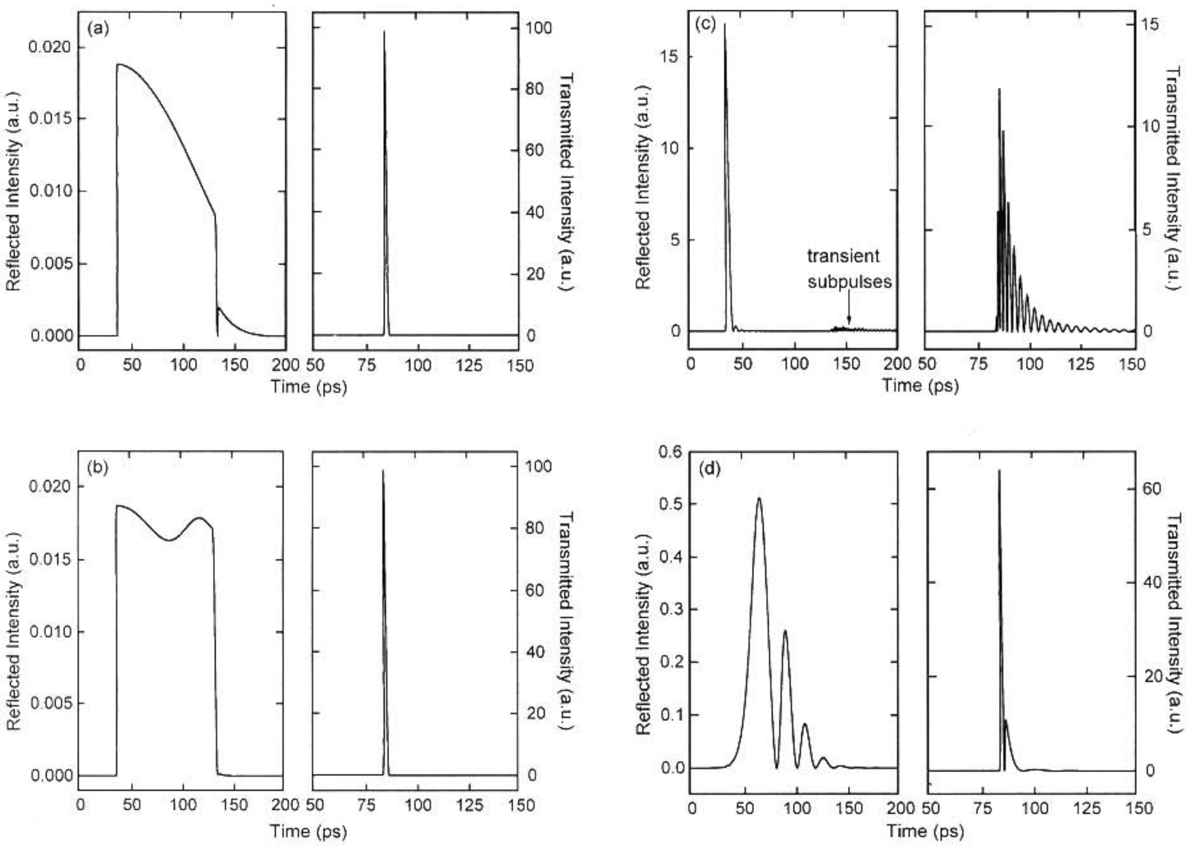
Fiber gratings have numerous applications for optical communications and sensing. They are typically used with incoherent broadband sources or continuous-wave (cw) and quasi-cw (pulsed) sources, whose spectral bandwidth is narrower than that of the grating response. Linear pulse propagation through gratings for the above cases has been studied and is well understood.[1] Recently, there have also been investigations of propagation through fiber gratings under different regimes than those already listed. For example, Eggleton *et al.* have experimentally studied nonlinear propagation through various grating structures.[2]

Over the past year, we have been examining the linear propagation of ultrashort pulses through fiber gratings, *i.e.*, the ultrashort pulse response of fiber gratings.[3–5] Here, the spectral bandwidth of the incident pulse is broader than that of the grating response. Furthermore, the physical length is significantly smaller than the length of the grating. In this regime, the reflected and transmitted signals from fiber gratings differ substantially from the usual cases. Although the dynamics of the interaction may be complex, there are numerous intriguing possibilities for the development of novel devices and applications—especially in the area of optical communications—to be found by combining ultrashort pulses with fiber gratings.

Figure 1 shows the calculated reflected and transmitted pulses from several uniform and nonuniform gratings, assuming a transform-limited 1-psec Gaussian input pulse. Depending on the grating characteristics (peak index modulation, chirp, and apodization), the reflected and transmitted pulses take on significantly different shapes, and their duration varies in comparison to the input. To obtain both an understanding of the ultrashort pulse response features and physical insight into the dynamics of the pulse-grating interaction, different numerical methods have been used to compute



L. Chen Figure 1. Simulated reflected and transmitted pulses from (a) weak uniform grating ($L = 10.0$ mm, peak index modulation $\delta n = 4.4 \times 10^{-5}$), (b) weak grating with linear chirp ($L = 10.0$ mm, $\delta n = 4.4 \times 10^{-5}$, chirp = 0.4 nm/cm), (c) very strong uniform grating ($L = 10.0$ mm, $\delta n = 1.5 \times 10^{-3}$), and (d) Gaussian apodized grating (FWHM width = 5.0 mm, $\delta n = 4.4 \times 10^{-4}$). The input is a transform-limited 1.5-psec Gaussian pulse tuned to the peak reflectivity of the grating (1.55 µm) and with a peak intensity of 100 (arbitrary units).

the resultant reflected and transmitted signals, as well as their evolution.[4, 5] We have been able to qualitatively explain these features and further correlate them with the grating properties. For example, the dispersive nature of the gratings are responsible for the creation of transient subpulses in the reflection response. Furthermore, sidelobes in the grating response result in a beating of such frequencies, and hence corresponding oscillations in the reflected or transmitted pulses. Our preliminary experimental measurements of the temporal response of transform-limited picosecond (1.5-psec) Gaussian pulses reflected and transmitted from fiber gratings show good agreement with the numerical simulations.

The results of our studies are significant for understanding the dynamics of the response so that the range of fiber grating applications can be extended to include the ultrashort pulse regime. In particular, the ultrashort pulse response of fiber gratings is an important consideration when designing multiwavelength sources based upon spectral slicing of coherent ultrashort broadband pulses using serially multiplexed gratings.[3] Another potential application is the use of simple or complex grating structures for optical pulse shaping and coding/decoding. The shapes of the reflected and transmitted pulse can be controlled by suitably tailoring the grating parameters and characteristics.

References

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A New Type of Lens with Binary Subwavelength Structures

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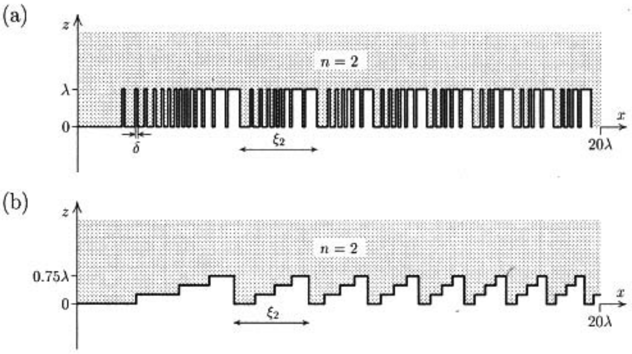
Cylindrical microlenses are frequently applied in optical technology, for example, collimating light emitted by laser diodes and coupling light in integrated optics.[1] These applications require diffraction-limited microlenses with high numerical apertures (NA).

Microlenses can be refractive or diffractive. Diffractive microlenses offer greater flexibility in their design. With an increase of the NA, the lateral extension of the structure details of diffractive microlenses decreases and it is necessary to use rigorous electromagnetic diffraction theory for their design with high NAs. We have used the volume integral method[2] for this purpose.

The design concept[3] is based on physical considerations: If the transmitted electric field in a plane immediately behind the microlens is known, the angular spectrum of plane waves can be applied to evaluate the field in the focal plane. It is sufficient to optimize the transmitted electric field to increase the density of energy in the focus. The profile of cylinder lenses can be varied until an adequate agreement between the actual and the desired phase distribution of the transmitted electric field is obtained.

We have applied this design concept to optimize binary cylinder lenses with subwavelength structures. This type of microlens acts in the same manner as a gradient-index lens. The effective-medium theory can be used to assign effective refractive indices to the subwavelength-structured regions. In each single zone (ξ_i of the cylinder lens) the filling factor decreases in the x direction as well as the refractive index (see Fig. 1a). Within the design, the minimum feature sizes may be fixed to 0.1 λ. It is possible to realize these structures with modern lithographic techniques.



Schmitz Figure 1. (a) Binary cylinder lens with subwavelength structures and (b) conventional four level cylinder lens.

The profile of a subwavelength-structured F/0.5 cylinder lens is illustrated in Figure 1a. The density of energy in the focus is increased by 40% compared to the conventional cylinder lens with four depth levels in Figure 1b. This significant enhancement indicates that binary subwavelength structures are suited for the design of diffractive cylinder lenses with large NAs. Further lithographic technique improvements will enable the fabrication of even smaller feature sizes. Numerical calculations show that the perfomance of subwavelength-structured cylinder lenses increases with the decrease of the minimum feature size. We expect that multilevel cylinder lenses will be replaced by binary subwavelength-structured cylinder lenses in the future.

References

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