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Photonic Integration at Sandia National Laboratories

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Abstract: This talk will discuss recent work on photonic integration for applications in optical signal processing, digital logic, and fundamental device research with an emphasis on InP-based photonic integrated circuit technology.

OCIS codes: (250.5300) Photonic Integrated Circuits

1. Introduction

Photonic integration allows for advancements in system performance and photonic circuits with new capabilities, such as timing sensitive or low latency circuits, as well as reductions in SWaP and packaging costs, while increasing reliability. In particular, monolithic integration reduces the number of sensitive optical on-off chip coupling interfaces which reduces coupling losses and increases the mechanical robustness, as opposed to discrete components. Monolithic photonic integration with the InGaAsP materials system is particularly attractive since it enables an integrated light source as well as high performance active elements including modulators, amplifiers and detectors.

This talk will focus on the advanced photonic integrated circuit (PIC) platform developed at Sandia National Laboratories. Additionally, it will cover the highly-functional PICs that we have developed for a variety of applications including optical signal processing, digital logic, and fundamental device research.

2. InP-based Photonic Integrated Circuit Platform

We have developed a fundamental capability in InP-based PICs that enables the monolithic integration of a diverse set of lasers, modulators (both phase-based and absorption-based), photodetectors, amplifiers (both high-gain and high-saturation power varieties) and routing waveguides, in addition to electrical passive components such as resistors, capacitors, and transmission lines. The foundation of the capability is quantum-well-intermixing which enables the realization of multiple bandedges to be formed across the wafer with very low optical reflections (<1 dB) at the interfaces [1], coupled with simple blanket MOCVD regrowths. Using a catalyst, the QWI process takes advantage of the metastable interface between quantum well and barrier layers to interdiffuse well and barrier atomic species and thereby blue-shift the quantum well energy levels. This process can be controlled to allow different degrees of intermixing in selected parts of the wafer. This allows the bandedge to be tailored to the specific device, for instance as-grown quantum wells could be used for gain sections in lasers and amplifiers, moderately blue-shifted regions used for electroabsorption modulators (EAMs), and strongly intermixed quantum wells (blue-shifted >35 nm) used for passive waveguides, mirrors and phase shifters. A blanket MOCVD regrowth is typically used after intermixing to add the top p-type cladding and contact layer. Additional blanket regrowths can be used to add versatility in device design and therefore improve the device performance, an example of this is the regrowth of a set of quantum wells above the waveguide core which enables high-saturation-power semiconductor optical amplifiers (SOAs). An example cross section of the PIC platform that we have developed is shown in Figure 1.

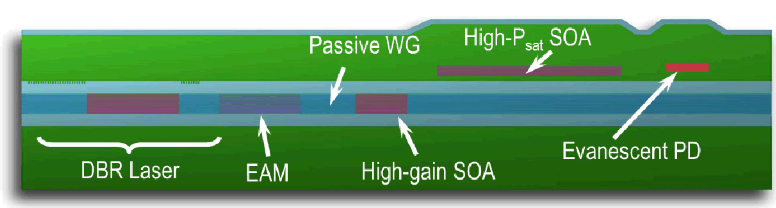

Figure 1: Cross sectional view of the InP-based PIC platform with example device sections labeled. The quantum well bandedge (i.e. degree of blue-shifting) is highlighted by the blue (blue-shifted >35 nm),blue-purple (blue-shifted 5-20 nm) and purple (as-grown) colors of the waveguide core.

3. Highly-functional PICs

The PIC platform allows for high performance components including >40 Gbps EAMs (electroabsorption modulators) and photodetectors [2], <1 GHz passband optical filters and wavelength-tunable lasers with >40 dB side mode suppression ratio on a single monolithic chip. This variety of devices enables the creation of unique, highly-functional PICs.

A tunable optical-RF channelizing filter array for RF optical signal processing was demonstrated [3]. A photo of the chip is shown in Figure 2. This circuit consists of an integrated laser, 20 GHz EAM, and cascaded ring filters. The filters include both an optical amplifier to offset the passive loss and optically transparent regions which are used to tune the filters over 12 GHz through current injection resulting in a 3.5 GHz linewidth for a three-pole filter.

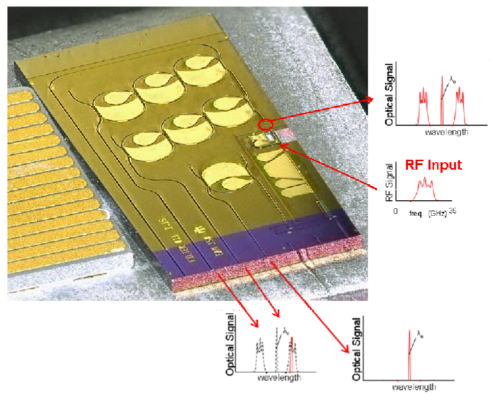

Figure 2: Optical image of an optical RF channelizing chip. The laser in the lower right generates an optical CW signal which is modulated by an EAM generating sidebands with RF data. This data is channelized using the three pole ring filters. There is a single pole filter on the backside of the laser to monitor the laser wavelength.

Another example of InP-based monolithic integration includes optical logic circuits, both AND and NOT, that we developed which can be cascaded to create a NAND gate which forms a complete logic set. These circuits are based on photodetector – EAM pairs where the photocurrent from the photodetector is fed to an on-chip resistor modulating the voltage on the EAM thereby changing the output state. The logic functionality is determined by the input signal configuration, and the interconnection between the photodetector and modulator. Using this technology, AND and NOT logic gates have been demonstrated at 40 Gbps. These devices are described in reference [4].

3. Summary

A foundational capability in InP-based PICs has been developed to address the needs of a wide array of applications. Using the QWI platform coupled with epitaxial regrowth, we have demonstrated a diverse set of high-performance integrated components that have enabled new functionality that discrete components cannot match. Where it makes sense, InP-based technology can also be combined with other Sandia developed capabilities in Si photonics and heterogeneous integration to reduce costs and expand the application space.

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References

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