Abstract of Dissertation

All-optical Wavelength Converter and Monolithically Integrated Switch Based on Electro-absorption Nonlinearity

電界吸収非線型効果を用いた波長変換器およびモノリシック集積型全光スイッチ

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Abstract

The tremendous development of the internet or other wide band access technologies such as DSL、FTTH has driven the development of the high-capacity optical networks from research laboratories into commercial deployment such as Synchronous optical networks or Synchronous digital hierarchy. In the first generation, optics is used only in transmission, and all switching and other intelligent functions are handled in electronics. Now people are seeing the deployment of the 2nd generation optical networks, where some of the routing, switching and intelligence are handled optically. In this network, data is carried from its source to its destination in optical form, without undergoing any optical-to-electrical conversion so that the electronic devices will not limit the speed. In this network, both of the two current primary techniques for data multiplexing i.e. wavelength-division multiplexing (WDM) and time-division multiplexing (TDM) are used including all optical devices such as wavelength converters, all optical switches, optical add/drop multiplexer, 2R, 3R and etc..

This thesis introduces two novel devices for all optical processing by using multiple quantum well (MQW) electroabsorption modulators (EAM) for high-speed telecommunication: wavelength converters and all optical switches. The reasons why the EAM is used to replace the traditional semiconductor optical amplifier (SOA) are short recovery time under reverse bias (possible to be <10ps), high stability, no amplified-spontaneous emission (ASE), and easy integration with other devices, especially, lasers. Moreover, we chose InGaAlAs as the core layer material in our devices due to its merits of large refractive index ratio between waveguide and cladding layer, large conduction band offset suitable for uncooled operation, and large spectral range.

The proposed wavelength conversion is based on the optical nonlinear polarization rotation in an EAM. Nowadays, most of the EAM-based wavelength conversion is using cross-absorption modulation (XAM) due to its simple configuration. However, XAM suffers from the large input power, typically larger than 15dBm. In order to reduce the input power, we investigated the cross-phase modulation (XPM) for TE mode and TM mode, and the polarization rotation. In the static wavelength conversion experiment, we demonstrated that the input powers for π phase shift are only 5dBm for upward conversion (from 1555nm to 1560nm) and 8dBm for downward conversion (from 1555nm to 1550nm), and the extinction ratios are 34dB and 31dB respectively. 10Gb/s dynamic wavelength conversion has also been demonstrated. Further simulation shows that the narrowing of the quantum well and compressive strain of MQW enhance the polarization rotation, thus reducing the required input power for saturation state. Higher speed operation is also possible by using higher reverse and optimizing the RF response.

For all optical switches, a Mach-Zehnder interferometer (MZI) configuration with EAM on the MZI arms is proposed. On account of the low relaxation time of EAM, no push-pull operation is needed. Moreover, compared to SOA, EAM has no current injection, so lower heating and low power consumption can be achieved.

The main challenge of our MZI-EAM device is the monolithic integration of the EAM and other passive waveguide. Due to large insertion loss of EAM and no gain devices in the whole structure, etch and regrowth method is chosen to reduce the total insertion loss by optimizing the active and passive regions individually. Till now, etch and regrowth technology has been well developed for InGaAsP material, but for Al-containing material, it still remains a challenge, especially for ex-situ cleaning procedure. The difficulty arises from the formation of stable Al-Oxides due to the often inevitable air-exposure of the InGaAlAs core layer during device processing, which degrades the crystal quality grown at the interface and causes large scattering loss. We optimized the growth conditions by MOVPE and processing procedures for both one-step regrowth and two-step regrowth and obtained good connection at the interface of the passive waveguide and active EAM region, with high coupling efficiency and low coupling loss (0.21dB/facet).

Another big issue of the EAM-based all optical switch is the large insertion loss. This is mainly due to the large absorption of EAM and scattering in the waveguide. High mesa structure is superior for small size, but suffering from the significant scattering loss at the sidewall. Ridge structure has much lower loss, but has longer S-bend and multimode interferometer (MMI). Moreover, the doping profile in the cladding layer has also influence on the total loss.