mode) and in He I via direct electron impact (in pulsed mode). Details of laser operational data are presented, and the importance of H_2 additions to the laser species is reported.

Note added in proof. New interferometric results indicate that the observed He lines are due to Stark splitting in the electric field of the cathode fall region.

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Chirped-grating demultiplexers in dielectric waveguides*

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A wavelength-selective beamsplitter has been realized by fabricating chirped (variable period) grating in an optical waveguide. This beamsplitter can demultiplex a signal traveling in a fiber and send each frequency component to a different fiber.

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We have recently described the fabrication of chirped (variable period) gratings in dielectric waveguides[1] and have demonstrated the use of these gratings in fabricating focusing output couplers.[2] In this work we report the use of chirped gratings for the realization of multiplexing or demultiplexing devices.

Consider a dielectric waveguide with a corrugated region of period Λ, and a guided optical beam of wavelength λ incident on the corrugated region at an angle α [see Fig. 1(a)]. The beam will be deflected[3] at an angle 2α, provided Bragg's law $\Lambda = \lambda/2n\cos\alpha$ is satisfied, where n is the effective refractive index of the waveguide.

If the corrugated region consists of a grating with a variable period $\Lambda(z)$, then it follows that different locations in the corrugated waveguide will deflect different wavelengths as shown in Fig. 1(b). A particular wavelength λ_1 will be reflected from that part of the chirped grating where the period Λ_1 satisfies the condition $\Lambda_1 = \lambda_1/2n\cos\alpha$, while a (different) wavelength λ_2 will be reflected from the portion of the grating where the period Λ_2 satisfies the condition $\Lambda_2 = \lambda_2/2n\cos\alpha$. These two wavelengths, which initially occupy the same beam, are thus demultiplexed, i.e., separated spatially. The fraction of the light of wavelength λ_i that is reflected depends on the length of the waveguide section for which the wavelength λ_i falls within the "forbidden" propagation gap. It is thus a function of the chirp rate and the coupling constant, which in a given waveguide depends on the corrugation height and profile.

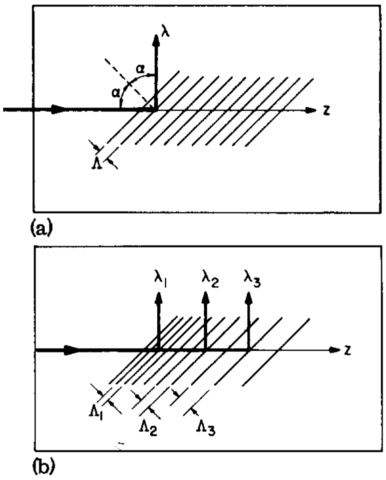

FIG. 1. (a) Beamsplitting in a dielectric waveguide with a constant grating period Λ. (b) Beamsplitting and demultiplexing in a dielectric waveguide with chirped [variable period $\Lambda(z)$] grating.

To fabricate waveguides we used an ion-milling system, and sputter deposited a waveguiding layer of 7059 Corning glass on No. 3010 Clay-Adams microscope slides. The samples were cleaned according to the method described in Ref. 4, and the back surface was painted flat black. A layer of AZ-1350B photoresist was then deposited, and after 30 sec was spun at 3600 rpm for 30 sec. This was followed by baking for 30 min at 125 °C.

The chirped grating was recorded in the photoresist by exposing the latter to the interference pattern of a collimated laser beam with a converging one, generated by a cylindrical lens. The chirping depends on the angle between the illuminating beams, the wavelength, the *F* number of the lens, and the position of the lens with respect to the sample.[1]

For this experiment we used an Ar$^+$ laser at the 4579-Å line. The angle between the collimated beam and the bisector of the converging beam was 95°. The *F* number of the lens was chosen to be 2.66 and the pattern was recorded over a distance of 9 to 14 mm. This arrangement resulted in a total period variation of 8 to 10% over the grating length. The samples were exposed for 65 sec and the power per beam was 1.2 mW/cm^2. Subsequently they were developed for 10 sec in AZ-303A developer and rinsed for 2 min in deionized water. They were vacuum baked at 100 °C for 30 min, and then the chirped-grating pattern was transferred onto the waveguides using the same ion-milling machine.

In the first experiment reported here we have used a single mode waveguide of thickness 0.95 μm, as measured at a number of points by a Sloan Dektak machine. The thickness uniformity was better than 15%. The total period variation of the chirped grating was 2930 to 3210 Å over a distance of 6.5 mm, normal to the grating lines, and it was determined from the diffraction angle of an externally incident Ar$^+$ laser beam. The peak-to-trough height of the corrugations in the glass was approximately 500 Å.

In the demonstration of wavelength demultiplexing we launched the tunable output beam of a cw dye laser into the waveguide using a prism coupler. The angle α between the propagating beam and the grating was adjustable, and was chosen to be approximately 48°.

It was found that for yellow light, the light is reflected from the left side of the chirped grating, and as the wavelength increases the reflected beam moves to the right. The reflection at two distinct wavelengths 6070 and 6270 Å is shown in Fig. 2(a). These beams are separated spatially by 4 mm. Figure 2(b) shows the outline of the grating, as well as the positions of the reflected beams.

To measure more quantitatively the z coordinate of the location where reflection occurred as a function of wavelength, a second experiment was performed. A 0.65-μm waveguide with surface uniformity better than 5% was used. The effective index of refraction of the waveguide was measured with conventional prism coupling methods and was found to be 1.53 ± 0.01. The period variation as a function of distance was measured as before and was found to vary from 2975 to 3360 Å over the total distance of 9.9 mm. This variation was linear over the region of interest of 3.5 mm and ranged from a low of 2975 ± 10 Å to a high of 3105 ± 10 Å. By measuring the diffraction efficiency of the Ar$^+$ beam used, the peak-to-trough height of the grating was estimated to be 400 Å. The angle α between the incident beam and the grating was measured to be 50° ± 1°.

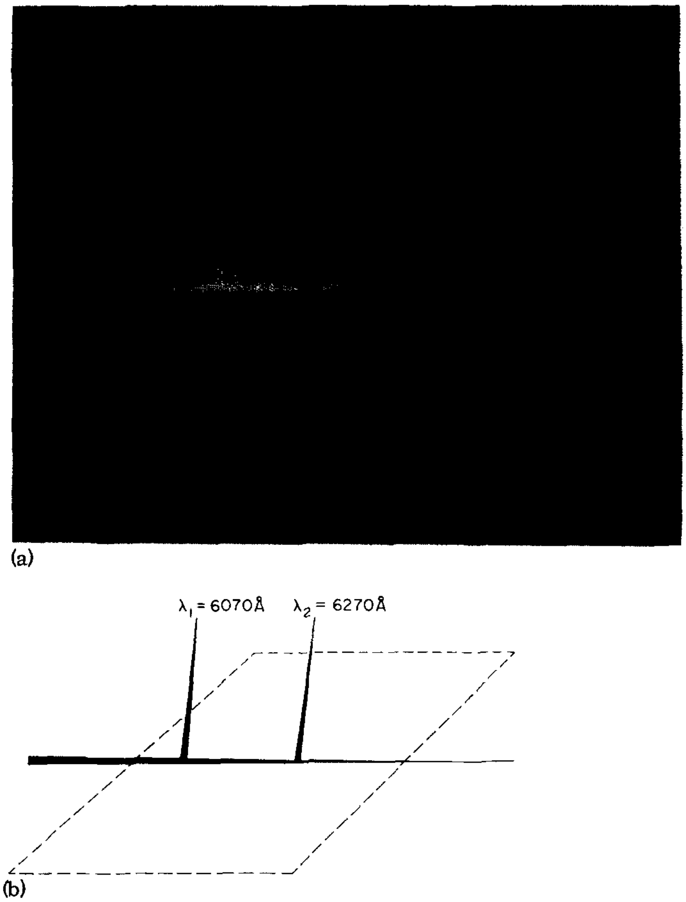

FIG. 2. (a) Double-exposure photograph showing the reflection of two different wavelengths from two different locations in a chirped-grating beamsplitter. (b) Schematic representation of the experiment shown in Fig. 2(a). The dashed lines outline the corrugated region and the solid ones outline the laser beams.

The dye laser was tuned from 6030 to 6300 Å and the locations of the reflection of different wavelengths were determined by using a traveling telescope mounted on a translation stage. Since the period variation Λ as a function of z was already known, we could now correlate the wavelength λ_i and the period Λ_i that caused reflection. The plot of λ as a function of Λ is shown in Fig. 3.

The straight line plot of Λ versus λ agrees with Bragg's law $\Lambda = \lambda/2n\cos\alpha$. From the slope of the line and the measured incidence angle $\alpha = 50° \pm 1°$ we calculate an effective index of refraction $n = 1.5 \pm 0.1$ in agreement with the value determined, independently, by the prism coupling method.

As a rough estimate of the reflection at a given wavelength we use the expression for the power reflection

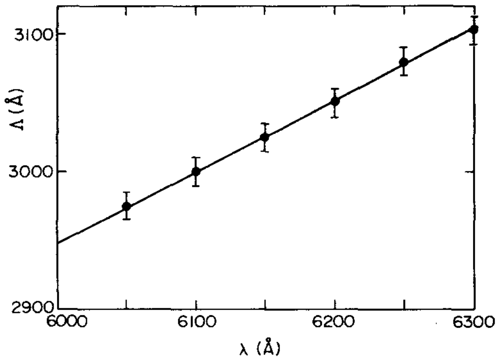

FIG. 3. The dependence of reflected wavelength λ on the period Λ at the reflection region. The straight line plot agrees with Bragg's law $\Lambda = \lambda/2n\cos\alpha$.

at the Bragg condition from a corrugated section of length L of a dielectric waveguide

$$R = \tanh^2(\kappa_l L), \tag{1}$$

where κ_l is the Bragg lth-order coupling constant.[5] In the case of a corrugated waveguide we replace L by L_{eff} which is taken as the length of the waveguide section in which the period $\Lambda(z)$ falls within the forbidden propagation gap. The range of Λ which is within the forbidden gap is

$$(\Delta\Lambda)_B = \frac{\kappa_l \lambda^2 l}{8\pi n^2 \cos^3\alpha}. \tag{2}$$

Assuming a linear chirp

$$\Lambda(z) = \Lambda_0 + az, \tag{3}$$

we find that the distance over which the period varies by $(\Delta\Lambda)_B$ is

$$L_{\text{eff}} = \frac{\kappa_l \lambda^2 l}{8\pi a n^2 \cos^3\alpha} \tag{4}$$

which when substituted in Eq. (1) gives

$$R \approx \tanh^2 \frac{\kappa_l^2 \lambda^2 l}{8\pi a n^2 \cos^3\alpha} \tag{5}$$

for the reflectivity at λ.

From the corrugation depth and the waveguide parameters we obtain $\kappa_l \approx 100\ \text{cm}^{-1}$, $a \simeq 2\times10^{-6}$ which leads to $R \approx 0.50$. This value does not clash with the visual observation of roughly equal power splitting by the grating. Quantitative determination of R was thwarted by excessive waveguide scattering. An examination of Eq. (4) shows that in practice values of R between zero and unity are obtainable by controlling the coupling constant κ and the chirp constant a. We note that κ_l is a decreasing function of l (typically $\kappa_l \propto l^{-1}$) so that the reflection will tend to decrease with increasing Bragg order.

In this work we demonstrated the fabrication of a chirped-grating beamsplitter in an optical waveguide. The beamsplitter reflects light in the plane of the waveguide, and separates spatially beams of different wavelengths. As a device, this beamsplitter can demultiplex, according to wavelength, a signal traveling in a fiber, and send each frequency component to a different fiber or detector. If the directions of the beams are reversed, the same beamsplitter can be used for multiplexing, thus combining beams of different frequencies into a single beam.

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Integrated interferometric reflector

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We propose a new integrated interferometric reflector (IIR) with electrical control. The IIR is suitable for incorporation in integrated optical devices as a laser reflector.

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In this paper we propose a new type of integrated device for use as a laser reflector. To date two basic types of integrated laser reflectors have been demonstrated. The first, which in its various implementations has been referred to as distributed feedback (DFB) or distributed Bragg reflector (DBR), utilizes a periodic structure. The second type uses a index discontinuity, which may be created by etching, etching and regrowth, or simply growth. The new third type described herein, which we call an integrated interferometric reflector (IIR), employs interferometric principles and electrical control. The latter flexibility is not readily available with the first two types. We note that modulators using similar interferometers have previously been demonstrated by Martin[1] and Wang.[2]

A top view of the IIR is shown schematically in Fig. 1. The device consists of a single-mode lossless input waveguide, which branches into two identical symmetri-