Recent Advances in InP PICs

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Abstract: Within the past couple of years InP-based Photonic Integrated Circuits (PICs) have become the subject of aggressive development for commercial applications primarily for the telecommunications industry. Chips with hundreds of photonic components carry live traffic in the field, but questions remain about cost/volume/performance tradeoffs, as well as the need for common integration platforms and/or foundry services. Research efforts have been influenced by these issues.

1. Introduction

Small-scale PICs in InP have been researched for over two decades[1], and there have been a few successes that have had some commercial impact over the past decade or so. However, for many years success with hybrid integration techniques as well as limited market volumes has slowed the commercial adoption of PICs, except for a few limited examples. The classic success example is the so-called EML, the electro-absorption modulated (EAM) laser, usually consisting of a DFB laser integrated with a waveguide section at one end that has a slightly higher absorption energy so that it is nominally transparent[2,3]. A reverse bias to this section increases its optical absorption so that it can function as a high-speed modulator. Other PIC examples include various single-chip widely-tunable transmitter chips that have included integrated amplifiers, modulators, and monitoring detectors together with multiple-section lasers[4,5]. Larger-scale PICs with hundreds of components have been offered commercially only in the past few years[6]. Most of this work has involved chips with numerous parallel channels, which each might contain four or five elements, multiplexed together in a wavelength-division-multiplexed (WDM) transmitter or receiver[6,7]. Research efforts on larger-scale PICs have included work with more complex chains of components to provide a higher level of functionality within each channel[8,9].

This Plenary presentation will endeavor to mention representative examples of different classes of PICs that have been worked on in recent years. The emphasis at the IPRM will be on the materials and integration issues as well as some of the device/circuit tradeoffs. Partly due to necessity because of proprietary issues, and partly due to convenience, an overemphasis on our work at UCSB will result.

2. Integration Platforms

The most elementary of photonic ICs requires the ability to switch between active and passive optical waveguide sections without undue loss or reflections. Perhaps three or more waveguide types need to be abutted in such a 'seamless' manner to integrate all of the desired functionalities within some PIC. Figure 1 illustrates some examples of active-passive junctions along the axis of the optical waveguides.

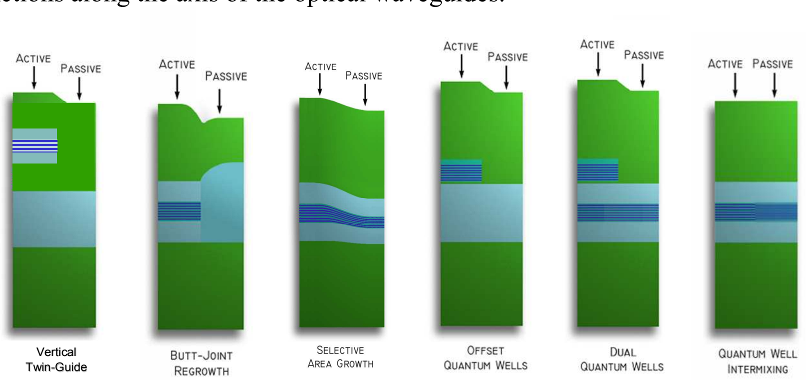

Fig. 1. Schematic waveguide cross sections of six active-passive integration platforms. All have been used in commercial products.

Pros and Cons of each active-passive junction include the following: the vertical twin guide allows for independent properties in the upper and lower guides, but a long coupling length is needed to accomplish the vertical light transfer; the butt-joint regrowth approach also allows for independent properties in the active and passive sections, but a critical alignment of the regrown waveguides is necessary; the selective area growth technique provides a scaling of the vertical dimensions to change the absorption edge of the quantum-wells, but the properties of each are still linked and the patterned growth results in some transition length as well as being critically dependent on the lateral diffusion properties of the precursors; the offset quantum-well approach only requires an unpatterned blanket

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regrowth over a small step after etching away the active wells, but offsetting the gain results in a reduced net gain for the mode; the dual quantum-well case adds higher bandgap wells in the waveguide to provide better modulators in the 'passive' guide; the quantum-well intermixing approach can provide multiple bandgaps from a single growth with multiple diffusion steps, but only low saturation power SOAs are available without more growths.

In the lateral direction there are also many different possible waveguiding geometries that are more or less desirable for various PIC elements. These include surface ridge waveguides, buried heterostructures, buried ribs, deeply etched ridges, and the transitions between these. Many tradeoffs exist. High-index-contrast enables sharp bends, but it tends to bring higher losses. Active regions generally require high-quality epitaxial interfaces for low non-radiative recombination and high reliability, but this limits the fabrication options.

3. Example PICs

Figures 2-4 give recent examples of photonic ICs from some of our work at UCSB. Different integration platforms and lateral waveguide structures were used in each case. Figure 2 illustrates a photocurrent driven wavelength converter that integrates an all-photonic SOA-PIN receiver with a widely-tunable SGDBR laser—SOA—traveling-wave-EAM transmitter[10]. It uses the 'dual quantum-well' integration platform with a surface-ridge waveguide structure.

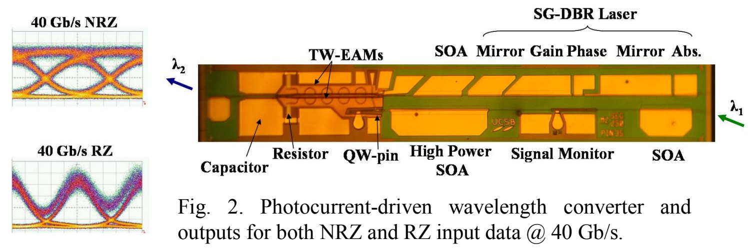

Fig. 2. Photocurrent-driven wavelength converter and outputs for both NRZ and RZ input data @ 40 Gb/s.

Figure 3 illustrates a chip which provides the fabric of an 8 x 8 all-photonic packet-switch[9]. In one of the most complex PICs ever created, 8 wavelength converters feed an 8 x 8 AWGR (which acts like a prism) that together enable any of 8 incoming channels to be switched to any of 8 output channels by switching the wavelength in the wavelength converters. In this case quantum-well intermixing is used for different bandgaps, and three different waveguides are employed in the different sections: surface-ridges, deeply-etched ridges, and buried ribs.

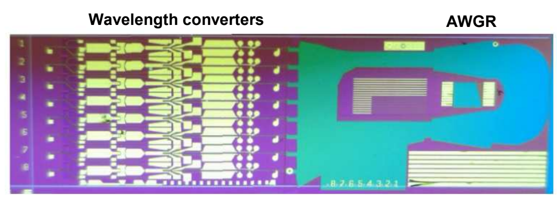

Fig. 3. 8 x 8 all-photonic space switch employing wavelength converters and a passive dispersive AWGR filter.

Figure 4 is a programmable integrated photonic lattice filter that incorporates three coupled ring resonators together with a Mach-Zehnder geometry[11]. Numerous FIR and IIR filter functions can be programmed. Illustrated is a repeating two pole response. In this case an offset-quantum-well layer structure and deeply-etched waveguides are used throughout.

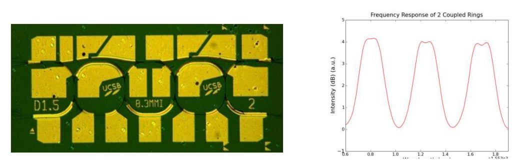

Fig. 4. Programmable lattice filter and 2-pole IIR response.

4. Acknowledgements

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