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Amorphous Silicon Waveguide Components for Monolithic Integration with InGaAsP Gain Sections

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ABSTRACT

Low loss, single mode rib waveguides, based on PECVD deposited multi-layer amorphous silicon are fabricated. These waveguide are refractive index and mode-matched to III/V laser waveguides. Methods for monolithic integration of these passive amorphous silicon waveguides with InGaAsP/InP gain sections are demonstrated. Results of a multi-wavelength laser based on an amorphous silicon arrayed waveguide grating integrated on a single chip with InGaAsP gain sections are presented.

Keywords: Photonic integrated circuits, amorphous silicon, waveguides

1. INTRODUCTION

Amorphous silicon is a material that is widely used for solar cells and for thin film transistors in display applications. Amorphous silicon and amorphous silicon alloys such as amorphous silicon nitride or amorphous silicon carbide have received little attention for use as optical waveguides [1,2] or for application in integrated optics [3].

Hydrogenation of amorphous silicon for termination of dangling bonds results in excellent loss properties in the telecommunication windows (1300nm, 1550nm). This makes this material suitable for high quality passive circuits. Incorporation of nitrogen allows adjustments of the refractive index of these materials covering a broad range of 2-3.5. Optical waveguides can be formed with layers of different refractive indices. And most notably it is possible to match the refractive index of amorphous silicon to the values of InP and its alloys (InGaAsP, GaInAlAs) used in active photonic components.

Hydrogenated amorphous silicon alloys can be deposited with plasma enhanced chemical vapor deposition (PECVD) processes at temperatures around 200 – 250 °C making them compatible with III/V materials. This simple and high yield process allows for easy and reproducible deposition on flat or structured surfaces.

Monolithic integration of passive waveguide based devices with active elements such as gain sections has been demonstrated using various techniques using InP / InGaAsP based structures for both active and passive parts [4-8]. The unique properties of a-Si alloys outlined above provide significant opportunities and advantages for realizing low cost integrated photonic circuits by monolithically combining passive amorphous silicon waveguide based circuits with active III/V components [9].

Results of amorphous silicon waveguides are presented. We outline the techniques we have developed for monolithic integration of hydrogenated amorphous silicon nitride (a-SiN_x:H) waveguides with InGaAsP gain sections, and present results of a monolithically integrated arrayed waveguide grating based laser.

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2. AMORPHOUS SILICON WAVEGUIDES

Two types of amorphous silicon waveguides were fabricated: planar waveguides and single mode rib waveguides. The planar waveguides are used to evaluate material loss and the single-mode waveguides are designed for photonic integrated circuits.

For the planar waveguides uniform 2 µm thick a-SiN_x:H films were deposited onto thermally oxidized silicon wafers. The SiO_2 below and the air above the a-SiN_x:H film provide vertical guiding. Optical loss at 1550 nm of planar amorphous silicon films was determined to be 1.1 dB/cm using a prism coupling technique [10]. The relatively thick film results in a low overlap of the mode with the surface minimizing loss contributions from surface roughness scattering.

By adjusting the nitrogen content in the amorphous silicon alloy it is possible to control the refractive index of the material. Vertical guiding inside the a-SiN_x:H film is achieved with a refractive index profile of n=3.3/3.4/3.3. The overall thickness of the multi-layer films is 2.9 µm and the stress is less than 100 MPa. 2 µm wide rib waveguides are formed with chlorine based reactive ion etching for lateral guiding. The waveguides are designed to provide negligible bending loss for waveguides with 0.6 mm or larger radii. A schematic of the waveguides is shown in the inset of Fig. 1. We determined a waveguide loss of 4.2 dB/cm by measuring transmission through straight waveguides of different lengths (Fig. 1). The increased value of the single mode rib waveguide loss compared to planar waveguide loss suggests some scattering loss at the etched sidewalls.

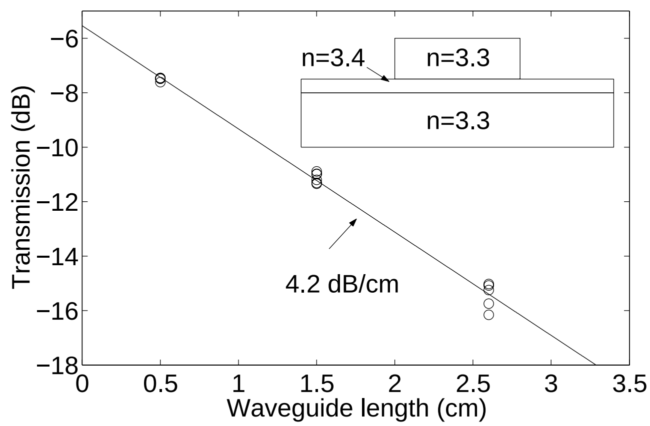

Fig. 1. Transmission through waveguides of different lengths. The measurements include coupling and reflection loss at the facets. Inset: schematic of the 2 µm wide 3-layer amorphous silicon ridge waveguides.

The waveguides are deposited using a PECVD process at 250 ºC. The low temperature process, the amorphous nature of this material and the high refractive index provides unique advantages for integration with optical III/V devices. Other amorphous materials popular for passive optical components such as SiO_2/SiN/SiON and polymers are less attractive for monolithic integration with active III/V components due to large refractive index mismatches.

3. INTEGRATION OF AMORPHOUS SILICON WAVEGUIDES WITH InGaAsP/InP OPTICAL GAIN SECTIONS

The amorphous silicon waveguides and are integrated with InGaAsP gain elements on InP substrates. The passive waveguides are butt-coupled to the active InGaAsP/InP sections.

A standard InGaAsP quantum well laser structure is grown by MOCVD on an InP substrate. The only modification of the structure is an InGaAsP etch-stop below the active region. The wafer is patterned and etched in the open areas to the etch stop mentioned above using a combination of dry and wet etching. A 3 layer a-SiN_x:H waveguide stack with the appropriate refractive index profile is deposited over the structured wafer with PECVD. In the next step the amorphous silicon is removed from the top of the un-etched III/V area. Using a single lithography step waveguides in the active InGaAsP/InP areas and in the amorphous silicon areas are defined. a-SiN_x:H waveguides are dry etched (chlorine based). The III/V waveguides are wet etched. A Si_3N_4 dielectric is applied for isolation and standard metal contacts are formed to the gain sections. A schematic of a completed active-passive junction area is shown in Fig. 2.

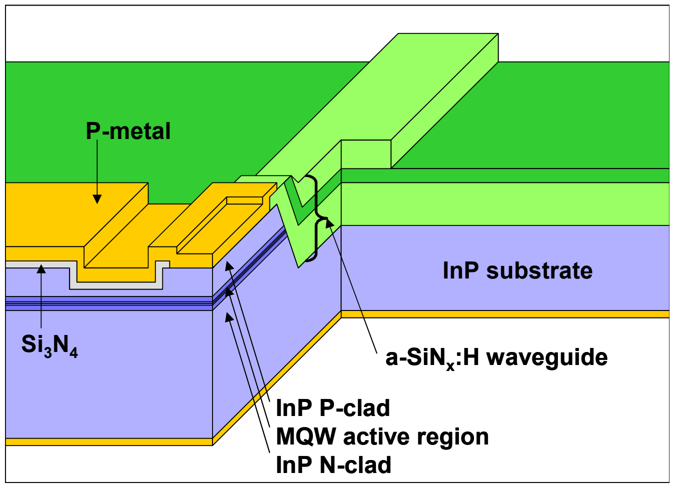

Fig. 2. Schematic of junction between active InGaAsP gain section and passive amorphous silicon waveguide.

The refractive index of the a-SiN_x:H is matched to the refractive index of the III/V material for low interface reflection. Residual reflection is further suppressed with the sloped junction interface. Matching of the mode in the active III/V waveguide and the passive a-SiN_x:H waveguide results in low loss. The interface region extends over a length of only 2 μm adding only insignificant diffraction loss. An SEM image of the junction cross-section is shown in Fig. 3.

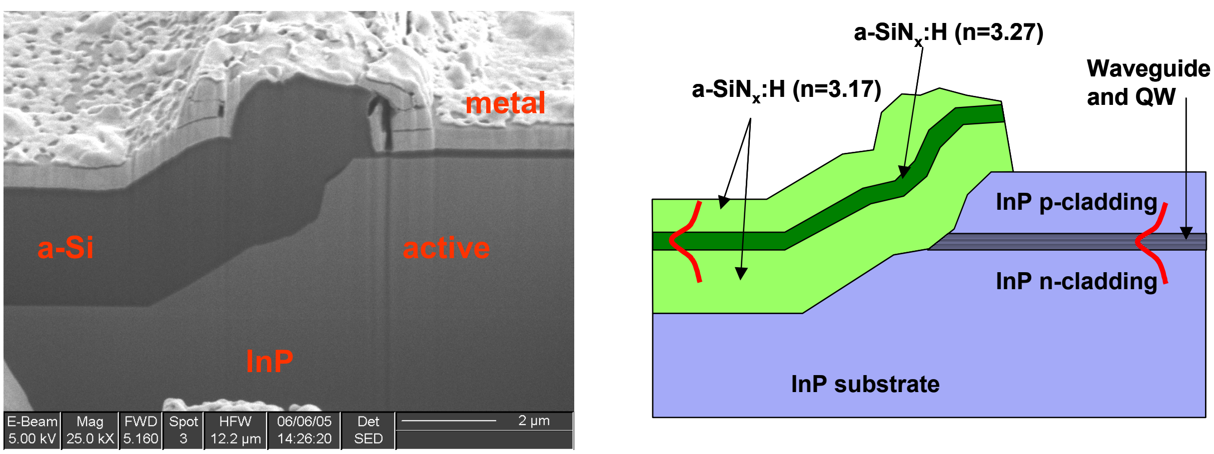

Fig. 3. Left: SEM image of interface cross-section showing III/V and a-SiNx:H waveguides. Right: corresponding drawing showing the core and cladding layers of the amorphous silicon waveguide and of the InGaAsP/InP waveguide.

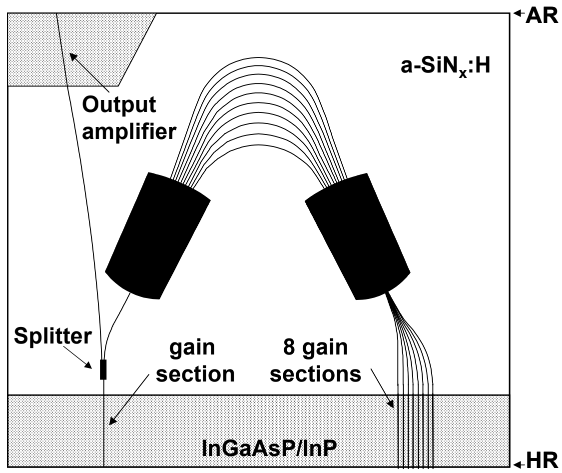

Fig. 4. Schematic of the integrated laser. Active InGaAsP waveguides are located in shaded zones. The amorphous silicon waveguides, the amorphous silicon AWG and the splitter are located in the white area.

4. INTEGRATED DEVICE DEMONSTRATION

A monolithically integrated laser was designed and fabricated. It consists of a-SiN_x:H waveguides, an a-SiN_x:H arrayed waveguide grating (AWG), a splitter and several InGaAsP gain sections. By appropriately biasing select gain sections of the device the laser wavelength can be selected to match one of the 8 AWG channel wavelengths. The 8 x 100 GHz AWG based on 2 µm wide rib waveguides has a free spectral range of 30 nm and contains 70 arrayed waveguides. Tightest waveguide bending radius of this device is 1000 µm and the overall chip size is 5 x 6 mm^2. A schematic of the monolithically integrated laser is shown in Fig. 4. Measured output spectra of the laser are shown in Fig. 5.

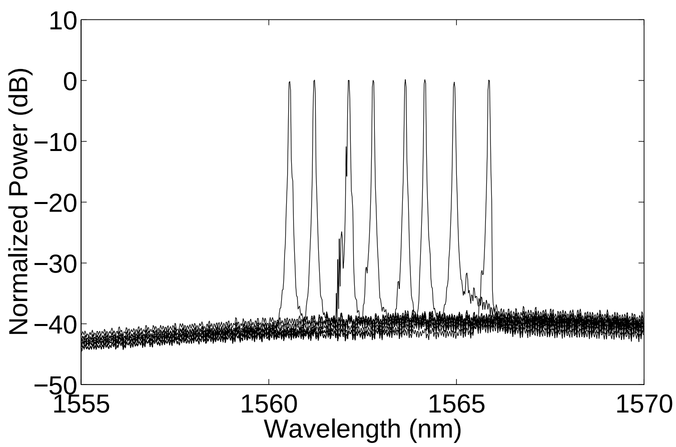

Fig. 5. Overlaid output spectra of the laser operated on the 8 individually operated laser channels.

5. CONCLUSIONS

Amorphous silicon waveguides deposited at low temperatures by PECVD have excellent optical properties. We developed monolithic integration of amorphous silicon based passive circuits with InGaAsP gain elements on a single chip. An integrated 8-wavelength channel AWG based laser was demonstrated. Monolithic integration of passive amorphous silicon circuits and InGaAsP gain sections is a technology, which is suitable for the realization of advanced integrated photonic circuits. This PECVD based integration technology may enable low cost integrated photonic circuits required in emerging local access applications, for example, WDM-PON.

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