

Propagation Effects in Optical Waveguides, Fibres and Devices

A thesis submitted for the degree of Doctor of Philosophy
of the Australian National University

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Declaration

This thesis is an account of research undertaken in the Laser Physics Centre and Applied Photonics Group within the Research School of Physical Sciences and Engineering at the Australian National University between June 1999 and January 2003 while I was enrolled for the Doctor of Philosophy degree.

The research has been conducted under the supervision of Prof. J. D. Love, Dr. Adrian Ankiewicz and Dr. Martin Elias. However, unless specifically stated otherwise, the material presented within this thesis is my own.

None of the work presented here has ever been submitted for any degree at this or any other institution of learning.

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January, 2003

Publications

Journal papers:

- [1] S. Tomljenovic-Hanic, J. D. Love, and A. Ankiewicz: "Low-loss single mode waveguide and fibre bends", *Electronics Letters*, 2002, vol.38, pp. 220-222.
- [2] S. Tomljenovic-Hanic, J. D. Love, and R. B. Charters: "Cut-off wavelength and transient effects in asymmetrically clad single-mode buried-channel waveguides", *IEE Proc.-Optoelectronics*, 2002, vol. 149, pp 51-57.
- [3] S. Tomljenovic-Hanic, J. D. Love, and A. Ankiewicz: "Effect of Additional Layers on Bend Loss in Buried Channel Waveguides", *IEE Proc.-Optoelectronics*, 2002, accepted for publication.
- [4] S. Tomljenovic-Hanic, J. D. Love: "Planar waveguide add/drop wavelength filters based on segmented gratings"-submitted to *Microwave and Optical Technology Letters*, #20653.
- [5] S. Tomljenovic-Hanic, and W. Krolikowski: "A new design of variable optical attenuator based on bent waveguide"-submitted to *Applied Physics B*.

Patents:

- [1] Australian provisional patent, Reg. No: PR8642
title: 'Optical waveguides and fibres with reduced bend loss'
authors: S. Tomljenovic-Hanic, J. D. Love, and A. Ankiewicz
- [2] Australian provisional patent, Reg. No: PS0831
title: 'Curved Waveguide-based variable optical attenuator'
authors: G. R. Atkins, R. B. Charters, W. Krolikowski, and S. Tomljenovic-Hanic
- [3] Australian provisional patent, Reg. No: PS2262
title: 'Optical filter structure'
authors: J. D. Love, and S. Tomljenovic-Hanic

Conference proceedings:

- [1] S. Tomljenovic-Hanic, J. D. Love, and R. B. Charters: "Fundamental Mode Cutoff in Buried Channel Waveguides", *25th Australian Conference on Optical Fibre Technology*, Canberra, Australia, 2000, pp 48-50.
- [2] S. Tomljenovic-Hanic, J. D. Love, and A. Ankiewicz: 'Low-loss single-mode waveguide and fibre bends', *Australian Conference on Optics, Lasers and Spectroscopy*, Brisbane, Australia, 2001, pp 82.
- [3] S. Tomljenovic-Hanic, J. D. Love, and A. Ankiewicz: 'Optical waveguides and fibres with reduced bend loss', *10th International Workshop on Optical Waveguide Theory and Numerical Modeling*, Nottingham, UK, 2002, pp 74.
- [4] S. Tomljenovic-Hanic, J. D. Love, A. Ankiewicz, and W. Krolikowski: "Effect of added layers on bend loss in buried channel waveguides", *4th International Conference on Transparent Optical networks*, Warsaw, Poland, 2002, pp 16-19 (Invited).
- [5] S. Tomljenovic-Hanic, and J. D. Love: "Planar Waveguide Add/Drop Filter based on Segmented Gratings", *27th Australian Conference on Optical Fibre Technology*, Sydney, Australia, 2002, pp 19-22.
- [6] S. Tomljenovic-Hanic, W. Krolikowski, R. B. Charters, and G. R. Atkins: "New design of Variable Optical Attenuator based on a Bent Channel Waveguide", *27th Australian Conference on Optical Fibre Technology*, Sydney, 2002, pp 29-31.

Abstract

This thesis consist of a theoretical study of propagation effects in optical waveguides, fibres and photonic crystals, with some comparison with experiment.

Chapter 1 gives a brief introduction with the current view of optical components in photonic integrated circuits and issues related to the loss mechanism.

In **Chapter 2** the characteristics of single-mode propagation and transient effects in practical square- and rectangular-core buried channel planar waveguides are quantified, assuming a cladding which is unbounded in one transverse dimension and bounded in the other. The wavelength cut-off condition for the fundamental mode is determined when the cladding index is asymmetric and composed of step-wise, uniform index regions.

In **Chapter 3**, the application of segmented reflection gratings in planar devices that can function as either a single- or two-wavelength add/drop filter is investigated and a numerical technique developed in Chapter 2 is applied to the waveguides with high extinction ratio. The role of the segmented gratings is analogous to that of a blazed grating, but they can provide a higher reflectivity level at the Bragg wavelength, eliminate back reflection into the fundamental mode and provide arbitrarily small channel spacing in the two-wavelength case.

Chapters 4 address the problem of bend loss in a single-mode slab waveguide. A new theoretical strategy for reducing bend loss is presented and compared to existing designs. The results obtained in this chapter are the basis for the following two chapters.

Chapter 5 deals with bend loss in single-mode buried channel waveguides and demonstrates that the new strategy can lead to significant bend loss reduction when compared to other strategies, and, conversely, can be used to enhance bend loss for a fixed bend radius for application to devices such as optical attenuators.

In **Chapter 6**, a novel design of a variable optical attenuator based on a bent channel waveguide is proposed, realized by applying a new strategy for bend loss control in a polymer buried channel waveguide.

Chapter 7 investigates effects of the additional rings in a single mode step-index fibre on bend loss. It is supported with the experimental results of Ron Bailey from Optical the Fibre Technology Centre, University in Sydney.

In **Chapter 8**, bend loss of a one-dimensional photonic crystal is quantified and compared to bend loss of a standard single-mode slab waveguide and a bend-resistant waveguide.

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