Polarization based Integration Scheme (POLIS) for Active and Passive Components

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Polarization based integration scheme (POLIS) combines active and passive components on the same material, using polarization properties of compressively strained InGaAs/InP quantum wells. Devices have been fabricated, characterized and reasonable device performances have been observed.

Keywords: integration scheme, active, passive, polarization, indium phosphide, strained quantum well

Introduction

The evolution of information transport over optical networks is one of the drivers behind the upcoming information society. This development results in increasing demand for more complex optical functionality at ever-lower prices. The monolithic integration of these functions in an optical integrated chip (IC) opens the possibility for mass production, which will be able to fulfill this demand.

Essential to the success of mass production of optical integrated chips (IC) is a cheap, flexible and efficient integration technique. An optical IC will contain a variety of components, such as optical waveguides, light sources, detectors, optical switches etc. These functions put different requirements on the material system used, e.g. waveguides require transparent materials to keep the attenuation low, while on the other hand detectors need absorption of the light. Several solutions have been proposed and demonstrated to reconcile these conflicting requirements [1,2]. They all have however the disadvantage that additional processing steps are needed, e.g. applying extra material.

Here we report the idea of POLIS (POLarization based Integration Scheme) together with experimental results. It is based on the fact that properties of an optical IC are dependent on the polarization state of the signal. In general this is a severe problem, but here we use it to advantage. It is possible to design a layer structure on a substrate of indium phosphide (InP), which can guide light with one polarization, but absorbs light with the opposite polarization. This creates the possibility to integrate lasers and detectors together with waveguides, switches and demultiplexers on one material. The polarization is in this case a parameter that determines the material properties. Thus instead of changing the material via regrowth, the polarization state of the signal is changed to realize active and passive components. With polarization converters it is possible to obtain the required polarization, transparent or absorbing, in each component of the optical circuit.

Previously we have reported [3] that it is possible to realize efficient, short polarization converters on a wafer of indium phosphide. The TE-TM polarization conversion efficiency was more than 80% and the insertion loss was about 1.7 dB for entire structure of length 600 µm. They can be further improved to implement in POLIS technique.

Concept

As mentioned earlier, polarization for TE or TM, is the parameter that defines the active or passive part of the circuit. Therefore transparency for one polarization and absorption for the other is required at the same wavelength. This can be achieved through bandgap modification: strain in the quantum well splits the heavy hole and the light hole in the valence bandedge, and thus the two transitions give absorption at different wavelengths. At a single wavelength one polarization gives absorption while the other is transparent. Compressive strain, which moves the heavy hole (TE-transition) up in the valence band and light hole (TM-transition) down, can serve our purpose. For higher strain, the separation between the heavy-hole and light-hole valence bands increases, resulting in an increased wavelength separation between the bandgap for TE and TM polarization. Calculations [4] showed that 4 nm thick $In_{0.65}Ga_{0.35}As$ compressively strained quantum wells have both TE absorption and TM transparency at 1550 nm (800 meV) wavelength as shown in the Figure 1.

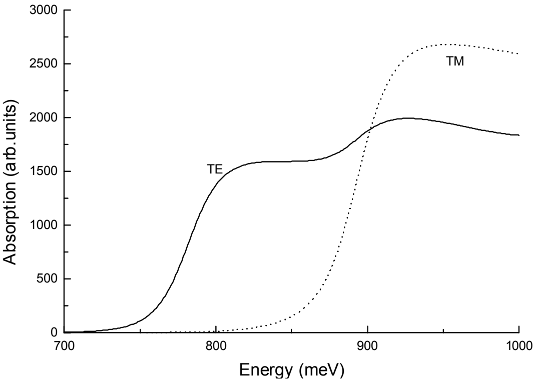

Fig. 1: Calculated absorption spectrum of a 4 nm compressively strained $In_{65}Ga_{35}As$ quantum well with InGaAsP barriers

Realization

Our material system contains InGaAs compressively strained quantum wells sandwiched between InGaAsP on an InP substrate. The designed layer structure consists of a 300 nm $In_{73}Ga_{27}As_{59}P_{0.41}$, a 3 nm compressively stained quantum well of $In_{64}Ga_{36}As$ and again 300 nm $In_{0.73}Ga_{0.27}As_{0.59}P_{0.41}$ as a waveguide layer. A layer of 505 nm InP as a cladding layer and finally a contact layer of 350 nm $In_{0.53}Ga_{0.47}As$ are needed. A layer stack according to this design was grown by MOVPE.

The layer stack was designed for 1550 nm wavelength absorption, but photoluminescence peak was found out to be at a higher wavelength i.e. at 1620 nm. A large enough separation for TE and TM absorption was observed, which is the basic requirement for the feasibility of the technique. To test the concept waveguides, detectors and light emitting diodes (LEDs) have been realized on this layer stack. The fabrication process involves standard photolithography, reactive ion etching, metal evaporation and lift off. Waveguides have widths ranging from 1 µm to 8 µm and lengths of 2 mm. On the passive waveguides the InGaAs contact layer was removed. The active structure could be used as a detector or as a light emitting diode (LED) by applying reverse or forward bias. The detectors/LEDs were 2 µm to 7 µm wide and 1.5 mm in length.

Different measurements have been performed on these devices to check their basic functionality. Both types of components passive (waveguides) and active (LEDs/detectors) are giving reasonable performance.

For waveguides transmission measurements have been done for both polarizations, TE and TM. The typical transmission curve obtained with a tunable laser is shown in the Figure 2. The curve shows transmission upto 1590 nm wavelength but transmission is measured till 1700 nm with a dye laser. For TM, transmission region is for wavelength above 1545 nm. Estimated losses for TM are about 2dB/cm at 1660 nm wavelength and above.

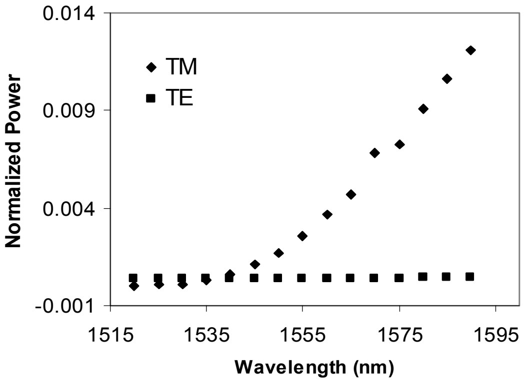

Figure 2: Transmission through waveguides as a function of wavelength for two polarizations.

For detectors and LEDs absorption and emission measurements have been performed, again for both polarizations. Detectors have shown very low dark current of 4.8 nA. The responsivity is calculated from the absorption curves and is shown in Figure 3. For TE at 1600 nm it is above 0.3 A/W and for TM polarization the peak value is around 0.2 A/W at 1480 nm wavelength including coupling losses. The two peaks are widely separated and the absorption ratio for TE and TM is above 20 at 1600 nm, which is good enough for POLIS application [5], and probably much higher at longer wavelengths.

Emission spectra measured for the two polarizations is shown in Figure 4. For TE polarization the peak value is at 1620 nm whereas for TM polarization the peaks are ranging from 1480 nm to 1500 nm for different diodes. This is also in accordance with the previous measurements. The width of the emission peak for TE is sufficient for multiwavelength applications [5]. A slight shift in the TM peak positions for different diodes may be due to the non-uniformity of the wafer.

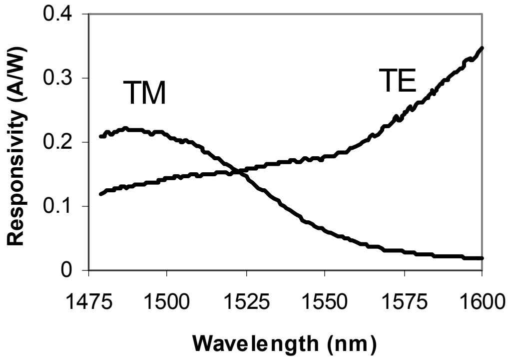

Figure 3: Responsivity of the detector for TM and TE polarizations, as a function of wavelength.

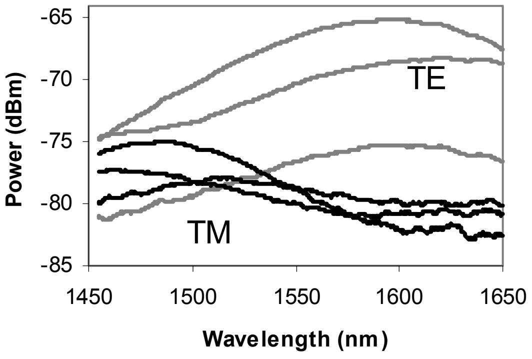

Figure 4: Emission from the LEDs at 20 mA input current for two polarizations, TE (light) and TM (dark) for three different devices.

Conclusions

The polarization based integration scheme (POLIS) can open up the possibility to integrate active and passive circuitry without regrowth. It is a simple technique to implement based on the fact that compressively strained quantum well increases the separation between the heavy-hole and light-hole valence bands, resulting in an increased wavelength separation between the bandgap for TE and TM polarization. TE polarization can be used to specify the active, TM the passive part.

Polarization can be switched from one to the other by polarization converter, which is also fully consistent with the processing of the rest of the circuit.

The idea is verified experimentally. Waveguides and LEDs/detectors fabricated on the same layer stack have given reasonable performances like low losses for waveguides, quite good responsivity for detectors and wide wavelength separation between TE and TM emission peaks for LEDs. These components can be further improved like the efficiency of the LEDs can be increased and losses of the waveguides can be reduced below 2 dB/cm by adjusting the doping profile in the layer stack.

The layer stack also needs to be adjusted for 1550 nm wavelength absorption. This can be done by choosing the right width of the quantum well, so that this technique can be used for telecommunication applications, where ultimately photonic integrated circuits have to be used.

Acknowledgement

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