Realization of POLIS components: waveguides, LEDs and detectors

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The first POLIS (POLarization based Integration Scheme) structure is grown. POLIS combines active and passive components on one chip using polarization properties of the material. Photoluminescence (PL) shows a strong difference between TE and TM polarizations for strained InGaAs/InP quantum wells. Waveguides, detectors and LEDs based on this structure have been fabricated and characterized. Waveguides show 2 dB/cm loss at 1660 nm wavelength for TM polarization. For TE-polarized light the detector has 0.08 A/W external responsivity, including coupling losses, and 4.8 nA dark current. The emission of the LED is around 1620 nm for TE, which confirms the PL measurements.

Introduction

Photonic integrated circuits (PICs) include active and passive components, which are integrated together by different integration schemes like twin guide structures, regrowth or shadow mask growth [1]. All these techniques require extra processing steps to meet the different material requirements i.e. absorbent for active and transparent for passive components. However in the POLIS technique [2] one material is used for both types of components, thus simplifying the PICs and reducing the costs. Polarization is a problem in PICs but in the POLIS technique it is used as an advantage. The polarization is in this case the parameter that determines the material properties. This effect is obtained by using strained quantum wells. With polarization converters it is possible to obtain the required polarization [3], transparent or absorbent, in each component of the optical circuit. In this paper we report for the first time realization of both active and passive components on one material system, thereby proving the feasibility of the POLIS concept.

Design and Fabrication

Our material system contains InGaAs compressively strained quantum wells sandwiched between InGaAsP on an InP substrate. The strain increases the difference between the light and the heavy hole subbands in the valence band, and therefore a difference in the bandgap for TE and TM is obtained. The most optimal result is obtained with the highest strain, however relaxation can occur if the strain is too large. In practice 1% of strain is possible. This is sufficient for the POLIS application. The designed layer structure consists of 300 nm waveguiding layer of $In_{73}Ga_{27}As_{59}P_{41}$ layer, 3 nm compressively stained quantum well of $In_{64}Ga_{36}As$ and 300 nm again $In_{73}Ga_{27}As_{59}P_{41}$ layer on an InP substrate. Then a layer of 505 nm InP as a cladding layer and finally a contact layer of 350 nm $In_{53}Ga_{47}As$ are needed. A layer stack according to this design was grown by MOVPE.

On this layer stack waveguides, detectors and LEDs have been realized. The processing involves standard photolithography and reactive ion etching. Waveguides have widths ranging from 1 μm to 8 μm and lengths of 2 mm. On the waveguides the InGaAs contact layer was removed. The active structure could be used as detector or as a light emitting diode (LED) by applying reverse or forward bias. The detectors/LEDs were 2-7 μm wide and 1.5 mm in length. A typical LED/detector structure obtained is shown in Figure 1.

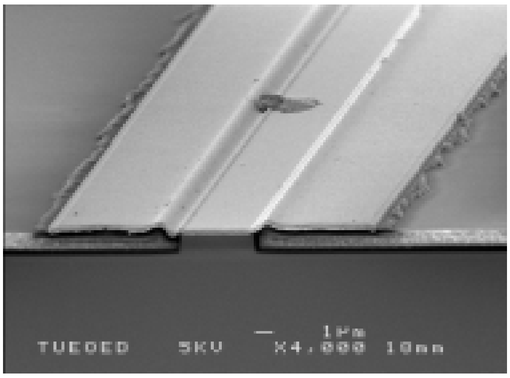

Figure 1: SEM picture of the processed LED/detector. Sidewalls of the detector are protected by SiN and metal at top is planarized by polyimide underneath.

Experimental Results and Discussion

Transparency for one polarization and absorption for the other is required at the same wavelength to have active and passive components together. Calculations [2] indicated that 3 nm thick $In_{0.65}Ga_{0.35}As$ compressively strained quantum wells have both TE bandgap and TM transparency in the 1550 nm wavelength window. Backscattering photoluminescence (PL) measurements have been done for TE and TM polarizations at room temperature (RT). Results are shown in Figure 2.

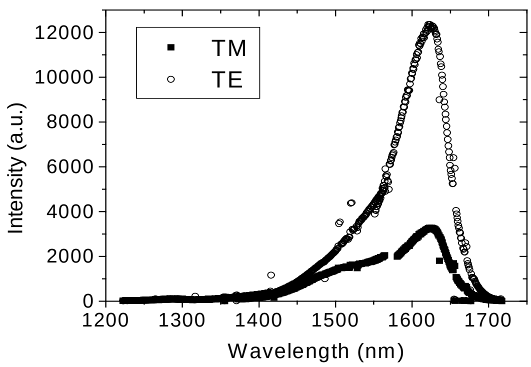

Figure 2: Photoluminescence spectra for TE (hollow) and TM (solid) polarizations at room temperature

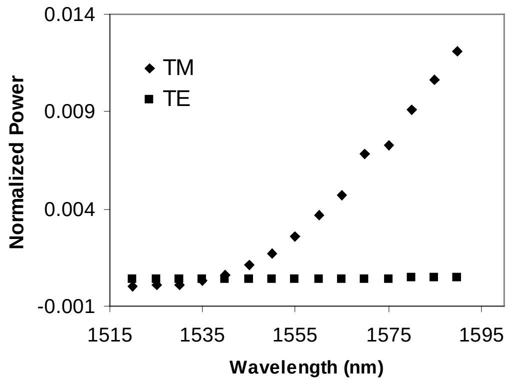

Figure 3: Transmission through waveguides as a function of wavelength for two polarizations.

The PL measurements show a quantum well peak at 1620 nm wavelength for TE polarization whereas for TM polarization there is a significant fall in the signal for TE. There seems to be a peak for TM polarization around 1500 nm, which was later confirmed by detector and LED measurements. The TM peak at 1620 nm probably comes from depolarization of the TE emission. Simulations based on the data obtained from the PL and X-Ray Diffraction (XRD) measurements suggest that the width of the quantum well was 4.6 nm and has 31% Ga concentration. Therefore a large deviation from the required wavelength is found in the PL spectra, but the effect of polarization is quite evident. Waveguides gave very high losses at 1535 nm wavelength, which was the only available wavelength to measure losses in our Fabry-Perot setup. Instead losses were estimated by comparing the signals with those of waveguides whose losses are already known. For this purpose transmission through the waveguides has been measured first with a tunable laser till 1590 nm wavelength and then with a dye laser above 1590 nm. The transmission curve obtained with the tunable laser is shown in the Figure 3. For TM, transmission starts around 1545 nm wavelength and for TE there is absorption till 1600 nm. Estimated losses for TM are about 2dB/cm at 1660 nm wavelength and above.

For the active components IV-measurements have been performed and absorption and emission spectra have also been measured, which support the PL and transmission measurements.

Current as a function of applied voltage was measured at different input powers. The response was quite good with the increase in applied power, as it is shown in Figure 4. At -0.6 V, responsivity calculated from this curve is around 0.08 A/W for 1550 nm wavelength including coupling losses. This measurement was done without using a polarizer. Dark current (without illumination) is about 4.8 nA. Current as a function of wavelength at two polarizations is plotted in Figure 5, peak values are around 1480 nm for TM and above 1600 nm for TE polarization, which was the limit of the tunable laser. This is in agreement with the PL measurements.

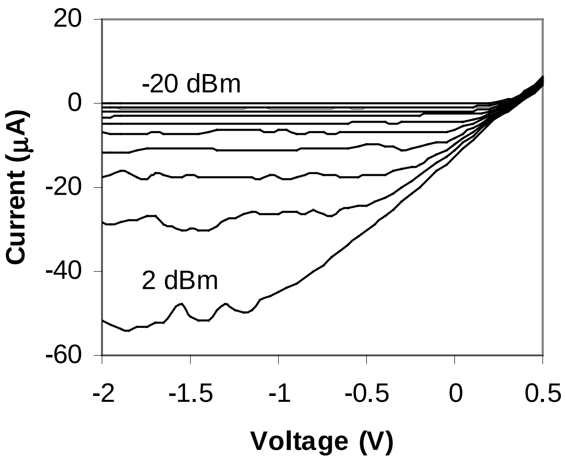

Figure 4: Current-Voltage characteristics of the detector at different input powers ranging from –20 dBm to –2 dBm.

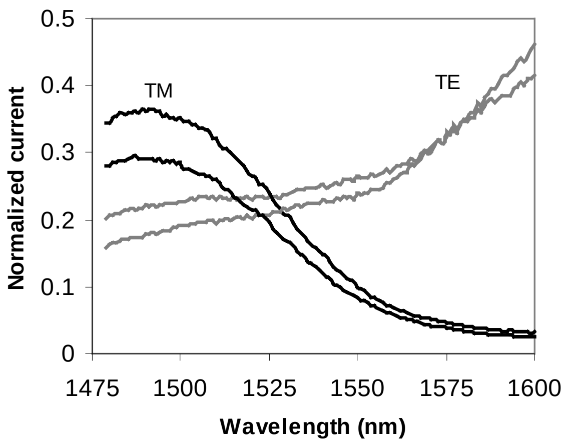

Figure 5: Absorption spectra of the detectors for TE and TM polarizations.

Responsivity calculated from these curves give the values shown in Figure 6. For TE at 1600 nm it is approximately 0.3 A/W and for TM polarization the peak value is around 0.2 A/W at 1480 nm wavelength. The two peaks are widely separated and the absorption ratio for TE and TM is above 20 for wavelength longer than 1600 nm, which is quite good. Emission spectra measured for the two polarizations is shown in Figure 7. For TE polarization the peak value is at 1620 nm whereas for TM polarization the peaks are around 1480 to 1500 nm. This is in accordance with the absorption and PL measurements. A slight shift in the TM peak positions for different diodes may be due to the non-uniformity of the wafer.

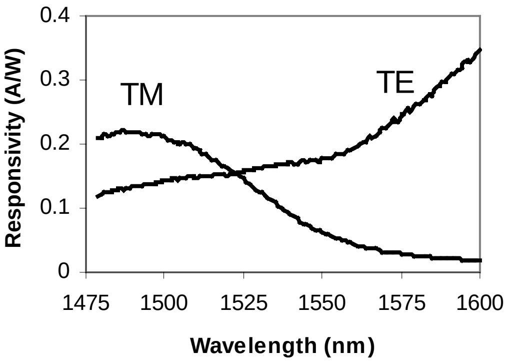

Figure 6: Responsivity of the detector for TM and TE polarizations, as a function of wavelength.

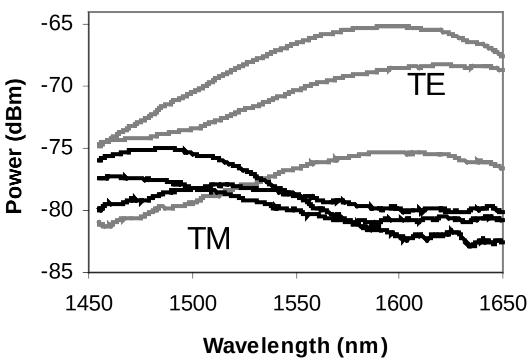

Figure 7: Emission from the LEDs at 20 mA input current for two polarizations, TE and TM.

Conclusions

Both types of components, active and passive, are fabricated successfully on the same layer stack. All measurements are well in agreement with each other. Polarization converter, which is an important component to integrate this active and passive circuitry together in the POLIS technique, has already been realized [3]. So the POLIS concept is practically feasible and can be implemented.

The layer stack needs to be optimized, not only for better performance of each of the components but also for a wavelength suitable for telecommunication, where ultimately photonic integrated circuits have to be used.

Acknowledgement

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