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► **To cite this version:**

Yohan Barbarin, X.J.M. Leijtens, E.A.J.M. Bente, C.M. Louzao, J.R. Kooiman, et al.. Extremely Small AWG Demultiplexer Fabricated on InP by Using a Double-Etch Process. *IEEE Photonics Technology Letters*, 2004, 16 (11), pp.2478-2480. <10.1109/LPT.2004.835217>. <hal-02550324>

HAL Id: hal-02550324

<https://hal.science/hal-02550324v1>

Submitted on 24 Apr 2020

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Extremely small AWG demultiplexer fabricated on InP by using a double-etch process

Y. Barbarin, X.J.M. Leijtens, E.A.J.M. Bente, C.M. Louzao, J.R. Kooiman and M.K. Smit.

Abstract—A compact low-loss 4x4 AWG demultiplexer with a channel spacing of 400 GHz is presented. By employing a double-etch process, a low-loss device is made with deeply etched waveguides that have a bending radius down to 30 μm . This small radius and a reduction of the number of array arms, reduces the device size to only 230 x 330 μm^2 . Measured insertion losses are less than 5 dB and the crosstalk is below -12 dB. To our knowledge, this is the smallest AWG reported to date.

Index Terms—AWG, PHASAR, semiconductor waveguide, integrated optics, wavelength-division multiplexing.

I. INTRODUCTION

PHASED-ARRAY demultiplexers [1] or Arrayed Waveguide Gratings (AWGs) are key components for Wavelength Division Multiplexing (WDM) applications. Large-scale integration of this component pushes the size reduction to the limits of the current processing technology. Small polarization-independent phased-array demultiplexers have been reported with a size of 300 x 340 μm^2 by Bissessur et al. [2] using only deeply etched waveguides and a bending radius of 100 μm . To further decrease the size of an AWG and to have an acceptable loss value, it is required to decrease the radius of curvature of the waveguides and to combine deeply and shallowly etched waveguides [3,4]. The increased scattering losses introduced by the straight and curved deeply etched waveguides are compensated by the reduction of the device size. We have tested many AWGs, varying different parameters. In this paper we present the design and the performance of the smallest: the size is reduced to 230 x 330 μm^2 . Afterwards follows an analysis of the reduction of the Array Acceptance Factor (AAF) on AWG's crosstalk and insertion losses.

Manuscript received March 15, 2004. This research is supported by the Dutch NRC Photonics programme and the Towards Freeband Communication Impulse of the technology programme of the Dutch Ministry of Economic Affairs.

Y. Barbarin is with COBRA, Eindhoven University of Technology Den Dolech 2, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands (e-mail: y.barbarin@tue.nl).

X.J.M. Leijtens, E.A.J.M. Bente, C.M. Louzao, J.R. Kooiman and M.K. Smit are with COBRA, Eindhoven University of Technology Den Dolech 2, P.O. Box 513, 5600 MB, Eindhoven, The Netherlands.

II. DESIGN

We have designed an extremely small four-channel AWG with a 400-GHz channel spacing (3.2 nm at 1550 nm) and a Free-Spectral-Range of 12.8 nm (Fig.1). The minimum bending radius used for the array waveguides was 30 μm . Although an even smaller minimum radius could have been used, it does not significantly reduce the device size. The AWG was designed for a ridge waveguide structure consisting of a 720 nm thick InGaAsP waveguide layer (bandgap wavelength 1.25 μm) with a 1200 nm thick InP upper cladding layer.

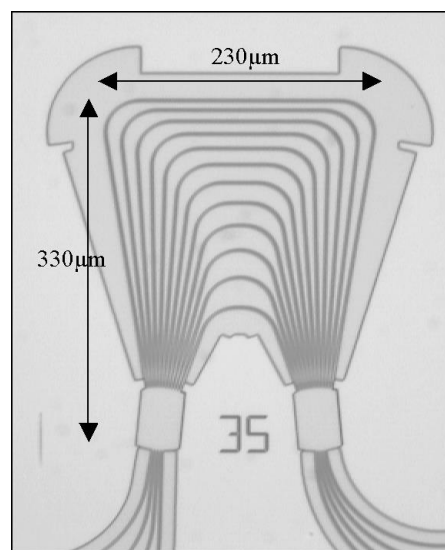


Fig. 1 Photograph of the fabricated device.

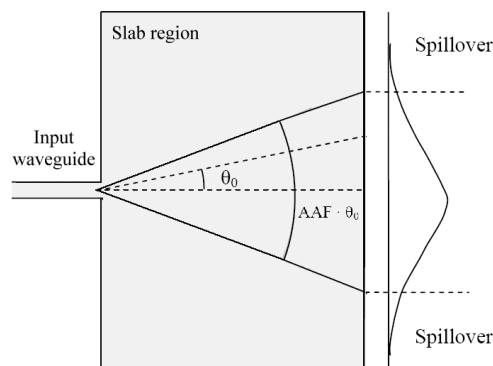


Fig. 2. Definition of the Array Acceptance Factor (AAF)
A value of AAF = 4 is shown.

Next design parameter to be defined is the Array Acceptance Factor (AAF). A definition of this parameter is plotted in figure 2. The beam propagating through the input waveguide and entering the slab region is no longer laterally confined and becomes divergent. The divergent beam is approximately Gaussian with a waist parameter θ_0 . Only a part of the far field is accepted by the array of arms. The corresponding far field angle divided by θ_0 , defines the Array Acceptance Factor (AAF). In this design, the angular region corresponding to an AAF of 2.4 holds 12 array waveguides.

The first 10 μm of the waveguides in the array of the small AWG, connected to the slab region (Fig.3), are 2.0 μm wide and shallowly etched (100 nm depth in the filmlayer). The array arms themselves and the input waveguides are 1.7 μm wide and deeply etched (150 nm through the filmlayer). The deep-shallow transition is done gradually using a 50 μm long taper. A better coupling is obtained by using an extra width of 0.3 μm between the taper and the shallow waveguide.

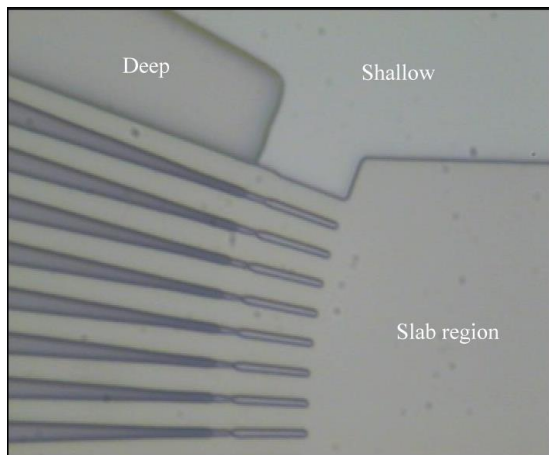


Fig. 3. Photograph of deep-shallow waveguide transition. The transition is done gradually using a 50 μm long taper.

The device was designed for a 720 nm thick filmlayer (bandgap wavelength 1.25 μm) and a 1200 nm thick InP cladding layer. With this layerstack and a deeply etched waveguide width of 1.7 μm the propagation constant of the fundamental mode is polarization independent. However, due to the material available, we have realized this AWG in a layer stack with a 500 nm thick InGaAsP waveguide layer (bandgap wavelength 1.35 μm) with a 300 nm thick InP cladding layer. Because of this change, the device is not polarization independent.

III. FABRICATION

The layerstack of the small AWG was grown using Low-Pressure Metalorganic Vapor Phase Epitaxy (LP-MOVPE). A SiN_x Layer of 50 nm was deposited using Plasma-Enhanced Chemical Vapor Deposition (PECVD). This layer served as an etching mask for the waveguides. The pattern was defined using contact photolithography with positive photoresist and transferred to the SiN_x layer by CHF_3 Reactive Ion Etching (RIE). Then deep areas were defined using a second contact photolithography with positive photoresist. The photoresist

served as a mask for the deep etch. The deep waveguides were partly etched employing an $\text{CH}_4\text{-H}_2$ etching process (RIE). The depth corresponds to the difference between shallow and deep waveguides. After the resist was removed, deep and shallow waveguides were etched with the same process. The SiN_x layer was removed in a buffered HF solution.

IV. MEASUREMENTS

Losses for deeply and shallowly etched straight waveguides were measured using the Fabry-Pérot technique [5]. An average of 2.2 dB/cm was obtained for shallowly etched straight waveguides. 5.5 dB/cm was obtained for deeply etched straight waveguides. Losses for a 1.7 μm wide deeply etched waveguide are almost 2 dB/cm higher than with a single etching process. This is due to the masking of the shallow parts by photoresist, which has introduced sidewall roughness. Losses for 2 μm wide shallowly etched waveguides are slightly higher in comparison to similar waveguides made with a single etch process.

The transmission spectrum of the small AWG was measured using the spontaneous emission spectrum of an EDFA as a broad-band light source and a polarizer to select the polarization state. Light was coupled into the chip using microscope objectives, then coupled out of the waveguides by a single-mode lensed fiber and analyzed with an optical

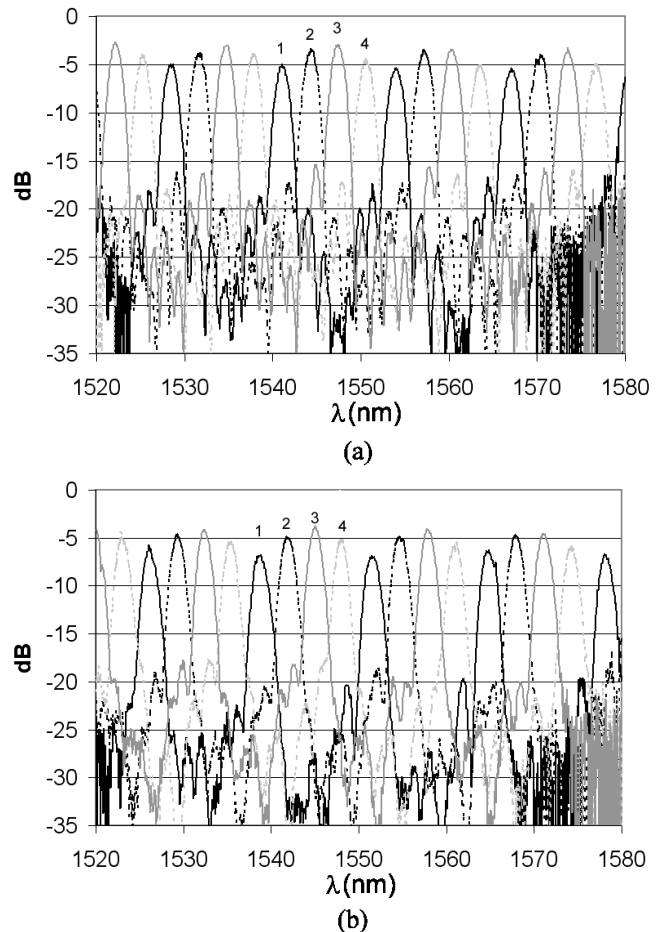


Fig. 4. Measured transmission spectra of the small AWG for TE (a) and TM (b). As expected with a 500 nm thick filmlayer the device shows some polarization dependence.

spectrum analyzer. The reference EDFA spectrum that defined the insertion loss level was determined from transmission spectra of a large number of separate good waveguides.

Figure 4 shows the measured transmission spectra for both polarizations of the small AWG. Measured insertion losses are less than 5 dB and the crosstalk is below -12 dB. As expected, due to the fact that we used a 500 nm thick filmlayer instead of 720 nm, the devices have some polarization dependence in agreement with simulations. This particular device shows a 2.3 nm shift between the two polarizations. We notice a difference of 2 dB between the transmission of the center channel and the outer channels. This is to be expected for a periodic device.

Because of the crosstalk, the device presented is more suitable to be integrated in a multi-wavelength laser (MWL) [6,7] than in an add-drop multiplexer (ADM) or an optical crossconnect (OXC). For MWL integration, the periodicity of the device requires narrow gain material centered on the transmission spectra to avoid the lasing in other Free Spectral Range.

V. EFFECT OF THE REDUCTION OF THE AAF

The Array Acceptance Factor (AAF) is an important parameter in the design of a small AWG as it determines the number of arms and thus the size of the device. Figure 5 and 6 show the AAF influence on the insertion losses and the crosstalk measured from a series of AWGs with a constant a bending radius of $100\ \mu\text{m}$ and a design similar to the one described in [3].

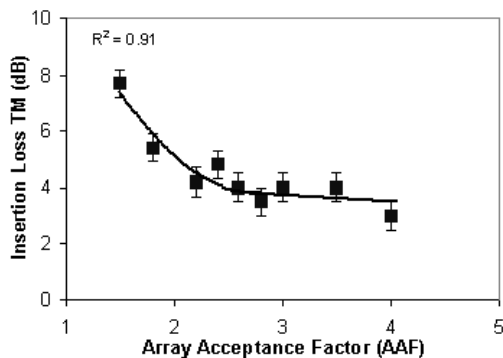


Fig. 5. Measured insertion losses versus the Array Acceptance Factor (AAF)

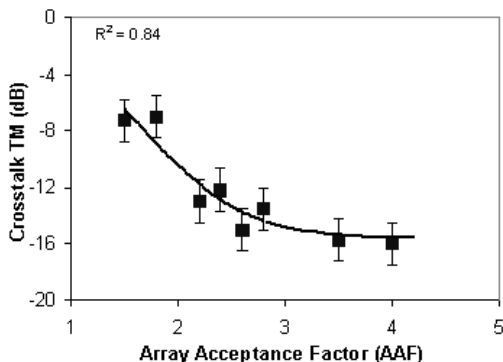


Fig. 6. Measured crosstalk versus the Array Acceptance Factor (AAF)

The insertion loss is almost independent of the AAF for values above 2.5. Below that factor, however, the loss starts to rapidly increase. The crosstalk shows the same behavior: a clear increase for an AAF factor below 2.5. We believe that these results are independent of the bending radius and the specific design of the array arms.

The device presented above has an AAF of 2.4 and a minimum bending radius of only $30\ \mu\text{m}$. The measured insertion losses are less than 5 dB and the crosstalk is below -12 dB. Those values fit well with the previous graphs for this value of the AAF.

VI. CONCLUSION

A compact low-loss 4×4 AWG demultiplexer with a channel spacing of 400 GHz has been fabricated. The device size is only $230 \times 330\ \mu\text{m}^2$, and to our knowledge, this is the smallest AWG reported to date. Measured insertion losses are less than 5 dB and the crosstalk is below -12 dB. The device is suitable, for example, for use in very compact multi-wavelength lasers.

ACKNOWLEDGMENT

This research is supported by the Dutch NRC Photonics programme and the Towards Freeband Communication Impulse of the technology programme of the Dutch Ministry of Economic Affairs.

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