論 文 の 内 容 の 要 旨

論文題目

Polarization Control inside Photonic Integrated Circuits Using InP Half-Ridge Polarization Converters

（InPハーフリッジ型偏波変換器を用いた光集積回路内偏波制御）

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The current optical communication systems, which are inevitable in the modern information society, have gained the transmission capacity by multiplexing data signals. Owing to further developments of the information technologies such as introduction of cloud computing, optical communication systems with large transmission capacity have been more and more important not only in core network but also edge network. Photonic integrated circuits (PICs), integrating a number of optical components into a small chip, have proved to be a promising technology to realize the advanced optical systems in a low-cost and a small-footprint. The PICs have adapted to wavelength-division multiplexing and coherent modulation technologies, and more recently a polarization-multiplexing technology has been introduced into the PICs. However, control polarization states of lightwaves inside the PICs is an important issue because planar lightwave circuits usually employ lightwaves with only a single polarization state.

Various types of polarization handling devices inside PICs have been proposed and demonstrated on several platforms such as InP, Si, and silica. However, most of them have a quite different waveguide structure compared with conventional photonic devices in PICs, especially with active photonic devices such as laser diodes (LDs) and

semiconductor optical amplifiers (SOAs), and therefore the monolithic integration of the polarization handling devices is a challenging issue. Consequently, a fully-integrated polarization-multiplexed- (PM-) PIC has not been demonstrated yet. In such situation, polarization handling devices which can easily be integrated with active photonic devices have been demanded in order to realize the fully-integrated PM-PICs with low-cost and small-footprint.

In this thesis, I present an integrated InP half-ridge polarization converter (PC) which is significantly suitable for the integration with other photonic components. This device features its simple, ridge-like asymmetric half-ridge structure which can easily be fabricated without any critical lithographic alignment and enable a smooth connection with InP ridge waveguides. I demonstrate the integration of the half-ridge PC with a SOA on InP platform.

Chapter 1 presents the background of this research topic. Following a brief introduction of current optical communication and photonic integration technologies, several types of polarization handling devices are referred.

Chapter 2 shows fundamental theories to analyze and design waveguide photonic devices with several example numerical results. Through a slab waveguide analysis and cross-section eigenmode analysis based on a finite-difference method, a concept of eigenmodes in dielectric waveguides is described. Descriptions of polarization states of lightwaves are also shown based on Jones vector, Stokes parameters, and Poincaré sphere. Principles of a polarization conversion by using a birefringent medium are described.

Chapter 3 describes fabrication technologies of InP-based photonic devices. I express several fundamental fabrication procedures with some example results; crystal growth, lithography, deposition, and etching.

In Chapter 4 and 5, I present the integrated InP PC based on asymmetric half-ridge structure. Chapter 4 describes a design, principle, fabrication, and demonstration of the half-ridge PC. One side of the half-ridge PC is ridge structure and the other side is deeply-etched high-mesa structure. By employing an angled deposition, the half-ridge structure is fabricated without any precise lithographic alignment below sub-micron scale. More than 96% polarization conversion is achieved in a broad wavelength range covering C-band and quite low insertion loss below 1.0 dB using a small operating length of 150 μm. Also, the experimental results significantly agree with numerical characteristics. Based on detailed analyses of the fabricated PC, the half-ridge structure is optimized as shown in Chapter 5. By introducing a slope at the ridge side of the half-ridge PC, a fabrication tolerance in the width of the PC increases factor-of-two improvement. To fabricate the optimized structure precisely, I propose an improved fabrication procedure using a novel layerstack and hybrid etching processes.

In Chapter 6, I demonstrate the integrated of the half-ridge PC with a SOA. I employ an offset quantum well layerstack to integrate active and passive components monolithically. An incident transverse electric (TE) light is amplified by the SOA and then convert to a transverse magnetic (TM) mode by the half-ridge PC. Polarization conversion ratio of 99% is successfully achieved with the half-beat length of 70 μm.

Chapter 7 presents a proposal of a waveguide polarization modulator consisting of the half-ridge PC and a passive waveguide modulator. Since a refractive index modulation based on electro-optic effects depends on the polarization state, TE and TM modes, the birefringence of the symmetric waveguide can be controlled by an external voltage bias. An incident TE mode, assuming the output from an integrated LD, is converted to arbitrary polarization states by using two half-ridge PC with quarter-beat length and two symmetric waveguide modulators.