Production of submicrometer period Bragg gratings in optical fibers using wavefront division with a biprism and an excimer laser source

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Biprisms are used as a method of wavefront division with an excimer laser source to holographically write first-order Bragg gratings in single-mode optical fibers. Gratings with a period of 556 nm and peak reflectivity of 62% are produced using single pulses from a krypton fluoride (KrF) laser. A comparison is made between grating production with line-narrowed and nonline narrowed lasers.

There have recently been numerous reports on the external side writing of fiber Bragg gratings (FBGs) in singlemode optical fibers using various holographic methods with lasers operating in the ultraviolet *(UV).*[1-5] Because of the relatively large size (=10-20 mm) of their output beams, excimer lasers are particularly attractive as sources for spatial multiplexing by wavefront division. We previously reported the production of gratings using a biprism[6] where single pulses from an excimer laser were used to write gratings on polymers and ceramics. There has recently been a further report extending this technique to the production of photoinduced-type (type 1) gratings in fibers using a cw, frequency-doubled, argon-ion laser. Since interferometerbased systems can be quite complicated and alignment sensitive, one of our aims has been to develop a simple grating-writing system that can be used with a standard broadband excimer laser to record single-pulse damage-type (type 11) FBGs.

The two possible orientations in which a biprism can be used for wavefront division are shown in Fig. 1(a). The period of the interference pattern in the beam overlap region in each case is given by

$$d=\frac{\lambda}{2\sin[\sin^{-1}(n\sin\alpha)-\alpha]}\quad\text{(configuration A)},$$

$$d=\frac{\lambda}{2n\sin\{\alpha-\sin^{-1}[(\sin\alpha)/n]\}}\quad\text{(configuration B)},$$

where a is the biprism angle as shown, *n* its refractive index, and A the laser wavelength. Figure 1 (b) shows a plot of these equations as functions of a for different fused silica biprisms at 248 urn. It should be noted that the length of the grating produced can be easily changed by moving the sample through the overlap zone of the two beams. Provided that the biprism is accurately fabricated, then laser sources having relatively short *temporal* coherence lengths (broad linewidths) may be used to write gratings. The *spatial* coherence properties required of the source depend only on the length of the grating required, and since excimer lasers with unstable resonators produce transverse coherence lengths of =2-3 mm, the combination of unstable resonators with accurately manufactured biprisms should be capable of producing gratings several millimeters long.

Our 5.4°, 15°, 20°, 27°, and 38° biprisms, when used alone, produced gratings with Bragg reflections outside the range of our diagnostic light-emitting diode (LED), and so to provide greater flexibility two were used in series as shown in Fig. 2. The period in this case is

$$d=\frac{\lambda}{2\sin\left(\sin^{-1}\left\{n_2\sin\left[\alpha_2-\sin^{-1}\left(\frac{\sin[\sin^{-1}(n_1\sin\alpha_1)-\alpha_1]}{n_2}\right)\right]\right\}-\alpha_2\right)},$$

where α_1, α_2 and n_1, n_2 are the angles and refractive indices of the first and second biprisms, respectively.

A Lambda Physik EMG150 line-narrowed KrF laser oscillator with an injection-seeded unstable-resonator amplifier section operating at a wavelength of 248 nm was used as the source. The laser produced = 120 mJ of energy in a 20 ns pulse having temporal (longitudinal) coherence lengths of =3.5 mm and =250 µm with and without injection seeding, respectively. Biprisms with angles of 5.4° and 27° in series gave an interference period of 556 nm. A 75 mm focal length cylindrical lens was used to produce a line focus along the fiber with a maximum single pulse fluence 1.0 J/cm^2. The length of the FBG produced was =3 mm. Details of the fiber and diagnostics have been described previously.[8]

A typical reflection spectrum produced using a single pulse from the line-narrowed laser to write a type 11 FBG is shown in Fig. 3(a). For a first-order Bragg reflection at 1612 nm, the grating had a peak reflectivity of 62% and a band-

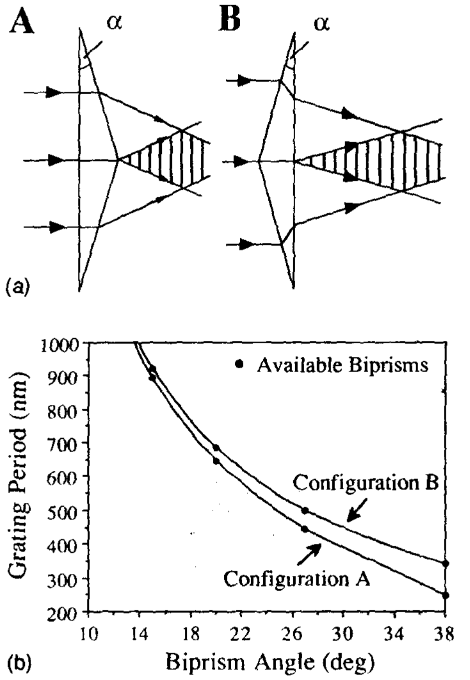

FIG. 1. (a) Possible configurations for wavefront division using biprisms; (b) Predicted periods for silica biprisms at $\lambda=248$ nm.

width of 0.6 nm. FBGs having similar reflectivities and bandwidths could be written reproducibly. From previous studies,[8] it is known that the optimum fluence for recording type 11 FBGs in this fiber is -1.4 J/cm^2 but due to practical constraints it was not possible to achieve such high fluences in this work. Type II gratings were also produced without injection seeding of the unstable resonator of the laser [Fig. 3(b)], although the peak reflectivities were somewhat lower (R=24%) and bandwidths larger. The reproducibility of the gratings produced using the broadband laser also tended to be less than with the line-narrowed laser.

To investigate the modulation depths of fringes produced by line-narrowed and broadband KrF lasers, measurements were made using the arrangement shown in Fig. 4(a). A 0.5 mm thick borosilicate glass slide was placed in the beam overlap region to produce UV-induced fluorescent fringes on its surface. This fluorescence was imaged with a X20 microscope objective onto a camera coupled to an Exitech P256NG laser beam profiling system. Since the spatial resolution of the imaging was limited to -10 um, a 0.39° biprism was used to produce coarser 36 um period fringes.

A cross-sectional analysis of the fringe patterns produced with a single laser pulse from both the line-narrowed and broadband KrF lasers is shown in Fig. 4(b). The fringe in the line-narrowed case had a contrast ratio of 33% compared to a value of 24% obtained with the broadband laser The lower contrast produced by the broadband laser likely results in the poorer reflectivity and broader linewidth observed from the FBGs.

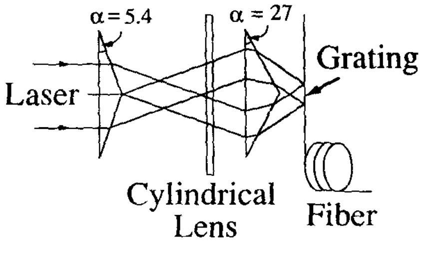

FIG. 2. Arrangement for production of FBGs with two biprisms.

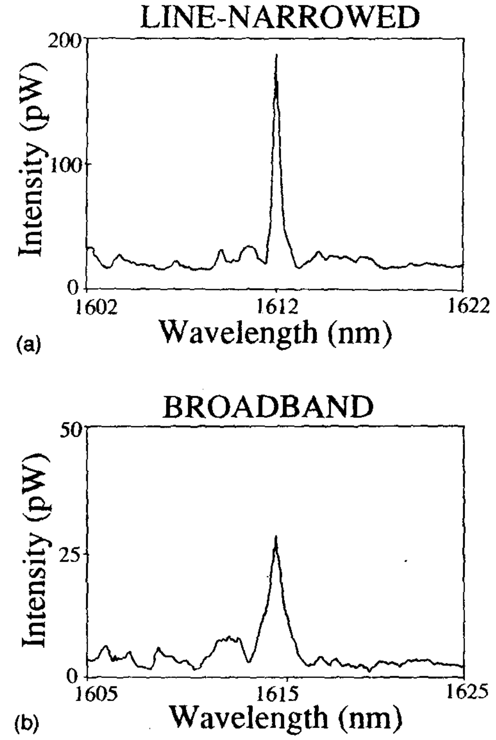

FIG. 3. Reflection spectra from FBGs written using (a) a 2.9 cm^{-1} line width laser and (b) a broadband 44.2 cm^{-1} linewidth laser.

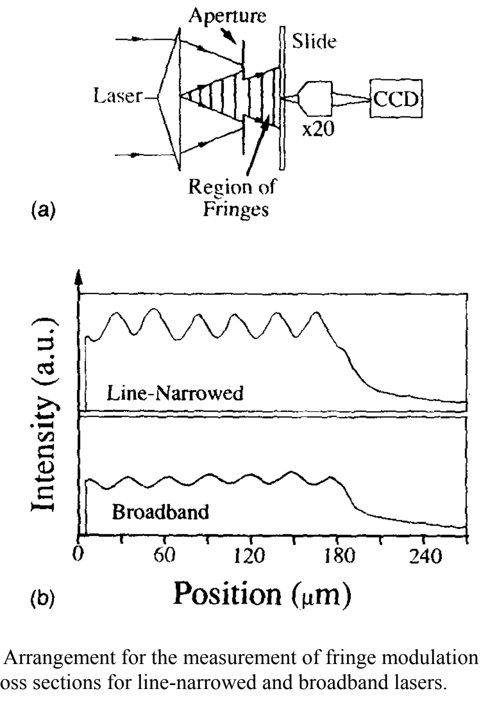

FIG. 4. (a) Arrangement for the measurement of fringe modulation depth: (b) fringe cross sections for line-narrowed and broadband lasers.

In summary, we have used simple biprisms to divide the wavefront of a KrF laser beam to produce type II, first-order Bragg gratings having a peak reflectivity of 62% in a single mode optical fiber at a Bragg wavelength of 1612 nm. We have also demonstrated that this arrangement can be used to record type II gratings using a broadband KrF laser source. The use of a biprism beamsplitter greatly simplifies the laser source requirements and much of the optical complexity currently employed for the production of FBGs.

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