4-channel wavelength flattened demultiplexer integrated with photodetectors

4-CHANNEL WAVELENGTH FLATTENED DEMULTIPLEXER INTEGRATED WITH PHOTODETECTORS

C.A.M. Steenbergen, C. van Dam, T.L.M. Scholtes[1], A.H. de Vreede, L. Shi
J.J.G.M. van der Tol[2], P. Demeester[3], M.K. Smit

Dept. of Electrical Engineering, Delft University of Technology
P.O. Box 5031, 2600 GA Delft, The Netherlands
Tel. +31 15 78 6106, Fax. +31 15 78 4046

[1] Dept. of Applied Physics, Delft University of Technology, The Netherlands

[2] Royal PTT Nederland B.V., PTT Research, Leidschendam, The Netherlands

[3] INTEC, University of Gent, Belgium

Abstract

We report the first 4-channel wavelength demultiplexer with flattened response, monolithically integrated with photodetectors. The demultiplexer is realized in InP/InGaAsP and operates around a centre wavelength of 1533 nm with a wavelength spacing of 2.0 nm. The response is flat within 1 dB for a 1.2 nm band centered around the transmission wavelength. Crosstalk remains below -20 dB. On-chip losses are estimated at -6.0 dB. Photodetector capacitances and dark currents at -5 V bias are 0.5 pF and better than 8 nA respectively.

Introduction

Wavelength Division Multiplexing (WDM) enables us to use both the electrical and optical domain for exploiting the huge bandwidth of optical fibers. A key-component in WDM-systems is a wavelength (de)multiplexer. Several wavelength demultiplexers have been reported [1, 2, 3]. A flattened response of the demultiplexer relaxes the tolerance conditions of the transmission laser wavelength. Such a flattened demultiplexer without detectors has been published recently by Amersfoort [4]. Wavelength demultiplexers without a flattened response, integrated with photodetectors have been reported [5, 6]. In this paper we report the realization of a wavelength flattened 4-channel demultiplexer integrated with photodetectors on an N^+InP substrate.

Design

The presented wavelength demultiplexer is based on the phased-array concept [7]. The channel spacing was designed at 2.0 nm around a centre wavelength of 1535.0 nm. We applied multimode output waveguides in order to obtain a flattened wavelength response [4]. The light in the output waveguides is coupled into the detectors by evanescent field coupling (see Fig. 2). The layer structure was optimized for maximum detector absorption [8]. The detector capacitance was minimized for high frequency applications. Based on earlier experiments [8] the detector length was chosen 60 μm, for which 90% of the power is absorbed. The detector width was adjusted to the diffraction pattern of the optical field in the output waveguide of the demultiplexer. Since the output waveguide is multimoded and the diffraction of the highest order mode is largest (see Fig. 1), the detector width was adjusted to the diffraction pattern of the highest order mode present in the output waveguides. Taking a 2.0 μm tolerance, we ended up with a diode of 10 μm width at the beginning and 40 μm at the end (Fig. 2 a). In this way the pin area of the detector is minimized, while maintaining equal absorption for all modes. This is essential for maintaining the flattening of the wavelength response. The contact pad is placed on a 3.0 μm thick SiN_x layer in order to reduce the parasitic capacitance.

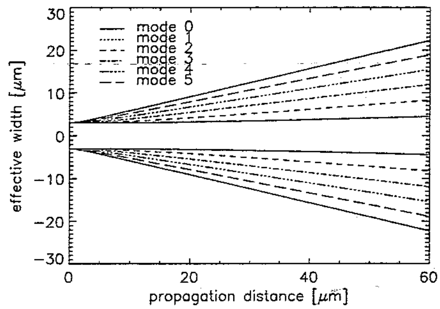

Figure 1 Effective width of the diffraction of modi into a slab waveguide from a 6.0 μm deeply etched waveguide.

Fabrication

The layer structure was grown on an N^+-InP substrate by low pressure MOVPE. It consists of a 1.5 μm undoped InP buffer layer, a 0.6 μm undoped InGaAsP (Q1.3) waveguide core, a 0.3 μm undoped InP waveguide cladding layer, a 0.27 μm undoped InGaAs absorption layer, a 0.6 μm graded p-type InP layer (100 nm undoped, 200 nm 10^{17} cm^{-3}, 300 nm 10^{18} cm^{-3}), and a 0.1 μm p-type 5 x $10^{18}cm^{-3}$ InGaAs contact layer.

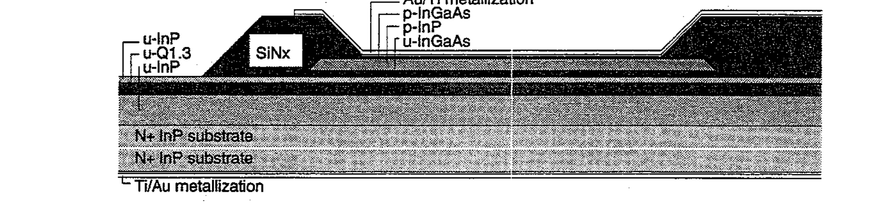

Figure 2 Topview and cross-section of waveguide detector integration.

Detector mesa's were formed by selective etching. The p-InGaAs/u-InGaAs and p-InP were etched by respectively H_2O_2:H_2SO_4:H_2O (1:1:10) and HCl:H_3PO_4 (1:4). Next a 140 nm PECVD SiO_2 layer was deposited on the whole wafer. The waveguide pattern was defined in photoresist and etched in the SiO_2 by CHF_3 RIE etching. The photodiodes were covered with photoresist. By CH_4/He RIE etching a 350 nm step was etched in the InP/InGaAsP, forming the phased array waveguides (see Fig. 2b). Through a window in photoresist the output waveguides of the phased array were further etched with the SiO_2 mask up to a depth of 1.0 μm (see Fig. 2c). This enables better confinement of the higher order modes, in order to obtain a flattened response of the wavelength demultiplexer.

After removal of the photoresist and SiO_2, the photodiodes were passivated by a stress free SiN_x layer, which was 3.0 μm thick for reduction of the probe pad capacitance. The contact windows were etched in the SiN_x. The PECVD depostion process was optimized in order to obtain a V-groove type sidewall profile, which is suitable for interconnect metallization. The metallization of the p-contacts was formed by evaporation of Ti/Au, which was wet chemically etched. The n-type backside of the chip was metallized by Ti/Pt/Au. Finally, the contacts were annealed at 375 °C for 30 seconds and the chip facets were formed by cleaving. No AR-coating was applied. Fig. 2 shows the topview and cross-sections of the waveguides and detectors.

Measurements

The chip was characterized by coupling linearly polarized light from a HP 8168A tunable laser source into the waveguides with an AR-coated microscope objective. The light was aborbed by the integrated detectors and the photocurrent was measured.

Fig. 3 shows the wavelength response for TE-polarization, measured by sweeping the wavelength of the tunable laser source. The excess losses were determined to be between -6 and -7.5 dB by comparison of straight waveguides integrated with photodetectors. The crosstalk level remains below -20 dB. Part of the cross-talk is caused by residual TM-polarization. The TE-TM shift is 5 nm, which is due to the birefringence of the array waveguides. The measured centre wavelength is 1533 nm, which is 2 nm less than the design value.

The waveguide losses were determined by measuring the detector current for photodiodes with various waveguide lengths in front of the detector. The losses are estimated to be 1.5 dB/cm for both polarizations. The external efficiency was about 30% including the fiber-chip coupling losses.

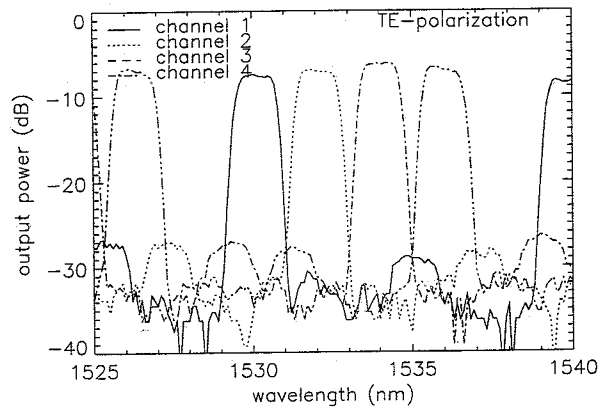

Figure 3 Wavelength response of the demultiplexer integrated with detectors. The measurements were calibrated against equal detectors integrated with straight reference waveguides.

The detector capacitance was determined at 1 MHz by CV measurements. Figure 4 shows the capacitance as a function of the bias voltage. Excellent uniformity is achieved and the capacitance is lower than 0.5 pF at -5 V bias. The dark current was below 8 nA at -5 V for all four photodiodes as depicted in Fig. 4.

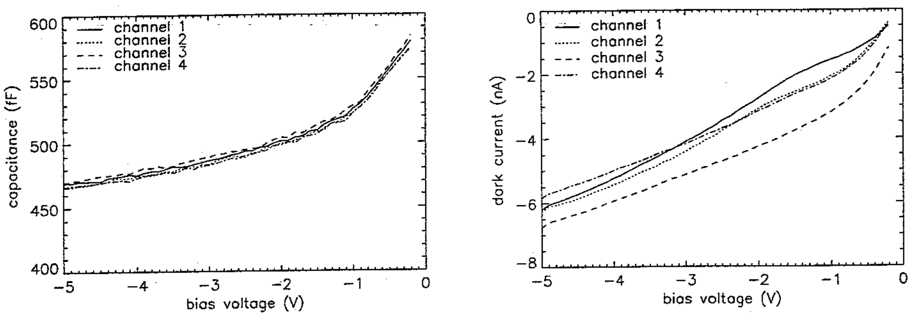

Figure 4 CV measurements at 1 MHz and dark current measurements for all four detectors.

Conclusions

A 4-channel phased array wavelength flattened demultiplexer integrated with photodetectors has been fabricated. The flattening occurs within a 1.2 nm band. Crosstalk levels below -20 dB have been measured. The detector capacitance is below 0.5 pF and dark current better than 8 nA for all four channels at -5 V bias.

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