# WRITING OF BRAGG GRATINGS WITH WAVELENGTH FLEXIBILITY USING A SAGNAC TYPE INTERFEROMETER AND APPLICATION TO FH-CDMA

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*Abstract: We present an interferometric setup to write apodized or apodized-chirped Bragg Gratings at any wavelength with the same phase mask and to a precision of 0.1 nm. An encoder for CDMA applications is realized.*

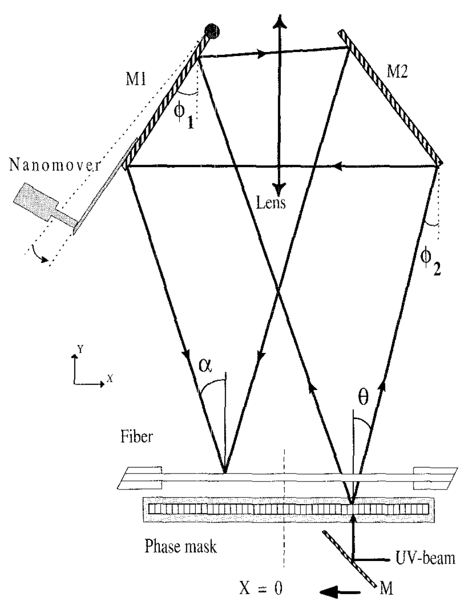
**Introduction**

In the past few years, several telecommunication applications of optical fibre Bragg Gratings (BG) have demonstrated including chromatic dispersion compensation, add and drop multiplexers, optical filters and mirrors for optical amplifiers and laser diodes, etc... [1]. These applications have often require apodized BGs or apodized-chirped BGs at different wavelengths. We demonstrate a new interferometric technique to write BGs at several wavelengths with the same phase mask. This method also allows writing of apodized BGs to reduce the reflectivity sidelobes and of apodized-chirped BG for chromatic dispersion compensation. Recently BGs have been proposed for frequency-hop code division multiple access (FH-CDMA) [2] and we demonstrate the realization of an encoder for this application.

**Experiment**

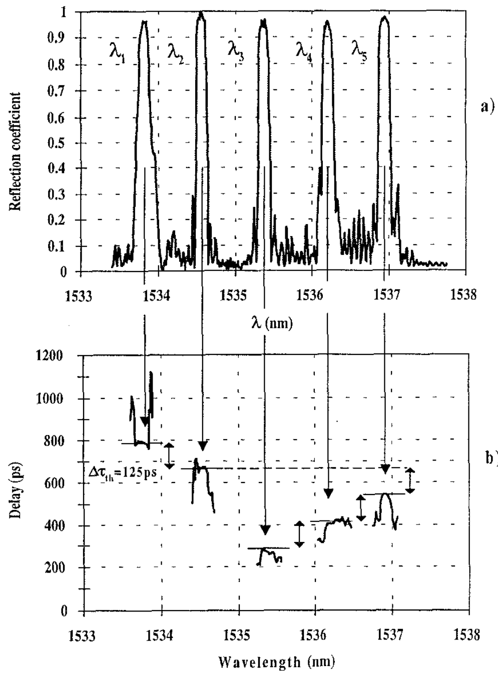
The experimental setup displayed in Fig.1 basically consists of a Sagnac interferometer where the phase mask acts as a beam splitter [3]. The optical path difference between the two interfering UV-pulses result in intrinsic apodization of BGs [3]. The optical fibre is placed slightly above the phase mask. One of the two diffracted UV-beams is reflected off mirrors M1 and M2 while the other diffracted beam goes in the reverse direction. The two beams are recombined on the optical fibre by introducing a tilt of the mirrors M1 and M2 with respect to the x-y plane. By moving the mirror M along the phase mask, the interference pattern is formed along the fibre as in other phase mask scanning techniques. The angle $\theta$ is determined by the phase mask period $\Lambda_m$ and the angle $\alpha$ depends on the three parameters $\theta$, $\phi_1$ and $\phi_2$. When the $\phi_1$ and $\phi_2$ angles characterising the mirror positions are identical to $\pi/4-\theta/2$, the grating peak wavelength will be approximately given by $\lambda_{B0} = n_{eff}\,\Lambda_m$ where $n_{eff}$ is the effective index of the fundamental guided mode including the photoinduced DC component. In this case, $\alpha = \theta$ and the interference pattern occurs just above the phase mask. To write a grating at another Bragg wavelength, the angle of the mirror M1, $\phi_1$, is changed. Calculations show that a variation of $\Delta\phi_1$=4.875 $10^{-4}$ degree corresponds to a 0.1 nm shift for the Bragg wavelength. A 42-cm long lever combined to a nanomover with 50-nm resolution is used to control the mirror rotation. The minimum rotation angle that can be achieved with this system is about $\Delta\,\phi_1$=7.$10^{-7}$. In theory, this experimental set-up could be used to cover a wavelength range starting to 800 nm and going beyond 6 µm with a very high precision.

**Fig. 1: Experimental set-up**



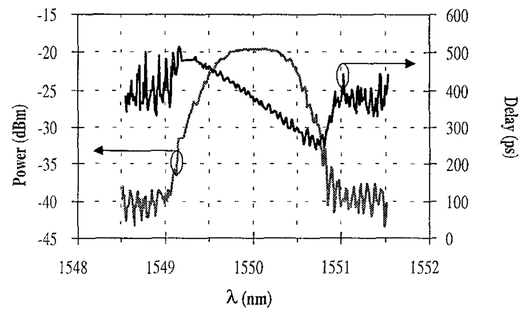

Note that the interference pattern moves parallel to the x-axis when the angle $\phi_1$ changes. For $\lambda_B < \lambda_{B0}$, the fibre is brought closer to the mirrors to position it in the interference pattern. In the same way, for $\lambda_B > \lambda_{B0}$, the fibre is moved away from the mirrors. In this paper, we demonstrate Bragg gratings at wavelengths near 1.5 µm for optical communication systems. Recently, it has been proposed to use Bragg gratings to achieve the encoding/decoding function of FH-CDMA. This communication protocol is attractive for high bandwidth local area networks. The encoder consists of a series of gratings tuned to different wavelengths ($\lambda_2$,$\lambda_5$, $\lambda_1$, $\lambda_8$... as example) that are regularly spaced along the fibre. The wavelengths, chosen from a predetermined set, together with the order in which they are placed determine the user code. In the decoder, the peak wavelengths would be placed in reverse order to perform the correlation function.

**Fig. 2: Encoder for FH-CDMA with 5 BGs: a) reflection spectrum, b) delay versus wavelength.**




Experimentally, to obtain an encoder and a decoder, two identical series of gratings must be written in two fibres. The decoding operation is then obtained by launching light in the opposite direction in the fibre. Figure 2 shows a typical example of an encoder made of five BGs, each is 1.2 cm long. The reflection amplitude and phase were measured using a characterisation set-up with a tunable laser source, a wavemeter and a network analyser. The BGs are not completely apodized and some residual sidelobes can be seen in fig. 2a. However, these sidelobes are weaker than the features of uniform grating. In the spectrum, the wavelength separations between two consecutive peaks are 0.73, 0.81, 0.83 and 0.75 nm. This demonstrates that we can write BGs with a precision below 0.1 nm. For this encoder, the ordering of the wavelengths was chosen to obtain the following code: $\lambda_3$, $\lambda_4$, $\lambda_5$, $\lambda_2$ and $\lambda_1$. The spacing between the gratings along the optical fibre length was approximately 1mm. To achieve this separation, the fibre was moved with regard to x-axis between the writing of each grating. Fig. 2b displays the plot of the reflection delay of the BGs. The theoretical delay of $\Delta\tau_{th}$=125 ps between each grating can be seen on the figure. The high resolution on the mirror rotation also makes it possible to obtain apodized and chirped BGs. The apodization function is produced by the variation of the temporal overlap between the UV pulses of the two diffracted orders as the phase-mask is scanned [3]. A Gaussian apodization results for gratings of 4 cm length and a truncated Gaussian is obtained for smaller gratings. To achieve a linear chirp, the angle $\phi_1$ is varied continuously during one scan of the phase mask length.

**Fig. 3: Spectrum and delay of an apodized-chirped Bragg grating.**




The period of the interference pattern therefore changes along the fibre length. An apodized chirped grating at 1550 nm is shown in figure 3. The BG length is 3.5-cm and the bandwidth measure 0.95 nm. The delay is linear with respect to the wavelength. Some residual sidelobes occur because the 3.5-cm grating length, limited by the mirror diameters, results in a truncated apodization profile. This grating will be used to compensate the residual dispersion experienced by picosecond pulses propagating near the zero dispersion wavelength of DSF fibers.

## Conclusion

We have demonstrated the wavelength flexibility of a Sagnac type interferometer with phase mask scanning to write Bragg gratings. A wide range of frequencies can be obtained with the same phase mask. An encoder for FH-CDMA applications with five BGs was realized and the wavelength dependant delay was measured. The wavelength spacing was 0.78 nm, the physical separation was 1 mm, and the wavelength ordering was chosen to represent the code of a specific user. The experimental setup also allows the writing of apodized-chirped gratings for dispersion compensation. Other applications of this technique would be in the realization of filters and mirrors for fibre lasers outside the communications window.

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## References

/1/ K. O. Hill and G. Meltz: "Fibre Bragg Grating technology fundamentals and overview", J. Lightwave Technol., 1997, 15, (8), pp. 1263-1276 .

/2/ H. Fathallah, S. LaRochelle and L. A. Rusch: "Analysis of an optical frequency-hop encoder with strain-tuned Bragg gratings", in Bragg Gratings, Photosensitivity, and Poling in Glass Fibres and Waveguides: Apllications and Fundamentals, 17, OSA Technical Digest Series, 1997, pp. 200-202.

/3/ P.-Y. Cortès, F. Ouellette and S. LaRochelle: "Intrinsic apodization of Bragg gratings written using UV-pulse interferometry", Electron. Lett, 1998, 34, pp. 396-397.