

Full length article

Monolithic integration of a InP AWG and InGaAs photodiodes on InP platform

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ABSTRACT

We demonstrate a monolithic integration of a photodiode array and a 13 channels arrayed waveguide grating (AWG) grown on InP substrate with a shallow trench structure between the AWG top cladding layer and the photodiode p-doped layer. A smooth epitaxial structure interface is obtained by nonselective regrowth to make the two epitaxial structure compatible and fabrication easy. Three-dimensional finite-difference time-domain (FDTD) solutions are used in the optical simulations. The highest simulation quantum efficiency can achieve 82%. The fabricated PD with a trench structure presents a responsivity of 0.68 A/W. The integrated device can achieve a total capacity of more than 200 Gb/s.

1. Introduction

The InP-based large scale photonic integrated circuits (PICs) is one of the most promising choices to meet the increasing demand for speed and capacity of telecommunication systems due to the possibility of monolithic integrating multiple active and passive components such as lasers, modulators, detectors, multiplexers/demultiplexers and optical amplifiers [1]. Wavelength division multiplexing (WDM) technology is one of the most effective and direct method to improve the bandwidth of optical fiber communications and optical interconnects [2,3]. The PICs based arrayed waveguide grating (AWG) is a key component of optical fiber communication system. An AWG based on InP deep ridge waveguides are suitable for multi-channel configurations for WDM systems due to the small footprint and weak polarization dependence [4,5]. The AWG integrated with photodiodes is developing for multi-channel and increasing the receiving rate [6,7]. The PIN photodiodes integrated with AWGs 16×2.5 Gb/s [8] and 10×10 Gb/s [9] have been reported. To further improve the device performance, we propose to use the evanescently coupled waveguide photodetectors instead of PIN photodiodes.

Evanescently coupled waveguide photodetectors are key devices in the field of digital, as well as analog, optical transmissions, due to their high bandwidth and high responsivity [10–13]. This structure permits the efficiency and bandwidth to be specified independently because the internal efficiency is determined not by the thickness but by the length of the photoabsorption layer [14]. A very high responsivity more than 1 A/W and 48 GHz bandwidth have been reported [15]. In addition,

their major advantages are the ease of integration with other optoelectronic devices to realize complex systems.

Unlike discrete devices, the monolithic integrated device must ensure that all components can work normally. So we must give priority to device yield and uniformity. This letter reports the novel design concept and simulation results of evanescently coupled photodiodes integrated with AWGs for high quantum efficiency and high yield. Monolithic integration of photodetector array and AWGs is demonstrated and the device's performance is investigated.

2. Design and simulation

As the epitaxial structure of the evanescently coupled waveguide photodetector and AWGs is quite different, the monolithic configuration has been a design consideration. Due to the abnormal growth at the boundary of the selective area growth (SAG), we choose the nonselective regrowth to make the fabrication easy and improve the yield of the photodetectors. The compatible epitaxial structure of the monolithic integrated device consists of two areas: the AWG area and PD area as shown in the Fig. 1(a). The AWG area includes the top cladding, bottom cladding and core layers and the PD area includes bottom cladding, core layer, a matching layer, an absorption layer and a p-contact layer. The p-contact layer is the same as the top cladding of the AWGs. At the interface, a suitable Ln-long portion of matching layer is inserted into the AWG top cladding to enhance the coupling efficiency of more than 20%, thus shortening the detector length to less than 20 μm to realize higher bandwidth [16].

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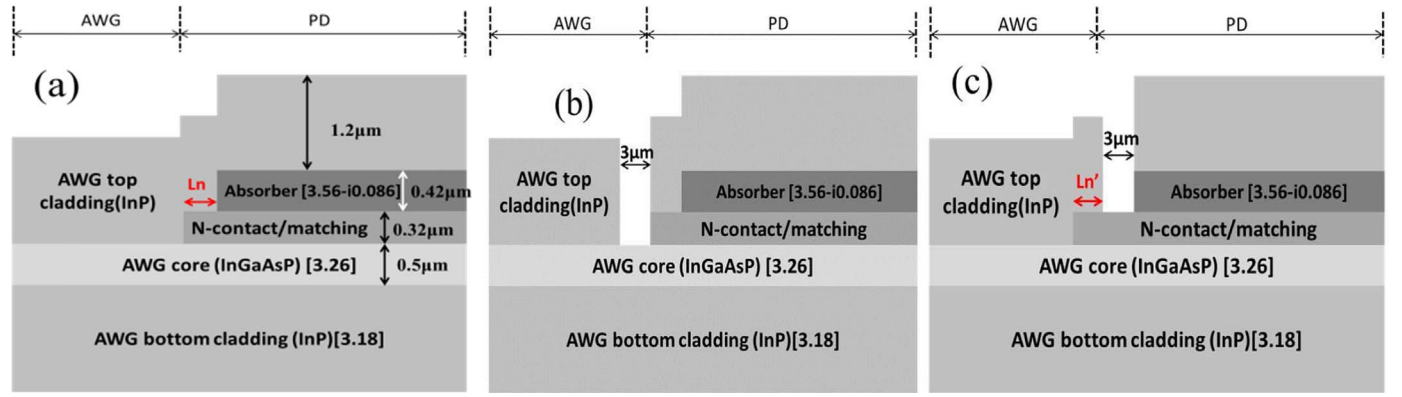


Fig. 1. (a) The cross epitaxial structure section of the monolithic integrated device. (b) The cross section of the monolithic integrated device with a trench structure on the core layer at the boundary. (c) the cross section of the monolithic integrated device with a trench structure on the n-contact layer at the boundary.

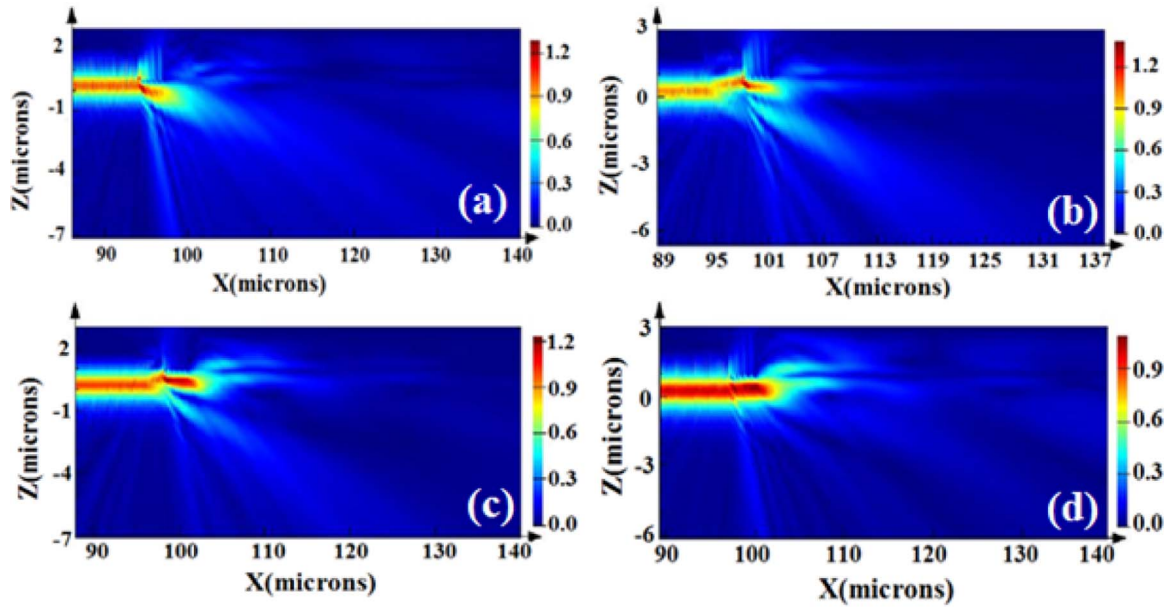


Fig. 2. The longitudinal section of the optical field distribution in device with different structures: (a) the trench is on the AWG core layer (b) the trench is on the matching layer and $Ln'=4 \mu\text{m}$ (c) the trench is on the matching layer and $Ln'=2 \mu\text{m}$ (d) the trench is on the matching layer and $Ln'=0 \mu\text{m}$.

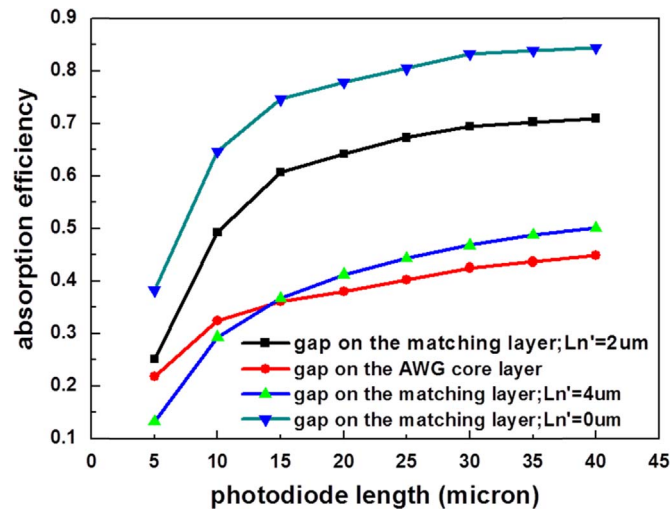


Fig. 3. Absorption efficiency as a function of device length L with the different insertion length Ln' and trench locations.

Table 1

The first epitaxial structure of the integrated device.

Function	Compound	D[nm]	dopant	$N[\text{cm}^{-3}]$
coat	InP	20		
absorption	$\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$	420		
etch stop1	InP	10		
n-contact	$\text{InGa}_{0.3}\text{As}_{0.64}\text{P}$	320	Si	$2.0\text{E}+18$
etch stop2	InP	10		
AWG core	$\text{InGa}_{0.11}\text{As}_{0.25}\text{P}$	500		
AWG bottom	InP	1000		
substrate	InP	50,000		

Table 2

The regrowth epitaxial structure of the integrated device.

Order	Compound	D[nm]	dopant	$N[\text{cm}^{-3}]$
5	$\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$	40	Zn	$1.0\text{E}+19$
4	InP	700	Zn	$2.0\text{E}+18$
3	InP	400	Zn	$1.0\text{E}+18$
2	InP	50	Zn	$5.0\text{E}+17$
1	InP	50		

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