Active Photonic Integrated Circuits

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Abstract: Recent advances in photonic integration technology on InP and related materials have enabled continued growth in the scale, performance and quality of active photonic integrated circuits. Complex widely-tunable transmitters, transceivers, and wavelength converters with state-of-the-art performance have been demonstrated.

1. Introduction

Photonic integration has long been sought after as the next big step toward low-cost, low-size, and low-power dissipation chips with increased capability. This dream has gone largely unrealized over the past couple of decades, during which time significant effort in this direction was undertaken. However, within the past several years there has been a resurgence of effort as well as significant progress in realizing practical photonic integrated circuits (PICs). This is despite the huge reduction in research effort in the area of optical communications components. It would appear that at least some of this is due to a few research breakthroughs that have enabled such integration to be more robust.

In this paper we shall review some of the recent advances that have been carried out at UCSB in developing new integration approaches[1-11]. Seamless transitions in absorption edge, which require no regrowths for the various elements of widely-tunable lasers, transmitters, and wavelength converters, have been provided by selective removal of quantum-wells as well as via novel quantum-well intermixing approaches. A variety of optical waveguide elements are involved, including gain regions, phase and amplitude modulators, grating reflectors, passive waveguides, semiconductor-optical-amplifiers (SOAs) variable-optical-attenuators (VOAs), and photodetectors. In principle, there is no limit to the scale of the PICs that can be created, once these elements can be integrated with high yield. These PICs achieve a high level of functionality by using only photonic components with no electronics or the interconnections to such electronics required. For example, optical amplifiers (SOAs) are used for power gain and pre-amplification of weak signals, in many cases obviating the need for any electronic components in the entire sub-system.

2. Technology Advances: Quantum-well intermixing

Figure 1 illustrates how quantum-well intermixing (QWI) works and details the process of the novel approach used at UCSB for InGaAsP/InP[1]. In this case, low-energy P^+ ions are implanted near the surface of a sacrificial InP layer to create vacancies, and in a subsequent rapid-thermal-annealing (RTA) step, these are then diffused through this layer and then across the multiple-quantum-well (MQW) active region to intermix this MQW region and increase its effective bandgap energy. Multiple bandgaps are formed by performing multiple short RTAs with intermediate selective etching steps to remove the implanted sacrificial InP, and thus vacancy source, in regions where the bandgap is to be frozen. Finally, all of the sacrificial InP is removed, other processing such as grating formation is performed if desired, and then the top waveguide cladding layers are regrown. Thus, only a single regrowth step, as required for grating reflector formation, is typically carried out.

Figure 2 shows new results for similar processes in a GaAs-based technology. Although QWI in GaAs-based materials has been reported for many years, robust processes for Al-free layer structures[10] as well as reproducible large bandgap shifts in InGaAs/GaAs/AlGaAs [9] have not been developed.

3. Example Device Advances: Photonic ICs

Figure 3 illustrates a widely-tunable transmitter in the 1550nm wavelength band formed with the QWI process. It includes a widely-tunable laser, a back-side absorber/detector, an electro-absorption-modulator (EAM), and a curved-waveguide output coupler, all monolithically integrated on the same chip with the process described above[5,6]. High output power, full C-band tunability, and negative chirp capability is demonstrated with three different QWI bandgaps formed from the single MQW growth.

Figure 4 illustrates an array of other PICs that have been created with the QWI or 'offset quantum-well' integration platform. The offset QW technique is the same basic platform as used commercially in supplying large numbers of widely-tunable lasers and transmitters to dense-WDM networks[12]. This collage of configurations includes an array of tunable SGDBR lasers having a bipolar-cascaded gain stage[2] for differential efficiencies > 1, a single-chip biosensor[4] that heterodynes two DBRs to provide a base-band output with out any light coupling to or from the chip, and a transceiver (or wavelength converter) that uses the photocurrent from a receiver stage to directly drive a laser or external modulator such as in a Mach-Zehnder modulator-SGDBR laser based transmitter without any need for rf to enter or leave the chip[3,11].

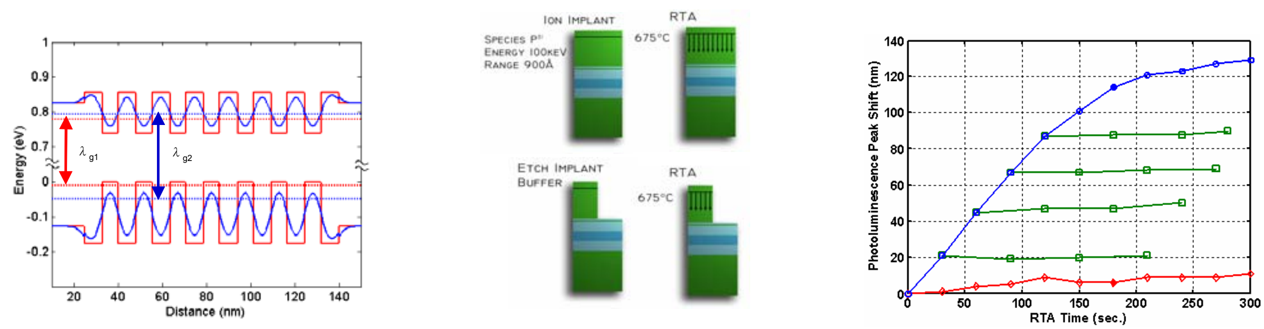


Figure 1. Schematic of QWI in InGaAsP/InP; procedure for multiple bandgaps from one implant; experimental bandgaps vs RTA time after sequential etch steps to remove vacancy source[1].

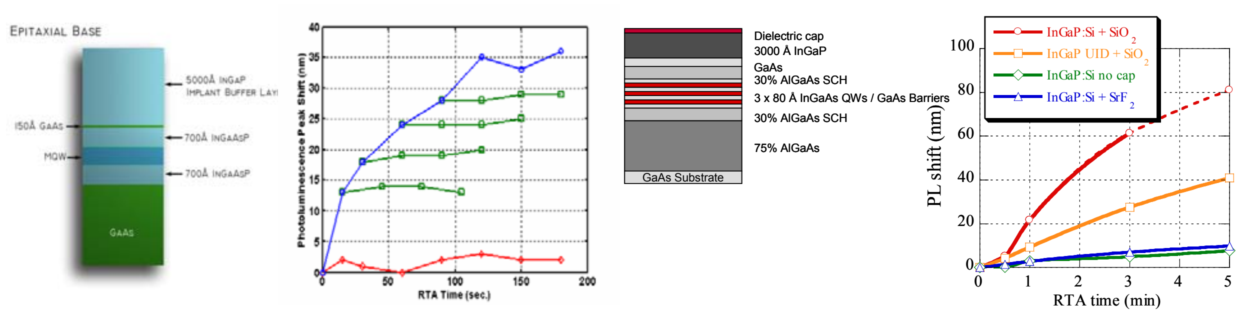


Figure 2. GaAs QWI: (left) 980 nm Al-free showing results after sequential RTA and etch removal of implant layer[10]; (right) 980 nm AlGaAs/GaAs/InGaAs case oxide deposition as vacancy source and surface fluoridation to inhibit QWI in desired areas [9].

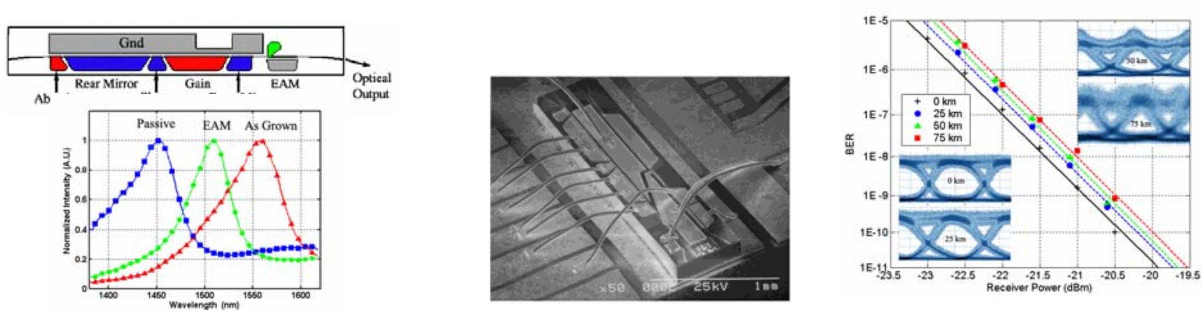
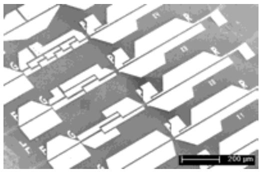
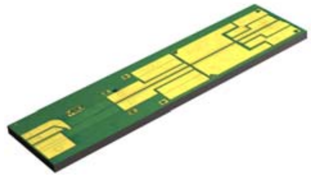


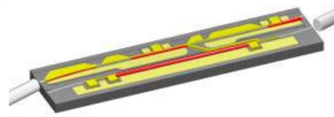
Figure 3. QWI-SGDBR-EAM full C-band single-chip transmitter (and wavelength converter with SOA-PIN receiver in SEM). Low power penalty 10Gb/s transmission over 75 km of standard fiber illustrates negative chirp that is available across the band[5,6].



Bipolar cascade SGDBR array



Biosensors w/heterodyned lasers



Photocurrent driven wavelength converters

Mach-Zehnder modulator-SGDBR laser transmitter

Figure 4. Various other PICs that have been formed. The bipolar cascade [2] also uses the QWI integration platform. The others use the offset quantum-well integration platform[4, 3, 8, 11].

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