HIGH SPEED POLYMER E-O MODULATOR CONSISTING OF A MZI WITH A MICRO RING RESONATOR

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SUMMARY

An integrated optical electro-optic modulator consisting of a Mach Zehnder Interferometer with a micro ring resonator has been realized and characterized. The response measurements exhibit a 3dB roll-off at 0.5 GHz.

KEYWORDS
polymer, electro optic, microring resonator, Mach Zehnder Interferometer

ABSTRACT

A Mach Zehnder interferometer with an polymer electro optic micro-ring resonator on one of its branches is realized in a polymer layerstack and characterized. Electro optic coefficients of 10 pm/V and modulation frequencies of 1GHz were measured.

INTRODUCTION

The role of integrated optics becomes more and more important in data communication. In order to let integrated optical components replace its electrical equivalents, active optical components are needed. A very important component is the electro-optic modulator, which is used to convert data-streams from the electrical to the optical domain. This paper deals with the realization and characterization of such a modulator that is based on the resonance principle of a micro-ring resonator (MR) and the phase response of a Mach Zehnder Interferometer (MZI).

DESIGN AND REALIZATION

A MR can be realized by fabricating a circular waveguide, which couples vertically to two straight port waveguides (figure 1), see, for example [1][2][3].

By changing the optical path within the ring its resonance wavelengths can be shifted and both in the through and drop port an amplitude as well as phase modulation can be generated [1]. This change in the ring can be induced by temperature (placing a heater above the MR) or by an electric field (sandwiching the MR between two electrodes). Because of their high thermo- and electro-optic coefficients, polymers are very suitable for this type of devices. One of the problems in realizing such a device in a vertical coupling arrangement is the position of the MR relative to the two port waveguides. This position determines the amount of light that couples from the waveguides to the ring (and vice versa) at both the through and drop port side (the coupling constants). These coupling constants are critical parameters determining the spectral behaviour. Coupling the MR to a single waveguide simplifies the fabrication process because there is only one coupling constant involved. In addition, the spectral behaviour of the MR is less sensitive to changes in this single coupling constant. In an ideal lossless ring the through port spectrum has no resonance dips because no light is coupled to the drop port waveguide. In order to use a MR coupled to a single waveguide, the phase

![Figure 1: Schematic view of a MR with two port waveguides](image-url)
change around a resonance wavelength can be used. Fig. 2 shows schematically the output spectrum and the phase response of a slightly lossy MR around a resonance wavelength ($\lambda_r$) [2]. This phase response can conveniently be converted to an intensity modulation by combination with an MZI. When switching between the on-resonance and off-resonance condition, the difference between the two branches of the MZI can switch from $\pi$ to 0. This combination between a MR and MZI is shown (including a cross section through MR and waveguides) in figure 3. The passive behaviour of such is device is described by [4].

The complete device is fabricated in a polymer layer stack, which can be deposited by spin-coating. The material used for the 2 $\mu$m wide ridge waveguides is the negative photoresist SU8. The ridges have a height of approximately 300 nm. The ridge waveguides can be defined in a two step lithographic process without any additional etching-step. The MR (with a radius of 150 $\mu$m) is fabricated in the nonlinear polymer PMMA-DR1 (synthesized by Ecole Nationale Superieure de Chimie de Montpellier within the IST project NAIS). The MR is defined by lithography followed by reactive ion etching. Both, the MR and the ridge waveguides, are surrounded by a methyl-silicone resin (sold under the name PS233 Glass clad by United Chemical Technologies). The splitter and combiner in the MZI are fabricated by making two y-junctions in the single mode waveguide. The fabrication process is shown in figure 4 in some detail.
The part of the SU8 layer under the MR is removed lithographically in order to prevent coupling of light from the MR to this layer. Coupling to this layer would induce additional optical loss in the MR. Fabricating a balanced MZI is relatively easy when applying a heater over one of the branches. This branch can be tuned, such that both branches have the desired optical path length difference.

While coupling in light at the input waveguide, the spectrum can be measured at the output waveguide. For the TE mode this spectrum shows two sets of resonance lines originating by two resonator modes, see figure 5. When using the MR as a modulator, this does not matter because a single input wavelength (on a flank of one of the steep dips) is chosen as a modulation wavelength. With an electrode above and below the MR an electric field is applied over the MR changing its refractive index. Only the shift in the position of this single dip is of influence on the output.

While applying a modulating voltage between top and bottom electrode, the amount of optical modulation is measured. Because the slope of the spectrum around the modulation wavelength is known, the induced wavelength shift of the spectrum can be calculated for a certain modulation ripple. From this wavelength shift, the change in the refractive index of the MR-material can be calculated and with the electric field applied known, the electro optic coefficient is determined. The $r_{33}$ value found for this device is approximately $10 \text{ pm/V}$, which is in accordance to the values found in literature [5]. The electrode structure used is a lumped element structure because the length of the electrodes above such a MR can be small. A rule of thumb in RF design states that an electrode can be used as a lumped element as long as its length is smaller than 10% of the wavelength of the electrical driving field. Even for electrode structures of 1 cm in length this corresponds to an electrical frequency as high as 2 GHz. The electrode size can even be reduced to the size of the MR, making frequencies of 60 GHz possible without special RF electrode design.

The frequency of the applied modulation voltage is changed by a network component analyzer (NCA) and the modulation depth as a function of the electrical frequency is determined. These measurements were done with and without an electrical amplifier between the NCA and the electrode. This amplifier is used to increase the limited voltage applied by the NCA. The setup is schematically shown in figure 6.

The detector used had a spectral response which started to decay around 1 GHz. This spectral response was measured and the measured device response was corrected for this response. The different measurements done are shown in figure 7.
In figure 7 four lines are shown. These lines are:
1. Measured frequency response of the device without electrical amplification and detector correction
2. Measured frequency response of the device with electrical amplification and without detector correction
3. Measured frequency response of the device with electrical amplification and with detector correction
4. The noise signal of the detector (with the laser power off)

In lines 2 and 3 a modulation can be seen with a periodicity of 50 MHz. This is probably caused by the amplifier which gets reflections from the electrodes back. This modulation is not caused by the device because in line 1 the frequency response is flat. It can be seen that modulation frequencies up to 1 GHz can be measured. With this performance, data-rates exceeding 1 Gbit/s can be transmitted. With some specific modulation techniques (like for instance quadrature amplitude modulation), data-rates of 2 to 3 Gbit/s will be possible. The roll-off above 500 MHz is caused by the layer stack. The effective current through this layer stack is dependent on $1/oC$ in which $o$ is the electrical frequency and C is the capacitance of the layer stack. Increasing the frequency results in an increase in the current through the layer stack. Because the NCA drives the electrodes with a constant modulation power, a higher current also means a lower voltage over the electrodes and therefore the electrical field decreases. The roll off is certainly not caused by bandwidth limitations of the MR, because the characteristic time for a MR to build up the optical field is equal to:

$$\tau_{opt} = \frac{FRn_g}{c}$$

In which F is the finesse of the MR, R the radius, $n_g$ the group index of the mode in the MR and c the speed of light in vacuum. With realistic values of R and $n_g$ (150 µm and 1.5) it can be seen that for 1 GHz modulation ($\tau_{opt} < 1$ ns) the finesse can be as high as 1300 before this effect would be dominant. As can be seen from figure 5 the finesse in our ring is much lower (about 10).

CONCLUSION
A polymer electro optic MR resonator has been fabricated and characterized. By coupling the MR with one of the branches of the MZI a modulator with larger fabrication tolerances than a standard MR is realized. With a NCA the frequency behaviour of the modulator was measured up to 1GHz with an electro optic coefficient ($r_{33}$) of 10 pm/V.

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