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Publication date	2016-06
Original citation	Baig, J., Roycroft, B., O'Callaghan, J., Robert, C., Ye, N., Gleeson, M., Gocalinska, A., Pelucchi, E., Townsend, P. and Corbett, B. (2016) 'Quantum Well Intermixing in 2 μm InGaAs Multiple Quantum Well structures', in Conference on Lasers and Electro-Optics. San Jose, California: OSA, SM4R.4 (2 pp). doi: 10.1364/CLEO_SI.2016.SM4R.4
Type of publication	Article (peer-reviewed)
Link to publisher's version	https://doi.org/10.1364/CLEO_SI.2016.SM4R.4 http://dx.doi.org/10.1364/CLEO_SI.2016.SM4R.4 Access to the full text of the published version may require a subscription.
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Item downloaded from	http://hdl.handle.net/10468/13734

Quantum Well Intermixing in 2 μm InGaAs Multiple Quantum Well structures

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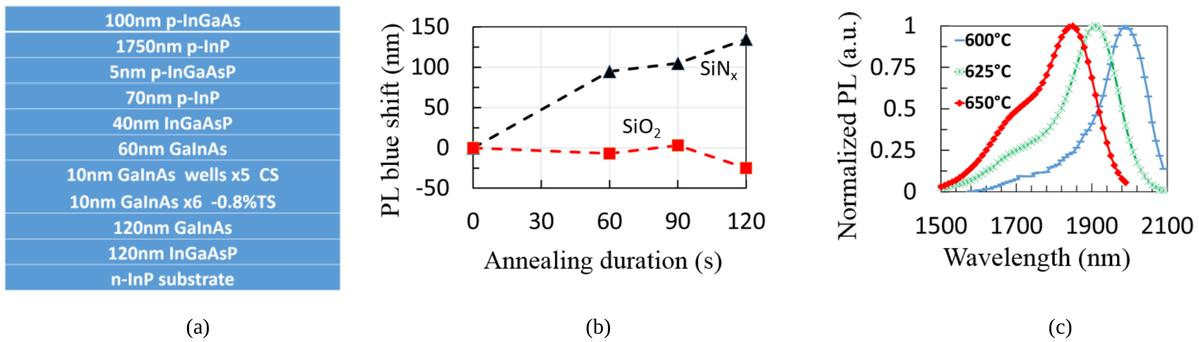
Abstract: Quantum well intermixing in 2μm emitting structures is presented for the first time. A photoluminescence and electroluminescence differential shift of 160nm is achieved between SiN_x and SiO_2 capped regions demonstrating potential for monolithic integration.

OCIS codes: (130.3120) Integrated optics devices, (130.3130) Integrated optics materials.

The data carrying capacity of optical transmission systems has exponentially increased over the last decade in response to the ever growing demand for greater connectivity and bandwidth. However, within the next few years, the internet is heading towards a 'capacity crunch'. To address this, a viable solution proposed recently is the use of Hollow Core Photonic Bandgap Fiber (HC-PGBF) to define a new hardware networking transmission technology operating at 2 μm. In addition to lower non-linearity, the HC-PBGF is shown to operate with half the propagation losses at 2 μm in comparison to the conventional band [1]. This has resulted in tremendous focus on 2 μm optical communication systems in recent years and thus on integration of 2 μm active and passive components on to a Photonic Integrated Circuit (PIC). Monolithic Integration of active and passive sections on to the same chip reduces manufacturing cost and significantly minimizes device to device coupling losses. While techniques such as selective area epitaxy and butt-joint regrowth [2] can be used to selectively alter the bandgap across a wafer, these require complex and proprietary growth processes which add yield and cost implications. The use of Quantum Well Intermixing (QWI) can overcome these problems due to its post-growth selective modification of bandgap and thus can be achieved with single step epitaxy. The high differential wavelength shifts obtained using QWI, reported in this study, has potential applications in gas sensing, particularly for gas molecules absorbing radiation at wavelengths around 2 μm.

In this paper, according to the author's knowledge, the first investigation of QWI in 2 μm Multiple Quantum Well (MQW) structures is reported. The InGaAs MQW structure, grown using Metal Organic Vapor Phase Epitaxy (MOVPE), investigated in this study is depicted in Fig. 1(a). The active region consists of five InGaAs Quantum wells, with ~1% compressive strain, which are 10 nm thick and six InGaAs 0.8% tensile strained 10 nm thick barriers. The photoluminescence (PL) emission peak of the as-grown epitaxial structure is measured to be approximately 1985 nm. The investigated intermixing process comprises of depositing a dielectric capping layer on the surface of the structure using Plasma Enhanced Chemical Vapor Depostion (PECVD) and subsequently performing Rapid Thermal Annealing (RTA) of the sample at various annealing temperature and duration to control the degree of intermixing. The shift in wavelength is measured using PL spectroscopy with a 532 nm pumped laser as the excitation source and a 2 μm photodiode coupled to a monochromator for detection. Fig. 1(b) presents the PL blue shift in the peak wavelength at an annealing temperature of 650°C for different annealing durations and different dielectric capping (SiO_2 and SiN_x). A PL blue shift as high as 135 nm is observed for annealing duration of 120 s for the SiN_x capped sample. Thus, SiN_x promotes interdiffusion of the atoms between wells and barriers in this structure. However, with the same conditions, SiO_2 capping inhibits intermixing, giving a red shift of 25 nm.

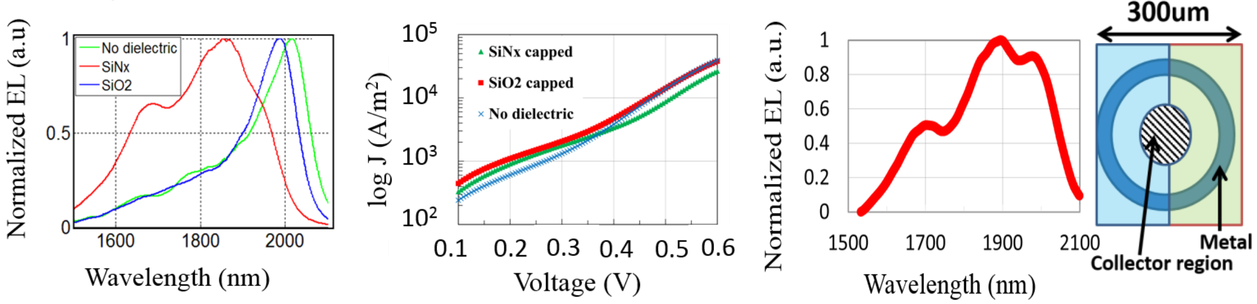


(a) (b) (c)

Fig. 1. (a) MQW structure under investigation, (b) PL blue shift at different anneal durations for different dielectric caps at annealing temperature of 650°C, and (c) Normalized PL spectra at different annealing temperatures for SiN_x capped samples for anneal duration of 120s.

Fig. 1(c) presents the normalized PL intensity at three different annealing temperatures for SiN_x as dielectric. With increasing annealing temperature, the spectrum exhibits a higher blue shift in the peak wavelength. In addition, at higher temperatures, a secondary peak is observed at a wavelength of 1670 nm. This peak originates due to reduced confinement in Quantum Wells, thereby resulting in luminescence from the InGaAs cladding layer in the structure. Within our investigation range, the largest differential peak wavelength between different dielectric capping is approximately 160 nm at annealing temperature of 650°C and annealing duration of 120 s. This significant band gap shift is postulated to arise from interdiffusion of Ga atoms as a result of vacancy and strain induced interdiffusion [3].

Fig. 2(a) presents electroluminescence (EL) spectra obtained at a current density of 1×10^3 mA/mm^2 for samples annealed with different capping layers. The peak emission wavelength shifts in line with the PL spectra indicating that radiative recombination of electrons and holes occurs at different bandgap energies for each of the dielectric capped region.



(a) (b) (c)

Fig. 2. (a) Normalized EL intensity for different dielectric capped samples with annealing temperature of 650°C and annealing duration of 120s. (b) Log-linear plot of current density and voltage for intermixed regions (c) (left): Normalized EL intensity from a region covering both SiN_x and SiO_2 capped regions. (Right): 'Split' diodes with collector region covering both SiNx capped region (blue) and SiO_2 capped (green) region.

Fig. 2(b) presents the current-voltage characteristics for the intermixed regions on a logarithmic scale. As seen from the figure, the SiN_x capped region requires a higher voltage (0.5 V) to attain a logarithmic current density of 10^4 A/m^2 than the other two regions, which require a lesser voltage (0.47 V). This is because the higher bandgap in the promote region implies decreased intrinsic carrier concentration (n_i) in this region, thus shifting the diode characteristic compared to the SiO_2 capped and no-dielectric region. However, at lower biases, around 0.2 V, there is increased leakage current for the SiN_x capped and SiO_2 capped regions, thereby showing a higher current density than the no-dielectric region. Thus, the electrical characteristics are also indicative of the enhanced intermixing in the SiN_x capped regions.

Fig. 2(c) shows the EL signal obtained from 'split' diodes, shown on the right, at a current density of 750 mA/mm^2. These 'split' diodes are fabricated to be partially capped with SiN_x and partially with SiO_2. A multimode fiber (core diameter of 100 μm) is positioned such that it collects EL from both SiN_x capped and SiO_2 capped regions, thereby giving a broadband spectrum as shown in Fig. 2(c). The broadened EL spectrum shows high intensity over a large region between 1650 nm and 2050 nm. Hence, subsequent control of the fiber position allows selection of the EL spectrum over this 400 nm range. This is very useful for realization of a broadband source for sensing applications in this wavelength range.

In summary, a first demonstration of QWI in structures emitting at 2 μm is presented. A high differential PL and EL wavelength shift of 160 nm is achieved between SiN_x capped and SiO_2 capped regions, hence making it possible to control bandgap spatially across a wafer thereby enabling monolithic photonic integration.

The authors acknowledge Science Foundation Ireland (Grant 12/IA/I270) and Irish Photonic Integration Center (Grant 12/RC/2276) for funding this work.

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