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Quantum Dot Optoelectronic Devices

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Quantum dots have drawn considerable interest in recent years due to their atom like density of states and predicted to have improved performance of quantum dot based optoelectronic devices. Though early attempts to fabricate quantum dots using lithographic techniques have shown some promises, real break through came when self assembled growth of quantum dots were shown to exhibit excellent optical properties. Currently, self-assembled quantum dots are widely used in optoelectronic devices such as lasers, infrared photodetectors, optical amplifiers. Molecular beam epitaxy is widely used to obtain high quality quantum dot devices. However, metal organic chemical vapour deposition is widely used in the optoelectronics industry and preferred choice for mass production. In this talk, we will discuss about growth issues of InGaAs and InAs quantum dots on GaAs substrates. Results on optical spectroscopy studies of quantum dots will be presented. InGaAs quantum lasers and quantum dot infrared photodetectors have been successfully fabricated based on MOCVD grown structures. Results on quantum dot optoelectronic devices will be presented.

Photonic integrated circuits are of immense interest for high performance optical communication systems. Two main approaches used for the creation of photonic integrated circuits are selective area epitaxy and quantum dot intermixing. Examples of both the methods will be presented with a special emphasis on quantum dot intermixing. Quantum well and dot intermixing leads to changes in the potential profile (Fig.1) which in turn modifies the eigen states of electrons and holes within the quantum dot. Typically, the effective bandgap of the quantum dot is increased after interdiffusion, resulting in a wavelength blueshifting. One of the complexities of interdiffusion in quantum dot (QD) structures is atomic interdiffusion in 3 dimensions, strain and compositional non-uniformities in the dots. By using planar masking technology, devices with differing functionalities could be integrated onto a single chip as shown in Fig.2

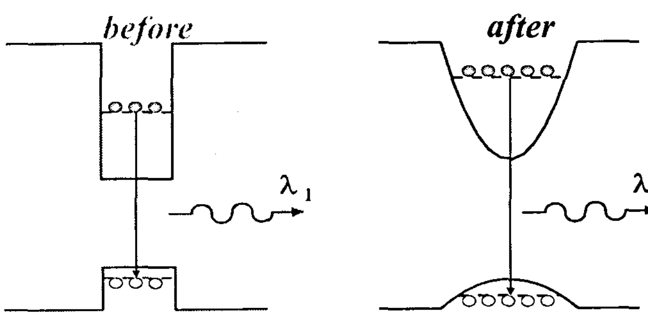

Fig. 1 Schematic of a quantum well/dot potential profile before and after intermixing

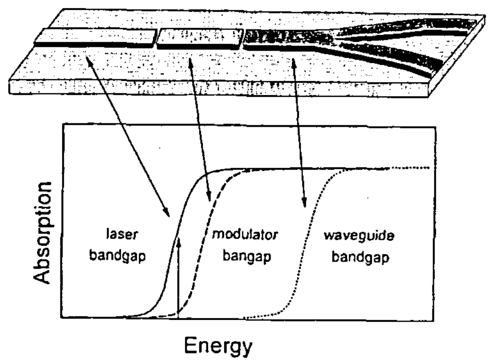

Fig. 2 Schematic showing devices of different functionalities (bandgap energies) integrated onto a single chip

There are several methods of achieving interdiffusion, such as impurity induced disordering, ion implantation induced intermixing, impurity free vacancy disordering (IFVD) and laser annealing. The two more common techniques are ion implantation and IFVD as schematically illustrated in Figs. 3(a) and (b), respectively. In the case of ion implantation, energetic ions are bombarded into the heterostructures and creates defects within the sample. During an annealing step, the recrystallization process (i.e. the movement of these defects) initiate interdiffusion. In the case of IFVD, a dielectric layer (typically SiO_2) is deposited on the surface of the sample (say GaAs). Upon annealing, the SiO_2 layer which has a high affinity for Ga atoms, promotes the outdiffusion of Ga atoms from the sample. In the process, a flux of vacancies is driven into the sample across the heterointerfaces and hence causes interdiffusion. Implantation technique has the advantage of reproducibility and precision in locating the defects within the samples. However, it suffers from residual defects in the sample even after annealing. On the other hand, IFVD leaves very little defects within the sample but the main disadvantage is that it is not very reproducible as it relies on the quality (i.e. the properties) of the dielectric layers.

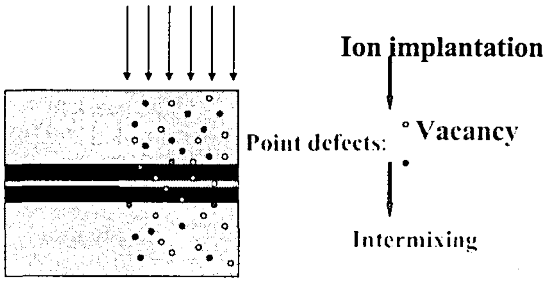

Fig. 3(a) Schematic of ion implantation induced disordering

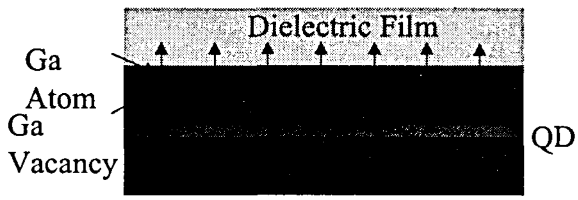

Fig. 3(b) Schematic of impurity free vacancy disordering

Both techniques have been shown to shift the wavelength of lasers, detectors and the fabrication of photonic integrated circuits based on quantum wells. We have demonstrated the tuning of lasing wavelength of GaAs/InGaAs laser diodes. This is promising in integrating sources of multiple wavelengths on a single chip for wavelength division multiplexing applications. In the area of quantum well/dot infrared photodetectors (QWIPs/QDIPs), we have demonstrated the ability to tune the detection wavelength of these devices with little degradation in their device performance. This offers a simple way of fabricating advanced detectors capable of capturing images/signals with both spatial and spectral information.

In summary, quantum dots are very promising for the creation of high performance optoelectronic devices. Quantum dot intermixing techniques may offer simple approach for the fabrication of quantum dot photonic integrated circuits.

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