Low-loss, single-mode $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As/InP$ optical waveguides fabricated by Zn-induced impurity-induced layer disordering

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We have investigated the properties of Zn diffusion in the $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ superlattice and have made optical guides delineated by Zn-induced layer disordering in the multilayers. Measurements on the single-mode waveguides show loses as low as 2.3 dB/cm including coupling loss.

Impurity-induced layer disordering (IILD) can create active and passive devices with very narrow lateral optical and electrical confinement through well-controlled implantations or diffusions. Optical waveguides, heterostructure lasers, and lateral heterojunction bipolar transistors (HBTs) have been realized by IILD.[1–3] Optoelectronic integrated circuits (OEICs) consisting of lasers and field-effect transistors (FETs) have also been successfully fabricated by this technique.[4] It is clear that IILD can be an important technique for defining complex structures and circuits using one-step epitaxy.

Most of the work reported to date have been with GaAs-based heterostructures. For optical communication systems it is important to make devices and circuits that operate in the 1.3–1.7 μm spectral range, where InGaAs/InAlAs and InGaAs/InP heterostructures become important. It is therefore necessary to demonstrate the viability of having IILD to define active and passive devices in these materials. We report here results from our study on Si and Zn-induced IILD in InGaAs/InAlAs superlattices and the properties of optical waveguides made with the disordered material.

Our first experiments were the study of IILD in InGaAs/InAlAs superlattices grown by molecular beam epitaxy (MBE) using implanted Si ions. It was evident that a high doping level and/or high annealing temperature would be required to create complete disordering. However the lightly doped or undoped regions exposed to these high annealing temperatures will experience a significant amount of In concentration modulation.[5] This is undesirable because the modulation adversely affects the optical and electrical properties of the InGaAs/InAlAs heterostructures. From the existing work of Kawamura *et al.*[6] it is expected that Zn-induced IILD of InGaAs/InAlAs heterostructures could provide complete interdiffusions of Ga and Al at lower temperatures.

The Zn-diffusion experiments were done with an InGaAs (35 Å)/InAlAs (100 Å) superlattice. The 74-period superlattice was sandwiched between thick InAlAs cladding layers, grown by MBE on a (100) InP substrate. The Zn diffusion was carried out in an evacuated ($<10^{-5}$ Torr) and sealed quartz ampoule containing a solid source of Zn_3As_2. The sample was annealed at a temperature of 725 K for 1 h and the Al, Ga, and As compositions were measured using Auger depth profiling and are shown in Fig. 1. It can be seen that Ga and Al are completely intermixed. Low-temperature photoluminescence ($T = 14$ K) measurements shown in Fig. 2 on the superlattice sample before and after Zn diffusion, shows a blue shift in peak energy from 1.21 to 0.94 μm and full width half maximum (FWHM) linewidths increasing from 13.1 to 66 meV, which further indicate the transformation of the InGaAs/InAlAs multilayer into a homogeneous InGaAlAs layer. Capacitance-voltage measurements indicate that the acceptor doping level due to Zn diffusion into an InGaAs sample

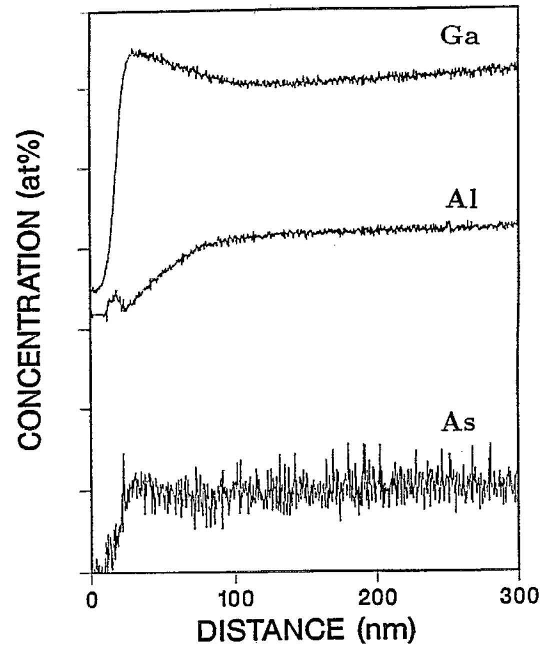

FIG. 1. Auger concentration depth profiles of a Zn-diffused InGaAs/InAlAs superlattice after annealing at 725 K for 1 h. One vertical dimension equals 20 at.% The curves have been arbitrarily offset for clarity.

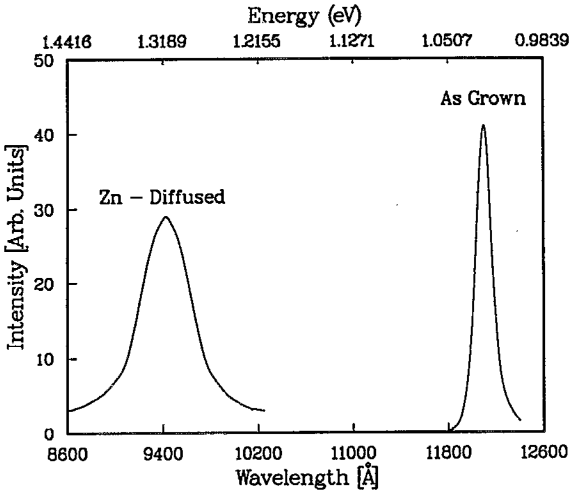

FIG. 2. Low-temperature photoluminescence spectra of InGaAs/InAlAs superlattice before and after Zn-induced layer disordering.

is significantly higher than $10^{20}/cm^3$. After annealing at a temperature of 725 K, regions which are lightly doped or undoped show little or no In modulations in sharp contrast to the observations in Si-induced IILD.

To delineate the waveguide, a 1500-Å-thick Si_3N_4 layer was deposited on the sample using plasma-enhanced chemical vapor deposition. The Si_3N_4 was patterned photolithographically into 6-μm widths. The samples were then Zn diffused in the same manner as described above and thinned for the waveguide loss measurements. A cross-sectional schematic of the Zn-diffused IILD waveguide is shown in Fig. 3(a).

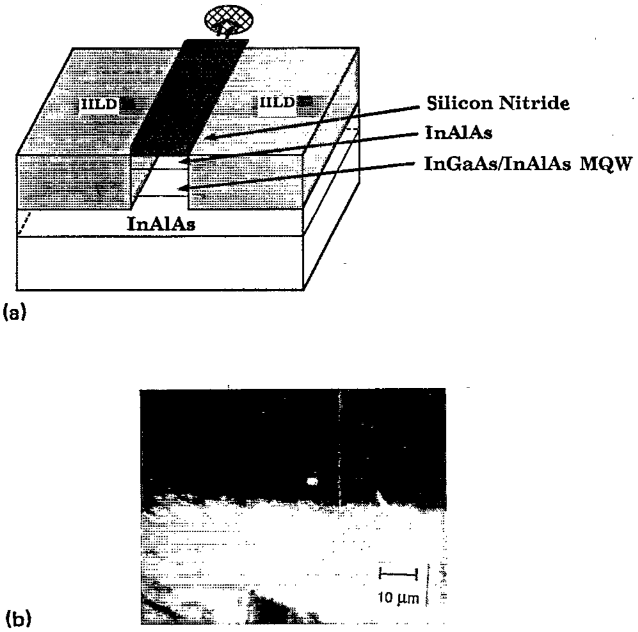

FIG. 3. (a) Cross-sectional illustration of an InGaAs/InAlAs optical waveguide structure delineator by Zn-induced IILD and (b) the observed near-field optical pattern.

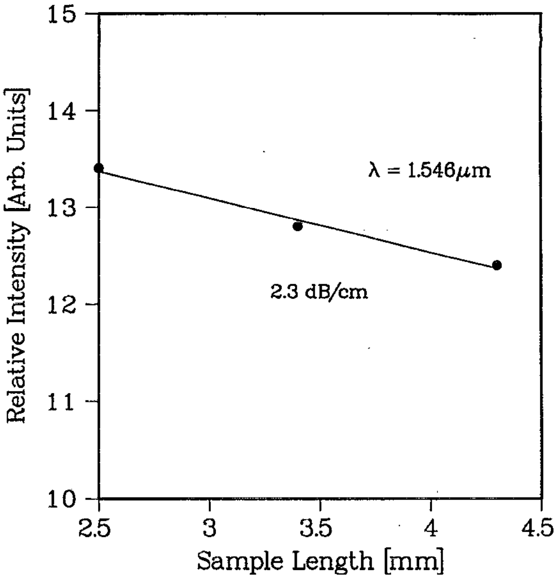

FIG. 4. Transmission vs length for a single-mode InGaAs/InAlAs optical waveguide using Zn-induced IILD.

The waveguide measurements were done with a Burleigh color center tunable laser with $\lambda = 1.48–1.67$ μm. For the loss measurements, the laser was adjusted to emit at 1.55 μm. The waveguides exhibited single-mode behavior, as observed in the near-field patterns shown in Fig. 3(b). Waveguide loss was measured by the sequential cutback method. The waveguides were oriented in the $(0\bar{1}1)$ directions to allow endfire coupling into the cleavage planes through an objective lens. The output was focused onto a Ge diode detector. Figure 4 shows the data obtained for waveguide loss. The attenuation coefficient is 0.53 cm^{-1} which leads to a loss of 2.3 dB/cm. This value is amongst the lowest measured in this material system, and provides clear evidence that IILD is a viable method of waveguide delineation.

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