Modeling and design of a high-speed reflective transceiver for the access network


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We present the modeling and design of an InP-based wavelength duplexer used in a transceiver module for the access network within the Dutch National Broadband Photonics project. The duplexer is made polarization independent by proper design of the waveguide geometry.

Introduction

With the advent of the first low loss optic fiber, optic fiber communication network has been developed all over the world with significant speed, and the deployment of the fiber is ever deeper into the subscriber access networks. Today’s access networks are mostly of a hybrid nature. Fiber is used in the feeder part of the network, but in the last drop to the residential user there is a variety of media, such as twisted pair, coaxial cable, and (increasingly) wireless drops. At the same time, communication speeds per user residence are foreseen to rise beyond Gigabit Ethernet and even 10 Gigabit Ethernet. As the capacity demand by the subscriber grows, also the capacity in the fiber feeder part has to keep up with it. Optical signal multiplexing techniques have proved to be the way for meeting capacity demands. The Dutch National Broadband Photonics project aims to develop and validate a novel system concept, which will enable to provide congestion-free access to users with traffic demands fluctuating in time and in place. The dynamic network reconfiguration technique for multi-casting will be explored, shown in Fig. 1. From the figure, we can see there are two wavelengths, one carrying the download stream data from the burst mode transmitter (BM Tx) and the other from multi-\(\lambda\) CW transmitter, entering the ring subnetwork simultaneously. The multi-casting \(\lambda\) router can guide the lights through the optic network unit (ONU) to the users. The tuning path by which the operator needs to control the wavelength selection at the router is indicated.

In the access network, one of the key elements is the ONU which will directly influence the performance and cost for the users. Different ONUs were already reported where different mechanisms were employed for the upstream data. Takeuchi used a modulator together with a laser diode to upload the modulated signal[1]. Park chose a different wavelength band from the downstream one together with a reflective SOA (RSOA) for upstream[2]. Prat succeeded in using one RSOA for both up and downstream at 1.25 GHz by changing the bias current[3], however it could not work for downloading and uploading at the same time. The ONU in our project does not need a laser diode (more economical), and works with two wavelengths spaced 200 GHz (1.6 nm) in the C band (from 1530 nm to 1560 nm) for up- and downstream. The schematic is shown in Fig. 2. From the figure, the two wavelengths from the router, \(\lambda_1\) and \(\lambda_2\) (CW) will be separated by a Mach-Zehnder (MZ) wavelength duplexer. \(\lambda_2\) is fed to a RSOA and is modulated with
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Figure 1: An implementation of the dynamic reconfiguration in a ring network topology including the routers and ONU.

Figure 2: Integrated transceiver consisting of a wavelength duplexer, a reflective SOA modulator and a detector.

the data to be sent upstream. After reflection it travels through the MZ duplexer upstream. Thus $\lambda_2$ is modulated and amplified. $\lambda_1$ is guided to a fast photodetector, which can be realised by reversely biasing a short semiconductor optical amplifier.

To optimize the transceiver, the wavelength duplexer has to be designed free of polarization dependence, with low crosstalk, and low loss. In the next part, we will analyze its polarization dependence, and fabrication tolerance by means of circuit simulation software[4].

Design and modeling of the wavelength duplexer

In our transceiver, three kinds of waveguide structure are employed, Fig. 3. All access waveguides are shallowly etched with 3 $\mu$m width to ensure low propagation loss, while all MMIs and MZ arms are etched through the waveguiding layer, giving stronger lateral confinement to allow smaller radii and better fabrication tolerance for the MMIs. In this chip, the radius of the curved waveguide is 120 $\mu$m for the deep etched part and 500 $\mu$m for the shallow etched waveguides. Thus, the total size of the structure is very compact, around 2.5 mm $\times$ 0.25 mm including the SOA and detector. For the active layer structure, a PIN heterostructure consisting of one undoped active layer sandwiched between p- and n-type cladding layers is used for the SOA modulator and detector.

Polarization independent wavelength duplexer

To design a polarization independent transceiver, we first need a polarization independent wavelength duplexer. Deeply etched waveguides with appropriate width are designed to satisfy this requirement. From Fig. 4, we can see that the effective mode indices of TE- and TM polarization are the same at 1.5 $\mu$m waveguide width.

To separate $\lambda_1$ and $\lambda_2$ spaced 200 GHz, two unequal arms of the MZ interferometer are designed to introduce the required $\pi$ phase shift. From the following equations, the length...
difference $\Delta L$ can be derived:

$$
\left( \frac{2\pi N_{g,1}}{\lambda_1} - \frac{2\pi N_{g,2}}{\lambda_2} \right) \times \Delta L = \pi,
$$

where

$$
N_{g,i}(\lambda, w) = N_{\text{eff},i}(\lambda, w) + \lambda \frac{dN_{\text{eff},i}(\lambda, w)}{d\lambda}
$$

in which $N_{g,i}$ is the group index for $\lambda_i$, and $w$ is the width of the waveguide. In our case, with $\lambda = 1.55 \mu m$, $N_{g,i} = 3.69$, $\Delta \lambda = 1.6$ nm: $\Delta L$ is around $200 \mu m$ where the $1.5 \mu m$ waveguide width ensures polarization independence.

**Tolerance analysis for the wavelength duplexer**

We designed two different wavelength duplexer structures, $1 \times 2$ MZ-duplexer with two different MMIs, Fig. 5(a), and $2 \times 2$ MZ-duplexer with two identical MMIs Fig. 5(b), of which the dimensions of the MMIs and $\Delta L$ are all optimized for TE polarization. To analyze the performance, the dependence on the waveguide width variation, due to lithographic limitations, was simulated, as is shown in Fig. 5(c) and (d).

From the simulation figures, it can be concluded that the excess loss for TE polarization is less than 0.6 dB within a realistic width variation of $\pm 0.2 \mu m$, and crosstalk is less than $-40$ dB within that range. Furthermore, we also can see that the $1 \times 2$ structure is more tolerant than the $2 \times 2$ structure. Both of them are insensitive to wavelength change.

To prevent light at the output facet reflecting back to the SOA, the input/output waveguide is placed at a $7^\circ$ angle with the normal to the chip facet, where the reflection for the fundamental mode is minimum. To prevent reflection of higher order modes, a mode-filter was integrated [5, 6].

**Conclusion**

A polarization independent wavelength duplexer for a transceiver module with low loss and crosstalk is designed. Two different types of structure were analysed by means of
(a) 1 × 2 wavelength duplexer. (b) 2 × 2 wavelength duplexer.

![Graph](image)

Figure 5: Dependence of loss and crosstalk performance of the duplexer on the waveguide width deviation of two structures.

tolerance comparison, which shows that the 1×2 duplexer structure is more tolerant, with less than 0.6 dB excess loss and −40 dB crosstalk within realistic waveguide width variations. The reflections of the modes from the facet are minimized by the facet angle and mode filter. Test devices both with and without detector and SOA are being fabricated to experimentally verify our findings.

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References


