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Modeling Vector Properties of Electromagnetic Fields in Semiconductor Optical Waveguides

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1. Introduction

A quantum well (QW) semiconductor laser, typically, emits only transverse electric (TE) mode or transverse magnetic (TM) mode optical waves. A QW semiconductor optical amplifier, likewise, amplifies only TE or TM mode optical signals. Key photonic devices such as these are often polarization sensitive.

Due to scattering in fibers, the polarization of an optical signal after propagating through a fiber network is randomized. To ensure that the signal is properly detected, one approach is to equip at the receiving end of a fiber converters to correct the polarization before the signal is processed. It is therefore vital for us to model polarization properties of optical waves accurately so that converters can be designed to improve the link between fibers and optoelectronic integrated circuits (OEIC). In this presentation, we will review our recent activities towards this endeavor.

2. Polarization Rotators

Semiconductor polarization rotators are compact devices capable of altering the polarization of an optical signal. Recently, a bending waveguide based polarization rotator, which promises easy fabrication, low loss and high conversion efficiency, has been proposed and demonstrated. We will review the device structure as well as a theoretical model that we have developed for this device [1,2]. Calculation results using our model are found to compare favorably with measurement data.

3. Field Singularities

Field singularities are manifestations of the vector nature of electromagnetic waves which occur at corners of rectangular dielectric waveguides such as those found in OEIC. Although well-known among microwave device designers, their significance have been acknowledged only recently within the photonics community when vector properties are found responsible for polarization conversion of optical field in bending waveguides. What has also been recognized, however, are difficulties with modal field analysis if these field singularities are to be modelled and resolved accurately. We will describe an algorithm that we have developed to circumvent such difficulties [3].

4. Polarization and Spin 1/2 — An Analogy

It is noticed that the coupled-mode theory formulations employed in [2] are similar to those used in the study of spin 1/2 in quantum mechanics. To further our conceptual understanding, an analogy is useful. For example, if the TE and TM mode polarizations of an optical wave can be looked upon as the spin-up and spin-down states of an electron, then the effect of the curvature of the bending waveguide on an optical wave are analogous to that of an applied tilted magnetic field on an electron. Further comparisons suggest that the coupling length of TE and TM mode polarizations in bending waveguides corresponds to the precession period of an electron in a magnetic field, and that the polarization conversion efficiency can be obtained by modifying Rabi's formula for spin resonance. By recognizing this analogy, the large body of literature on spin 1/2 in quantum mechanics can be applied directly towards design of optical polarization rotators.

References

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