Polarization-Independent Filtering in a Grating-Assisted Horizontal Directional Coupler

S. François, S. Fouchet, N. Bouadma, A. Ougazzaden, M. Carré, G. Hervé-Gruyer, M. Filoche, and A. Carenco

***Abstract*—We report here on the design and the first realization of a grating-assisted horizontal directional coupler filter exhibiting a highly reduced polarization sensitivity.**

The filter, which is based on InP–InGaAsP materials, is particularly suitable for integration in a 1.3 ± 1.3 μm duplexer. A polarization dependence below 1 dB has been measured for the separation of two 10 nm wide channels, respectively centered at 1.28 μm and 1.32 μm, for a rejection ratio of 10 dB.

I. Introduction

THE MAIN OBJECTIVE of this study is the realization of an integrated 1.3 ±1.3 μm duplexer, associating the emission and the reception of two 10 nm wide, 40 nm spaced channels, in the same 1.3 μm window. To our knowledge, only 1.3 μm/1.5 μm duplexers have been realized so far [1], [2]. Reduction of channel spacing requires single bandpass (to avoid perturbation of the 1.5 μm transmission window) isotropic filters centered either around 1.32 μm or 1.28 μm, with a 3 dB bandwidth compatible with the channel's width.

Unlike Mach–Zehnder interferometers, grating-assisted asymmetric directional couplers offer the advantage of a single bandpass response.

Two structures may be envisaged. The first one consists in a vertical waveguide superposition, which results in a strong coupler asymmetry and thus a narrow optical filter (a few nanometers wide) [3], [4]. The second one is the horizontal structure resulting in an simpler technological run as the two waveguides are realized in a single epitaxial growth [5]. This yields a larger bandwidth that, however, remains suitable for our application.

However, in both cases it turns out that the polarization sensitivity is high (about 20 nm between the TE and TM filter central wavelengths [5]), which is thus detrimental to the duplexer performance. Recently, a solution has been proposed consisting of the use of a double periodic grating [4]. However, this leads to a multi-bandpass filter response.

In this letter, we report on the first realization of a grating-assisted horizontal directional coupler filter exhibiting a highly reduced polarization sensitivity together with a single bandpass response. The filter achieves, with a polarization dependence below 1 dB, the separation of two 10 nm wide and 40 nm spaced channels with a rejection ratio of 10 dB.

Manuscript received January 31, 1995; revised March 6, 1995.

The authors are with France Telecom, CNET, PAB, Laboratoire de Bagneux, B.P. 107, 92225, Bagneux Cedex, France.

IEEE Log Number 9411816.

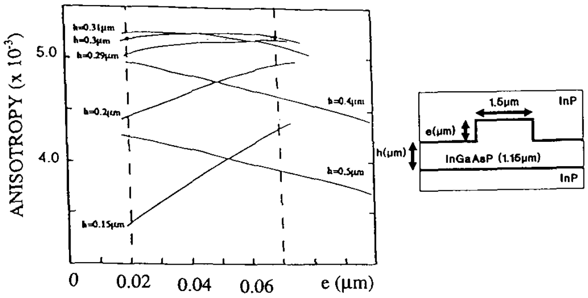

Fig. 1. Buried rib waveguides anisotropy (effective index difference between TE and TM) versus guiding layer thickness h and rib thickness e for a 1.15 μm gap wavelength, calculated at 1.3 μm.

II. Filter Design and Fabrication:

To perform the design, TE and TM-guided eigenmodes and their dispersion characteristics are calculated using a bidimensional mode computation software (included in CNET-ALCOR software) [7] and published values of InP and InGaAsP refractive indices [6]. Then, beam propagation method simulations (with CNET-ALCOR software [7], [8]), taking into account the coupling with radiation modes, are carried out to evaluate the coupling length and grating additional losses. Finally, the filter wavelength response is evaluated using the coupled mode theory.

The polarization insensitivity of an asymmetric directional coupler filter can be achieved if the two waveguides exhibit the same anisotropy: the filter response central wavelengths are then identical for both polarizations. Fig. 1 depicts calculated variations of buried rib waveguides anisotropy with the guiding layer thickness h and rib thickness e. When h is around 0.3 μm, the same anisotropy can be obtained for two different waveguides. It is then checked by using the BPM, that TE and TM coupling lengths are identical. Both material compositions and layer thicknesses have to be precisely controlled: 10 nm accuracy for the quaternary gap wavelength and 10 nm for thicknesses are required to obtain a low polarization dependence (<1 dB) and the desired central wavelength.

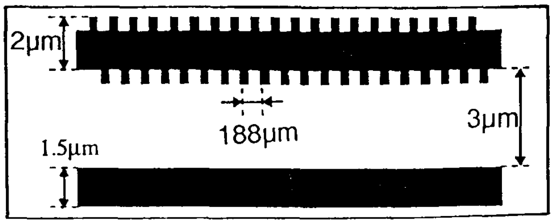

Fig. 2. Top view of the grating-assisted horizontal coupler filter.

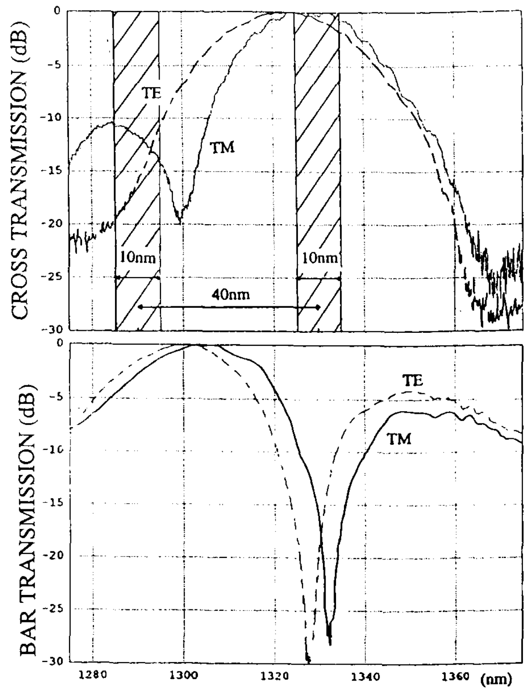

Fig. 3. Cross and bar filter responses for both polarizations ($\lambda g = 1.19$ μm).

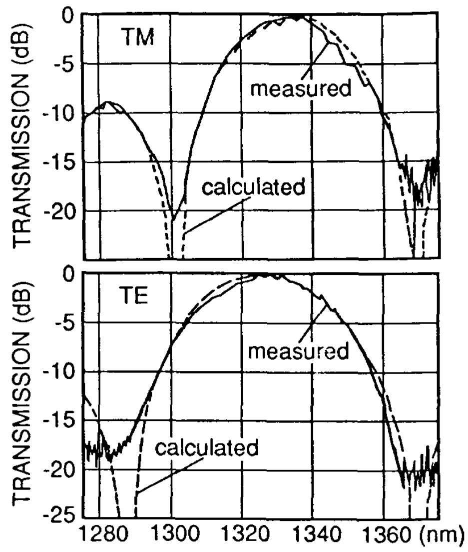

Fig. 4. Measurements (17 periods of 160 μm) and calculations in dotted lines (16 periods of 160 μm).

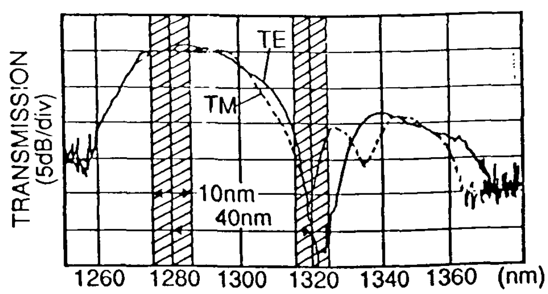

Fig. 5. Filter responses for both polarizations. The grating period is 132 μm and the coupling length equal to 16 grating periods.

Fig. 2 shows the geometry of the coupler made of two 2 μm wide, 3 μm spaced buried rib waveguides of different heights (20 nm and 70 nm). The grating consists of a periodic alternated 0.5 μm enlargement of the width of the most confined guide [9], yielding 16 periods of 188 μm for a 1.15 μm bandgap GaInAsP material. The coupler epitaxial layers are grown by AP-MOCVD. The structure is realized using a two-step self-aligned RIBE dry etching process, followed with burying in undoped InP.

III. Experimental Results

Couplers with different grating periods and interaction lengths have been realized and measured using a pigtailed LED source and an optical spectrum analyzer. For all the wavelength responses presented here, the variation of LED spectrum intensity is fully taken into account.

Fig. 3 presents the results (bar and cross output port) obtained for a grating with 17 periods of 160 μm, etched in a 1.19 μm bandgap quaternary. The shift between the TE and TM central wavelength is only 5 nm, to be compared with the 20 nm obtained in [5]. This filter could be used with two 10 nm wide channels centered on 1.29 and 1.33 μm. The polarization dependence remains below 1 dB on the whole filtered channel. The TM rejection ratio is 9 dB as theoretically expected for this type of coupler. Within the accessible DEL spectral range, no noticeable sidelobes have been detected in the TE response. Agreement between theory and experiment is very good (Fig. 4) when correcting by 5.10^{-3} the GaInAsP refractive index value taken from [6], which lies within the measurement uncertainty. The corresponding calculated grating would have 16 periods of 160 μm.

Taking into account the values inferred, the geometry has been modified so as to obtain a still lower anisotropy. The experimental filter responses for the bar output port are shown in Fig. 5. The TE and TM central wavelengths and 3 dB bandwidths are identical (respectively, 1.283 μm and 33 nm). This filter can be used with two 10 nm wide channels respectively centered on 1.28 μm and 1.32 μm. The rejection ratio between these two channels is 11.5 dB.

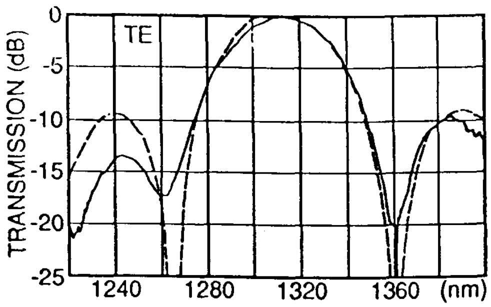

Fig. 6. Filter response for TE polarization ($\lambda g = 1.17$ μm, rib height of 200 A and 500 A, 14 periods of 260 μm), and calculations in dotted lines.

We have measured high propagation losses for the waveguides in this wafer (13 dB/cm for both polarizations), which seem to result from an as yet undetermined residual absorption of the material. Measured TE and TM grating excess losses are 4 dB (for one coupling length). However, measurements on a similar structure realized from a wafer with 1.17 μm photoluminescence peak wavelength, reveal propagation losses as low as 2 dB/cm. TE and TM grating excess losses are still evaluated to 4 dB. For this wafer, TE and TM responses exhibit, on the longer wavelength side, a sidelobe suppression ratio of about 9 dB, as theoretically expected. The short wavelength sidelobes present here again a lower level, which could be explained either by the wavelength dependence of the coupling coefficient (which is not taken into account in the modeling) (Fig. 6).

IV. Conclusion

The first realization and operation of a grating-assisted horizontal coupler filter exhibiting a highly reduced polarization sensitivity has been reported. The filter response, central wavelength and 3 dB bandwidth are the same for both polarizations (1285 nm and 33 nm, respectively). A rejection ratio of 10 dB is achieved for both TE and TM polarization between the two channels separated by 40 nm.

Work is in progress toward a higher sidelobe suppression ratio (>20 dB) by using a coupling coefficient varying along the propagation direction and toward the final filter integration in a duplexer.

Acknowledgment

The authors wish to thank F. Ghirardi, C. Ramus, A. Bruno, F. Huet, and G. Lemestreallan for helpful assistance and fruitful discussions.

References

[1] P. J. Williams, P. M. Charles, I. Griffiths, N. Carr, D. J. Reid, N. Forbes, and E. Thom, "WDM transceiver OEIC's for local access networks," *Electron. Lett.*, vol. 30, pp. 1529–1531, 1994.

[2] C. Bornholdt, D. Trommer, G. Unterborsch, H. G. Bach, H. Venghaus, and C. M. Weinert, "Monolithic integrated wavelength duplexer-receiver on InP," *J. Lightwave Technol.*, vol. 11, pp. 408–410, 1993.

[3] R. C. Alferness, L. L. Buhl, U. Koren, M. G. Young, and T. L. Koch, "Grating-assisted InGaAsP/InP vertical codirectional coupler filter," *Appl. Phys. Lett.*, vol. 55, pp. 2011–2013, 1989.

[4] F. Heismann, L. L. Buhl, B. I. Miller, M. Newkirk, U. Koren, M. G. Young, and R. C. Alferness, "Polarization-independent wavelength filter using a grating-assisted vertical directional coupler in InP," in *ECOC'93, Proc.*, vol. 3, pp. 69–71.

[5] H. Venghaus, C. Bornhold, F. Kappe, H. P. Nolting, and C. M. Weinert, "Meander-type wavelength demultiplexer with weighted coupling," *Appl. Phys. Lett.*, vol. 61, pp. 2018–2020, 1992.

[6] B. Broberg and S. Lindgren, "Refractive index of $In_{1-x}Ga_xAs_yP_{1-y}$ layers and InP in the transparent wavelength region," *J. Appl. Phys.*, vol. 55, pp. 196–198, 1984.

[7] G. Herve-Gruyer, M. Filoche, and F. Ghirardi, "2D finite element simulation of semiconductor directional couplers, comparison with experimental results," in *ECIO'93*, Neûchatel, Apr. 18–22, 1993, pp. 14–52.

[8] M. Filoche, "Simulation numérique des dispositifs micro-opto-électroniques à hétérojonction," thèse de doctorat de l'Université Paris Sud, Orsay, Mar. 1991.

[9] H. P. Nolting and G. Sztefka, "Eigenmode matching and propagation theory of square meander-type couplers," *IEEE. Photon. Technol. Lett.*, vol. 4, pp. 1386–1388, 1992.