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

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*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 small bending radius down to 30 µm. This small radius and a reduction of the number of array arms, reduce the device size to only 230 x 330 µm². Measured insertion losses are less than 5 dB and the crosstalk is below -12 dB. The device is suitable for very compact multi-wavelength lasers. To our knowledge, this is the smallest AWG reported to date.*

## 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 [2] with a size of 300 x 340 µm² 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 propagation losses introduced by the straight and curved deeply etched waveguides are compensated by the reduction of the device size. The size of the device presented here is reduced to 230 x 330 µm². It is suitable to be integrated in multi-wavelength lasers (MWLs) [5,6].

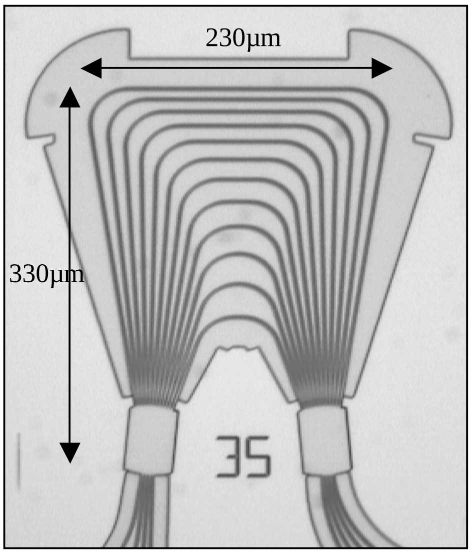


Fig.1 Photograph of the fabricated device.

## 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 minimal bending radius used for the array waveguides was 30 µm. 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 cladding layer. The number of arms is 12, which corresponds to an Array Acceptance Factor (AAF) of 2.4.

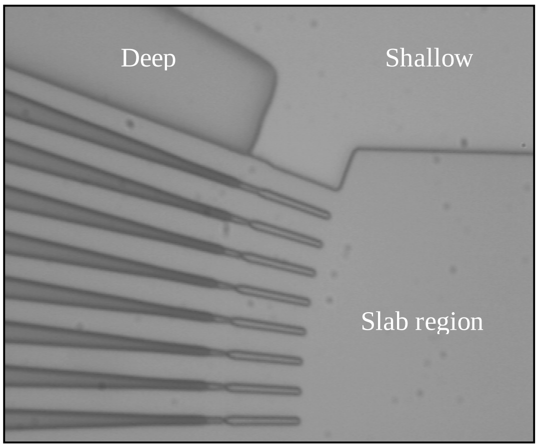


Fig.2 Photograph of deep-shallow waveguide transition. The transition is done gradually using a 50µm long taper.

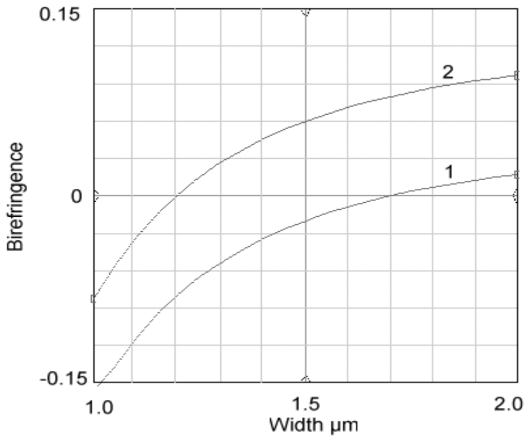


Fig.3 Birefringence as a function of the width. The curve 1 corresponds to a 720 nm filmlayer thickness and $\lambda_{bandgap}$=1.25 µm, the curve 2 to a 500 nm filmlayer thickness and $\lambda_{bandgap}$=1.35µm

The small AWG uses 2.0 µm wide shallowly etched waveguides to couple light out from the slab region (Fig.2). Inputs waveguides and arms are 1.7 µm wide deeply etched waveguides. The deep-shallow transition is done gradually using a 50µm long taper. A better coupling is obtained by using an extra width of 0.3µm between the taper and the shallow waveguide.

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 1.7µm the propagation constant of the fundamental mode is polarisation independent (curve 1 in Fig.3). We have realised this AWG using a material with a 500 nm thick InGaAsP waveguide layer (bandgap wavelength 1.35 µm) with a 300nm thick InP cladding layer, the device is not polarisation independent (curve 2 in Fig.3).

## Fabrication

The layerstack of the small AWG was grown using Low-Pressure Metalorganic Vapor Phase Epitaxy (LP-MOVPE). A SiNx Layer of 50 nm was deposited using Plasma-Enhanced Chemical Vapour 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 SiNx 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 optimised $CH_4$-$H_2$ 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 SiNx layer was removed wet chemically.

## Measurement

Losses for deeply and shallowly etched straight waveguides were measured using the Fabry-Pérot technique [7]. An average of 2.2 dB/cm was obtained for shallowly etched straight waveguides. 6 dB/cm was obtained for deeply etched straight waveguides. The results are similar for both polarisations. Losses for a 1.7 µm wide deeply etched waveguide are almost 2 dB higher than with a single etching process. The masking of the shallow parts by photoresist has introduced sidewall roughness. Losses for 2 µm wide shallowly etched waveguides are slightly higher in comparion 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 polariser to select the polarisation state. Light was coupled into the chip using microscope objectives, then coupled out of the waveguides by a single-mode lensed fibre and analysed with an optical spectrum analyser. The reference level was determined from transmission spectra of a large number of separate waveguides.

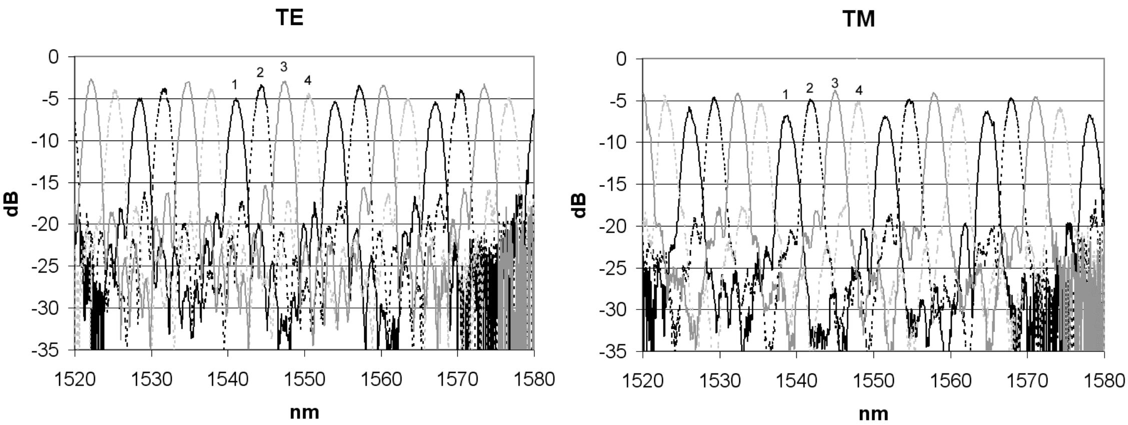


Fig.4 Measured transmission spectra of the small AWG for both polarisations. As expected with a 500nm thick filmlayer the device shows some polarisation dependence.

Figure 4 shows the measured transmission spectra for both polarisations. Measured insertion losses are less than 5dB and the crosstalk is below -12dB. As expected, due to the fact that we used a 500 nm thick filmlayer instead of 720 nm, the device shows some polarisation dependence. We notice a difference of 2dB between the transmission of the centre channel and the outer channels. This is to be expected for a periodic device. The device is more suitable to be integrated in a multi-wavelength laser (MWL) than in an add-drop multiplexer (ADM) or an optical crossconnect (OXC). For application of an AWG in a MWL or in a compact on-chip dispersion compensator [8], the crosstalk and the position and quality of each channel are critical parameters. Finally, since lasers typically operate at one polarisation only, polarisation independency is not an issue, so this AWG can be integrated using the same layerstack as that used for the lasers.

## Conclusion

A compact low-loss 4x4 AWG demultiplexer with a channel spacing of 400 GHz has been fabricated. The device size is only 230 x 330 µm², to our knowledge, this is the smallest AWG reported to date. Measured insertion losses are less than 5dB and the crosstalk is below -12 dB. The device is suitable for very compact multi-wavelength lasers.

## Acknowledgment

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