High-Return-Loss Narrowband All-Fiber Bandpass Bragg Transmission Filter

F. Bilodeau, K. O. Hill, B. Malo, D. C. Johnson and J. Albert

***Abstract*—An all-fiber narrowband transmission filter (FWHM = 0.25 nm) that is compact and exhibits high return loss (30 dB or better) is demonstrated using simultaneously written matched-pair, side-by-side Bragg gratings in a Michelson interferometer configuration.**

I. Introduction

In this paper we report the fabrication of an all-fiber narrowband transmission filter made using two identical Bragg gratings symmetrically located in each arm of a Michelson interferometer. The filter is compact, has a high throughput at the resonant wavelength, is narrowband and exhibits a high return loss. Fiber Bragg gratings based on photosensitivity [1] are narrowband reflectors at the resonant wavelength (stopband characteristic in transmission). Such a stopband filter response can be inverted to produce a passband transmission characteristic by combining Bragg gratings with Sagnac loops, Michelson interferometers or Mach-Zehnder interferometers [2], [3]. It is also possible to invert the stopband characteristic by combining circulators and Bragg gratings but this approach is expensive. Narrowband transmission filters find use in advanced fiber optic communication systems as bandpass filters, narrowband isolators, wavelength selective taps, dispersion compensators and amplified spontaneous (ASE) rejection filters. The advantage of using photoinduced Bragg gratings in the construction of transmission filters is that a high light throughput in a narrow bandwidth (< 1 nm) can be obtained for any desired wavelength in the spectral transmission band of optical fiber.

Although transmission filters based on photoinduced gratings have been fabricated in fiber optic Sagnac loops [4], Michelson interferometers [5], and Mach-Zehnder interferometers [6] and these filter devices demonstrated high throughput in a relatively narrow bandwidth, other important filter performance characteristics proved elusive: for example in Ref. [6] a return loss of only 8.8 dB is reported (Refs. [4] and [5] do not report experimental values of return loss). Optical devices which have a low return loss produce reflections in the network that impair its operation. The transmission filter reported here exhibits the superior characteristics demanded by todays high performance fiber optic networks.

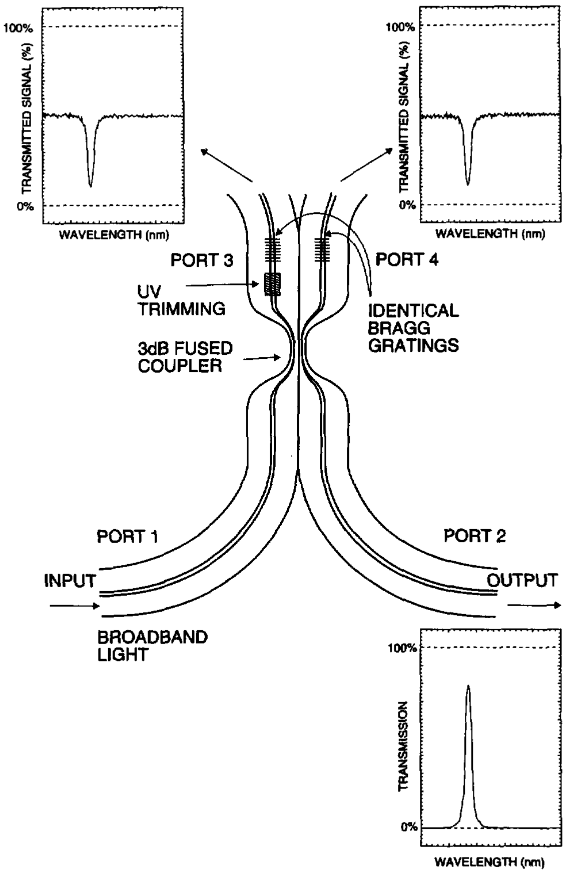

Fig. 1. Schematic of transmission filter.

II. Experimental

Figure 1 shows the schematic of the transmission filter which consists of a 3 dB, four-port coupler (Michelson interferometer) and two in-fiber Bragg gratings. Narrowband transmission exits the device at port 2. The fused taper coupler was fabricated from Corning SMF-28 optical fiber using a computer controlled jig [7]. Pulling of the coupler (excess loss = 0.1 dB or 2%) was stopped at the first 3 dB splitting point (50% splitting ratio of 1535 nm) after an elongation of 12 mm. The coupler was mounted on a glass slide, but not fully enclosed, to permit thereby the photoimprinting of the Bragg gratings in close proximity to the coupler.

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The authors are with the Communications Research Center, P. O. Box 11490, Station "H", Ottawa, Ontario, Canada, K2H 8S2.

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The natural photosensitivity of Corning SMF-28 fiber is relatively low (maximum photoinduced index change $\Delta n \sim 10^{-4}$) so the fiber has to be photosensitized in order to produce Bragg gratings exhibiting large reflectivities. We have used two different techniques to photosensitized the fibers. The first one is called "flame brushing" [8] and consists of moving a hydrogen fueled flame back and forth for a few minutes along the length of the fiber being photosensitized. This fiber processing is localized, very flexible and can be done before or after the fabrication of the coupler. The second photosensitization technique is "hydrogen loading" at high pressure and room temperature [9]. In this case the photosensitization can also be done before or after fabrication of the coupler but requires several days of treatment. Both techniques give large photoinduced peak-to-peak index changes (about 10^{-3}) which translate to reflectivities well over 30 dB (99.9%) for 5 mm long Bragg gratings in SMF-28 fiber.

Using a Lumonics KrF excimer laser the Bragg gratings were photoimprinted through a zero-order-nulled phase mask [10] to achieve Bragg resonance at about 1535 nm. The photoimprinting setup makes it possible to position matched-pair, side-by-side Bragg gratings simultaneously on the parallel fibers (port 3 and 4) just millimeters away form the coupler. This ensures that the two Bragg gratings are as close as possible to being identical and symmetrically located in the interferometer. Precise equalization of the interferometer's arms is done by UV exposure of a fiber section located between the coupler and one of the Bragg gratings to maximize narrowband transmission and return loss. Grating strength is also equalized by a similar process.

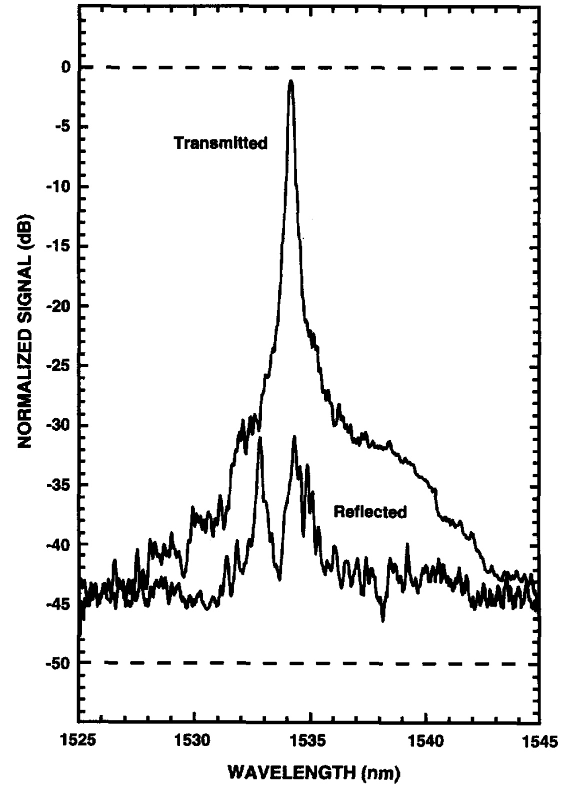

Fig. 2. Transmitted (port 2) and reflected (port 1) signals normalized to the input power.

III. Results and Discussion

Figure 2 shows the output response of a transmission filter (output port 2) and its associated return loss (reflected signal from port 1). The peak reflectivity of both Bragg gratings is 80% with a FWHM of 0.25 nm, in good agreement with theoretical calculations, assuming identical gratings. The gratings are 5 mm long and were exposed for 2 minutes at a pulse repetition rate of 50 Hz and a pulse energy of 300 mJ/cm^2. In this case hydrogen loading was used to photosensitize the fibers. The peak-to-peak index change modulation is 3.4×10^{-4}. The overall loss budget of this filter is 1.2 dB including the coupler contribution of 0.2 dB (double pass through the coupler). UV trimming of the path length difference produced a worst-case return loss of 30 dB.

The filter was designed with dense WDM applications in mind, i.e. the objective was to minimize the sidelobes and to maximize the return loss. The overall quality of the filter response is an indication of the coupler's precise splitting ratio (better than 49/51% at 1535 nm achieved with 50/50% being ideal), of the high quality and symmetry of the Bragg gratings and of good path difference equalization. Sidelobes are more than 20 dB down, 1 nm away from the peak transmission, and 45 dB down 10 nm away.

Other filters designed for minimum excess loss were also fabricated by using higher reflectivity Bragg gratings. A total excess loss of less than 0.3 dB was achieved for Bragg gratings of more than 30 dB reflection (99.9%) with an associated FWHM of about 1 nm. The return loss of these filters is typically 30 dB for light at wavelengths near the center of the filter passband but is significantly lower for light at wavelengths on the edge of the filter response curve. We attribute the lower return loss to the fact that the filter response curves for two Bragg reflectors fabricated under identical conditions are not identical in the wavelength region of the sidelobes. This mismatch in filter responses in the case of the 80% Bragg reflectors is not important since the sidelobes are small. However, a 99.9% transmission filter requires strongly coupled Bragg gratings which have filter responses with significantly higher sidelobes that limit the return-loss in this wavelength region.

Because the gratings are short and in close proximity to the fused coupler, standard coupler packaging techniques can be used that isolate the filter from outside environmental changes and guarantee excellent ruggedness. Total device length is about 25 mm.

The sensitivity of the filter to temperature changes was measured. The filter resonant wavelength tunes continuously by about 1 nm for a temperature change of 100°C. This result is consistent with the thermal sensitivity (~0.015 nm/°C at 1550 nm) of the individual Bragg reflectors forming the filter. During temperature tuning the performance characteristics of the filter wavelength are maintained except for a small decrease (5%) in filter transmission due to thermal erasure of the photoinduced gratings. The performance of this type of filter is very susceptible to environmental changes that induce small differences in path length between the interferometric arms forming the filter. The fact that the return loss did not change during tuning demonstrates that the filter interferometer maintains balance as the temperature changes. We attribute the ruggedness of the filter to environmental changes to the design and fabrication techniques used in forming the filter.

IV. CONCLUSION

A narrow band transmission filter was fabricated using high-quality Bragg gratings. The filter was optimized by using UV light trimming to balance the interferometer. A minimum return loss of 30 dB, an excess loss of 1.2 dB and a FWHM of 0.25 nm were achieved. Other filters with lower excess loss (0.3 dB) and FWHM of 1 nm were also fabricated by incorporating Bragg gratings of more than 99.9% peak reflectivity in the Michelson interferometer.

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