<table>
<thead>
<tr>
<th><strong>Title</strong></th>
<th>Impurity induced disordering produced lateral optical confinement in AlGaAs/GaAs quantum well waveguide</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author(s)</strong></td>
<td>Li, EH; Cheung, CB; Tsui, WK</td>
</tr>
<tr>
<td><strong>Citation</strong></td>
<td>Pacific Rim Conference on Lasers and Electro-Optics Technical Digest, Japan, 10-14 July 1995, p. 287-288</td>
</tr>
<tr>
<td><strong>Issued Date</strong></td>
<td>1995</td>
</tr>
<tr>
<td><strong>URL</strong></td>
<td><a href="http://hdl.handle.net/10722/45959">http://hdl.handle.net/10722/45959</a></td>
</tr>
<tr>
<td><strong>Rights</strong></td>
<td>This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.; ©1995 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.</td>
</tr>
</tbody>
</table>
tion coefficient \(\alpha\), which is calculated from a model similar to Ref. 4 without the polarization sensitivity.

It is interesting to note that the magnitude of \(\Delta T\) (between \(F = 0\) and \(50 \text{kV/cm}\)) is enhanced in the DFQW \((L_d = 50 \text{Å})\) for all values of \(R\), as compared to the \(L_d = 0\) case, at a chosen operational wavelength \(\lambda_{\text{op}} = 758 \text{ nm}\) (to obtain maximum \(\Delta T\)), see Fig. 1. One positive peak \((\Delta T/T)_1\), and one negative trough \((\Delta T/T)_2\), can be observed in each spectrum, where the former corresponds to the largest modulation depth while the latter, although slightly smaller in magnitude, corresponds to a lower resonance absorption \(\alpha(F = 0)\). It can be seen that \((\Delta T/T)_1\) increases from 1.53 \((L_d = 0)\) to 3.40 \((L_d = 40 \text{ Å})\), which is an attractive feature for developing a high sensitivity modulator with a narrow \(\lambda_{\text{op}}\) range. Also a steady \(\Delta T/T = 0.6\) (without any sign change) is obtained for a range of \(\lambda_{\text{op}}\) (740 to 760 nm = 20 nm) in the DFQW between \(F = 40\) and 50 kV/cm, therefore it can be operated as a 20 nm band-width transmission modulator with only a single DFQW structure. Finally, the \((\Delta T/T)_2\), has a wavelength range of \(\lambda_{\text{op}} = 850 - 782 \text{ nm}\) with an acceptable fluctuation of \(\Delta T/T = 0.62 - 0.54\) \(\alpha = 12\%\) for cases of \(L_d\) from 0 to 30 Å, so it can be employed as a wide band-width modulator with a multi-section consists of different \(\lambda_d\).


**P70 Fig. 1.** Schematic of the IID multi-quantum well waveguide structure.

**P70 Fig. 2.** Refractive index profile (half symmetry) of a structure with 20 multi-QW layers, 5000 Å mask width, and propagation wavelength at 1 µm.

**P69 Fig. 2.** The transmission \(T\) spectra as a function of reflectivity \(R\) for \(F (\text{kV/cm}) = 0\) (solid), 30 (dot), 50 (dash). (a) \(L_d = 0 \text{Å}\) at \(\lambda_{\text{op}} = 0.850 \mu\text{m}\) and (b) \(L_d = 40 \text{Å}\) at \(\lambda_{\text{op}} = 0.738 \mu\text{m}\).

**P69 Fig. 3.** The \((\Delta T/T)\) spectra for DFQWs of thickness \(d = 0.5 \mu\text{m}\) and \(R = 0.5\) for \(F (\text{kV/cm}) = 10\) (dash-dot), 30 (solid), 40 (dash), and 50 (dot). (a) \(L_d = 0 \text{Å}\) and (b) \(L_d = 40 \text{Å}\).

**P70** Impurity induced disordering produced lateral optical confinement in AlGaAs/GaAs quantum well waveguides

E. Herbert Li, Chun-Bong Cheung, Wai-Kin Tsui, Department of Electrical and Electronic Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong

The impurity induced disordering (IID) technique provides an efficient way to realize waveguiding structure in optoelectronic integrated circuits. The masked implantation process produces a modification of the quantum well (QW) material which in turn modifies its refractive index. This creates a refractive index step between the implanted and nonimplanted regions and produces lateral confinement for photons in the lateral dimension, thus a 2-D waveguide is formed. Although there have been a lot of effort spent in studying the electronic and optical properties of the IID modified AlGaAs/GaAs QW structures, detailed waveguiding properties of this type of devices is still not known. A detailed model is considered here on the two dimensional IID waveguide structure and results indicate guiding requirements on the structure’s dimension, effects on the optical confinement factor, and the wavelength requirement for single mode propagation. The structure to be modeled consists of ALaGaAs/GaAs QWs (10 to 40 periods of 100 Å wide well and barrier layers) and thick ALaGaAs buffer layer grown on a GaAs substrate; the schematic of the structure is shown in Fig. 1. In our model, Ga ion is implanted with a projected range located around the center of the QW layers. The annealing time and temperature in the simulation is 20 seconds and 900°C, respectively. In order to analyze the waveguiding properties accurately, the impurity density profile as-implanted was computed based on both experimental and simulation results. 2-D refractive index profile was then calculated from these diffusion lengths, as shown in Fig. 2. The TE mode waveguide equation was solved using a finite difference method to determine the propagation constant and the corresponding propagation length, \(\beta\), as well as the optical electric field profile, and followed by the determination of the optical confinement factor.

The parameters of the IID waveguide structure such as the mask width, \(L_{\text{wa}}\) QW layer thickness, \(d\), ion implantation energy, operational wavelengths, \(\lambda\), were varied in order to analyze the single and multiple mode waveguiding requirements. It is found that the waveguide dimension, that is the mask width and the thickness of the multi-QW layers, should be at least half of the dimension of the propagation wavelength to provide a satisfactory wave confinement factor of \(-0.5\). In fact guiding was found to be sup-
ported from $d = 2200 \text{ Å}$ up to $7500 \text{ Å}$ for single mode and beyond for multiple mode with $L_m = 5000 \text{ Å}$ at $\lambda = 1 \mu m$, see Fig. 3. The effect of $L_m$ ($5000 \text{ Å}$ to $10,000 \text{ Å}$) on the single mode properties remains unaffected for $d = 4000 \text{ Å}$ at $\lambda = 1 \mu m$, as is the variation of $\lambda$ ($0.8$ to $1.55 \mu m$) for $d = 4000 \text{ Å}$ and $L_m = 5000 \text{ Å}$.


P70 Fig. 3. The propagation constant, $\beta$, as a function the thickness of the multi-QW layers, with mask width equals $5000 \text{ Å}$ and propagation wavelength at $1 \mu m$.

Kerr nonlinearity in the core, a major axis of $\sqrt{2} \mu m$ and a minor axis of $1/\sqrt{2} \mu m$, a core index of $1.57$, a cladding index of $1.55$, and a nonlinear-optical coefficient of $10^{-12} \text{ m/W}$, where the wavelength $\lambda = 0.5145 \mu m$ and $N_s$ is the number of elements. In the present approach using isoparametric elements the convergence of solutions is very fast irrespective of the difference of polarizations. The peak birefringence is greatly enhanced with increasing optical power. We have confirmed that the results of the present approach for a circular core fiber are in good agreement with analytical solutions for axisymmetric structures. It is interesting to note that the power dispersion curve for the TE-like mode of an elliptical core fiber with a major axis of $\sqrt{2} \mu m$ and a minor axis of $1/\sqrt{2} \mu m$ is similar to that for the LP$_{01}$ mode of a circular core fiber with the same core area, namely, a core diameter of $1 \mu m$.

Next, we consider a graded-index optical channel waveguide as shown in Fig. 2, where $\lambda = 0.515 \mu m$, $t = 1.0 \mu m$, $n_a = 1.55$, $n_b = 1.55$, $n_c = 1.0$, $\Delta t = 0.02$, $\Delta t_{a/b} = 0.04$, $\eta = 10^{-7} \text{ m/W}$, diffusion length $d_1 = d_2 = 3 \mu m$, and the saturable nonlinearity is assumed. Fig. 3 shows power dispersion curves for various types of nonlinear optical channel waveguides: type 1 with Gaussian and exponential profiles in the $x$ and $y$ directions, type 2 with Gaussian profiles in both directions, and type 3 with step-index profiles in both directions. The dispersion curves exhibit switching and hysteresis nature, and the threshold power becomes higher and the width of the hysteresis loop be...