論文の内容の要旨

Fabrication of Monolithically Integrated Interferometer Switches by Selective Area MOVPE and their All-Optical Signal Processing Applications

(選択 MOVPE によるモノリシック集積干渉計光スイッチの作製とその全光信号処理への応用)

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With the immense growth of the data traffic in the so-called information era over this decade, the optical time division multiplexing (OTDM) has become one of the increasingly important fundamental techniques to increase the transmission capacity on a fiber. At the receiver side the base rate data signals must be extracted from the OTDM data stream by using an optical switch with a demultiplexing function. Different approaches have been proposed and used for optical switching. The possible approaches can be categorized as follows: electro-optical demultiplexer and all-optical demultiplexer. The electro-optical demultiplexers rely on the electrical control of the switching function. With increasing base rates, signal processing such as routing, restoration and format conversion becomes increasingly difficult using electronics. To overcome this so-called electronic bottleneck, the all-optical solutions are required to fulfill a fast data processing all in the optical domain. Some of the basic requirements for such an all-optical switch can be defined as follows: The switching time should be much less than the bit period of the OTDM data signal; it has to have high switching contrast of more than 10 dB; it should be stable to provide a good system performance.

This thesis presents the fabrication of workable monolithically integrated all-optical interferometric switches in the Mach-Zehnder Interferometer (MZI) and the Michelson Iterferometer (MI) configurations. The devices are realized in passive-active InGaAsP/InP planar waveguide technology with semiconductor optical amplifiers (SOA) as nonlinear elements in the interferometer arms. The operation principle of an all-optical SOA based switch relies on the control of light by another light through optically induced refractive index changes. By placing the SOA in an interferometric geometry, the consequent phase changes can be exploited to switch a signal from one output port to the other and back again in enormous speed of picosecond order. This all-optical interferometric switch therefore, gives the functionality to shunt or to modulate an optical signal by another optical control signal

The MZI switch in this thesis operates all-optically and can handle data rates up to 160Gbit/s. It has a high contrast ratio and the monolithic integration provides the required stability. Functional components were also monolithically integrated to the MZI switch for higher functionalities and performance. These were the phase shifters and the pre-amplifiers. Considering their different operating requirements, 4 different bandagap energy were used to integrate these components. The integration of all these 4 bandagp-energy was achieved through only one step of epitaxial growth. The integrated phase shifter utilizes the band-filling effect to achieve phase biasing functionality through the Kramar-Kronig's relation. Using the phase shifter, the switching extinction ratio can be enhanced by 5dB without significant additional absorption loss (<1 dB). The integrated pre-amplifier was designed to provide linear amplification to the input control signal with less amplified spontaneous emission (ASE) noise. Using the pre-amplifier, the switching power can be reduced by 10dB. The works presented in this thesis represents the first 4-bandgap-energy integration in a monolithically integrated MZI switch and its dynamics results are the first all-optical signal processing applications obtained using such devices.

In MI switch, 80Gbit/s demultiplexing operation has been successfully demonstrated. This was the first 80Gbit/s demultiplexing ever achieved with an MI switch fabricated through any kinds of integration schemes. We proposed a co-propagation scheme in which the switching window is tuned to gate one OTDM channel when both control and data signal travel in the same direction. With this scheme, ultra fast switching as high as 160Gbit/s, which is not limited by the data signal traveling time or SOA length can be expected to realized in an MI switch.

The integration technique used to monolithically integrate the inteferometric switches in this thesis is a simple, viable and attractive technique among various others more frequently used techniques. The selective area MOVPE is an integration technique that utilizes the difference in growth condition on a masked substrate. With a proper design of the masks width and the gap between them, arbitrary number of regions with different bandgap energies can be integrated simultaneously on a substrate. In this thesis, the PL wavelength in the active and the passive regions can be brought as farther as 190nm. Therefore, providing the required SOA for operation in telecommunication wavelength while keeping the passive waveguides transparent to the optical signal.

The interferometric switches in this thesis are the first switches fabricated using deeply-etched passive waveguides The deeply-etched waveguide gives strong optical confinement and therefore, the chip size of a typical MZI switch can be made as small as 3.5mm X 1.0mm. With this dimension, a high integration density can be achieved with more than 300 switches fabricable on a 2-inch substrate. Besides that, by adopting an improved fabrication process, a high device yield can also be obtained in our work.

We believe that the all-optical switches presented in this thesis and the selective area MOVPE technique that enable their integration would stand as the key devices as well as the key technology to steer important advancement for the future optical communications network.