# Plasma immersion $Ar^+$ ion implantation induced disorder in strained InGaAsP multiple quantum wells

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The authors report the disordering in compressively strained InGaAsP/InP multiple quantum wells induced by 20keV $Ar^+$ plasma immersion ion implantation. With an $Ar^+$ dose of $10^{16}cm^{-2}$ and a subsequent standard furnace annealing at 650°C for 90min, the implanted sample exhibits an extra blue-shift of about 20nm in comparison to the unimplanted control sample. For a sample that has been partially masked during implantation, a sharp intermixing step is observed after the 650°C anneal, indicating that the technique has the potential of introducing a localised disordering effect and, hence, may be a viable fabrication technique for integrated photonic devices.

*Introduction:* The disordering of III-V multiple quantum well (MQW) structures by techniques such as impurity diffusion, impurity-free vacancy diffusion, laser annealing [1] and ion-implantation [2] have previously been demonstrated by several groups. The fact that one can use such techniques to perform on-wafer microfabrication to produce integrated optical devices has generated much research interest. Ion implantation in particular is a process of considerable importance due to its extensive use in the silicon integrated circuit industry and the capability of well-defined patterning and damage control. Previous studies [2] have shown that, in an undoped 5nm wide InGaAsP single quantum well (SQW) capped by a 20nm InP layer, $Ar^+$ implantation ($10^{13}cm^{-2}$) at 30keV combined with rapid thermal annealing (RTA) at 675°C can induce significant layer disorder. The implanted sample has a significant excess photoluminescence (PL) blueshift in comparison to the un-implanted sample. The observed disorder in the SQW is attributed to the fact that upon RTA, lattice defects generated by the $Ar^+$ bombardment diffuse into the structure, promoting the inter-diffusion of the host atoms. There have been several other reports on implantation induced disorder in InGaAs/InP heterostructures using Si, Ga and P [3 – 5]. In all cases, conventional 'line-of-sight' DC implantation has been used.

In recent years, a new technique called plasma immersion ion implantation (PIII) or plasma source ion implantation has received much attention from both the scientific community and potential industrial users as an alternative to the conventional technique [6]. PIII is also an excellent processing technique for silicon wafers [7 – 9]. One of the favourable features of PIII in comparison to conventional beam-line ion implantation is its ability to treat non-planar and large samples. The latter advantage is quite important for semiconductor processing as large wafers require the same treatment time as small wafers.

In this Letter, we present results on the disordering effect in a strained InGaAsP MQW structure induced by PIII of $Ar^+$ and post-implant anneal at 650°C. Room-temperature PL was used to assess the disorder within the MQW structure. The nominally undoped 1.3μm MQW structure contained seven 60Å compressive strained InGaAsP wells and six 100Å InGaAsP barriers bounded by two InGaAsP confinement layers. The In/Ga ratio was constant throughout the MQW structure. The cap and buffer layers were 450nm thick *p*-InP and 2μm *n*-InP, respectively. The epilayers were prepared by metal organic vapour phase epitaxy (MOVPE). PIII was performed at 20kV for 120min to achieve an $Ar^+$ dose of $10^{16}cm^{-2}$. The operating pressure was $2 \times 10^{-1}$ Pa. Standard furnace annealing was carried out for 30, 60 and 90min at 650°C in a flowing nitrogen atmosphere. To suppress phosphorus evaporation, the samples were sandwiched between silicon wafers.

The annealed samples were characterised by PL spectroscopy using a 5mW He-Ne laser as the excitation source and a cooled Ge photodiode as the PL signal detector. In Fig. 1 the blueshift of PL peaks of the as-grown and the $Ar^+$ plasma immersion implanted samples are plotted against anneal time. It is clear that the implanted sample exhibited an extra blueshift of up to 20nm after the anneal. This is indicative of the enhanced intermixing effect related to implantation. Fig. 2 shows the scanning PL plot obtained from an annealed MQW sample that had half of its surface masked using a piece of InP during PIII. The PL peak wavelengths were measured along a line covering both regions. It can be seen that the implanted region exhibited a larger blueshift of 16–18nm. The spatial resolution of the PL measurement was around 250μm, which was limited by the spot size of the pump laser source in the PL spectrometer. Our results have nevertheless demonstrated that one can perform selected area disordering using the PIII technique.

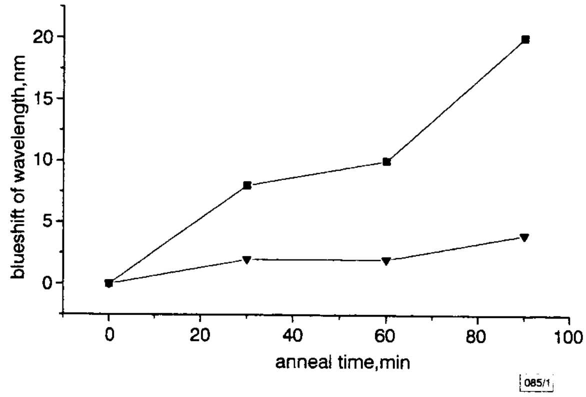

**Fig. 1** *Comparison of blueshift in $Ar^+$ implanted and unimplanted samples after annealing at 650 °C*

■ implanted
▼ unimplanted

The observed intermixing effect can be attributed to the diffusion of point defects generated by ion bombardment. PIII of $Ar^+$ deposits a large population of point defects in a thin layer of InP within a thickness of about 220Å at the surface, and subsequent anneal drives the defects into the material via diffusion. When the defects diffuse into the quantum well structures they provide vacant sites in the lattice to enhance the migration of the host atoms, hence resulting in the intermixing effect. Similar work has been performed by Oshinowo *et al.* [2]. In their experiment, the implanted $Ar^+$ penetrates into the quantum well behind the 20nm thick InP capping layer. During the subsequent anneal, intermixing occurs due to the re-absorption of defects, including interstitials of the host atoms, into normal lattice sites. The large concentration of defects in the vicinity of the quantum well accounts for the large blueshifts, about three times those seen in the present study, observed after the anneal. Our observations are consistent with their conclusion that defect diffusion after $Ar^+$ implantation can promote intermixing in quantum wells. To explain the intermixing effects due to defect diffusion from the surface, we refer to the experiments performed by Marsh and coworkers [1, 10]. Rapid thermal annealing of a multiple quantum well structure covered with $SiO_2$ leads to enhanced intermixing. As the structure has a 0.8 μm thick GaAs capping layer separating the quantum wells from the $SiO_2$ layer, they attributed the enhanced intermixing to the diffusion of group III vacancies from the surface. The vacancies are generated at the $SiO_2$/semiconductor interface under the tensile strain caused by the difference in thermal expansion coefficients at high temperatures. Because the structure used in the present study also has a thick InP capping layer separating the quantum wells some distance away from the implanted material, we conclude that the observed enhanced intermixing is primarily effected through the diffusion of defects generated during PIII of $Ar^+$.

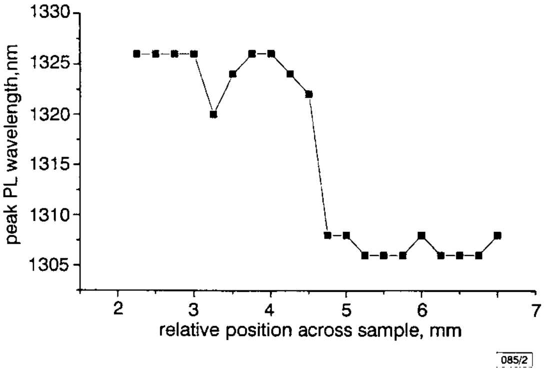

**Fig. 2** *Spatially resolved PL across annealed sample in which only half of area was treated by $Ar^+$ plasma immersion ion-implantation*

*Summary:* We have shown the enhanced intermixing effect in compressively strained InGaAsP multiple quantum well structures by plasma immersion ion implantation of $Ar^+$. We have also demonstrated the selected area disordering capability of this technique, thus indicating that it may be possible to use plasma immersion ion implantation for the fabrication of photonic devices, especially for wavelength division multiplexed optical networks.

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