Optimization of driving signal for thermal modulation of a Microring Resonator

R. Meijerink, D.H. Geuzebroek, E.J. Klein, H. Kelderman,
R. Dekker, M.B.J Diemeer, A. Driessen

Integrated Optical Micro Systems, University of Twente,
P.O.Box 217, 7500AE Enschede, the Netherlands, d.h.geuzebroek@el.utwente.nl

The thermal modulation of a microring resonator with integrated chromium heater has been investigated. It is shown that the modulation speed can be enhanced by optimizing the driving signal, i.e. creating an overshoot and biasing the signal. Measurements at a modulation frequency of 500 Hz showed that by applying an overshoot to the driving signal, the power needed for equal modulation depth can be reduced by 44%. Measurements with overshoot-and-bias driving showed that both rising and falling slopes can be improved.

Introduction

Microring resonators (MR) are promising devices for use in optical network elements. Their size and multi-functionality are favorable for VLSI photonics. The functions of a passive MR can be extended by adding a tuning functionality. Tuning can for example be done thermo-optically or electro-optically. Changing the parameters of the ring by applying a thermal or electrical field respectively, the resonance condition for the ring changes and so its wavelength response. In this paper the optimization of the modulation speed of a thermal driven MR is discussed. Since a passive device can easily be supplied with a heater structure (see figure 1) there has been chosen for a thermally tunable device. Although the speed for switching or modulating a ring thermally will be low compared to an electro-optically tunable ring, there will be some applications where this easy to implement structure is of use, for example in creating pilot tones.

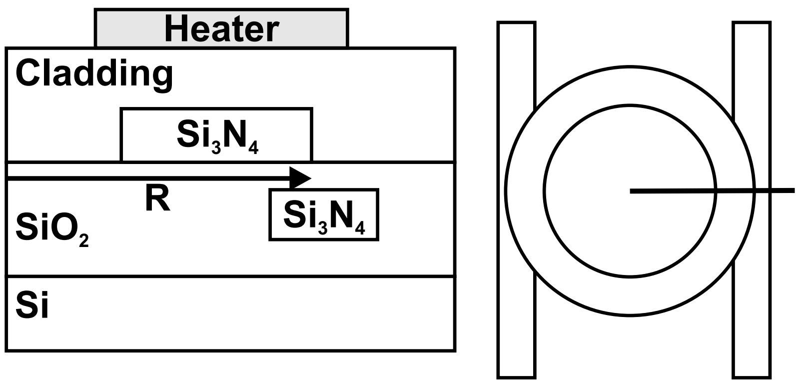

Figure 1: Cross section of Microring Resonator

Thermal driving of Microring Resonator

The thermal tuning of MR has been described in for example [1, 2] . A shift in resonance wavelength of 4 nm at low power consumptions (180 mW) was shown [2]. To modulate a signal by use of MRs only a shift of several tenth of nm is needed, as is shown in figure 2. The modulation takes place on the slope of a resonance peak. The better the Finesse of the ring, the steeper the slopes are and smaller modulation powers will be sufficient. Thermal modulation of MRs has therefore potentially low power consumption and expensive thermal stabilization is not necessary.

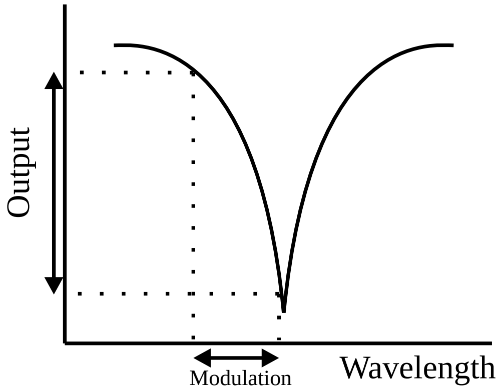

Figure 2: Modulation using a MR

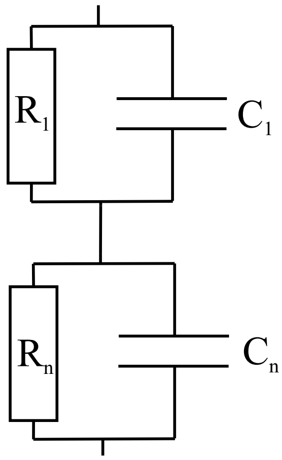

Figure 3: Electrical analogy of thermal behaviour of a single layer

To model the thermal behaviour of the MR an electrical circuit equivalent structure has been used. It turned out that a simple RC-circuit with one resistor and one capacitor can be used when only the steady-state response is of interest [4]. Since for modulation the transient response is more important the model needed to be extended. By modelling the structure as an infinite number of serial cascades of a resistor and capacitor in parallel, the proper response can be simulated as is described in [4]. The model is shown in figure 3. The resistor represents the thermal resistance of a infinite thin layer, the capacitor the thermal capacitance.

Optimization

In the optimization of the thermal modulation of a microring, there are several aspects and parameters that play a role. First, the material properties and geometry of several parts of the device structure are important. The heat capacitance and resistance of the layer between the heater and the distance of the heater to the ring are parameters which influence the behaviour directly. The material and shape of the heater structure influence the speed as well [3]. Secondly, the shape and amplitude of the driving signal can be optimized to increase the speed of the response with low driving powers. In this paper the focus is on optimizing the driving signal, since the material choice and geometry are in most cases optimized or a compromise was made with other design issues.
The amplitude and the shape of the current determines the speed and the magnitude of the heating. The application of a larger current will enhance the generated heat and therefore the increase in temperature, but this will also take more time. Furthermore, the final resulting modulation will not be perfectly linear with the power, because the resonance

peak that is used for the modulation can only be locally approximated by a linear function. Note that this also depends on the modulation depth, i.e. the amplitude of the current.
The shape of the driving signal is also of great importance. By applying an overshoot the heating can be made faster. This means that at the start of the driving pulse, a higher current than is needed for the desired steady-state temperature is shortly applied. Just before the desired temperature is reached, the current is changed to a level that results in the desired temperature.
So far, only the possibility of speeding up the heating of the material is discussed. The cooling down of the structure is equally important, though. Enhancing the speed of the cooling down process might be done by active cooling, but this would require major adaptations to the device and the low cost low power principle would not hold anymore. A much easier way to do this is biasing. In biasing, a DC-current is applied, that will result in a relatively small change in temperature, refractive index and therefore resonance wavelength. To heat the device, the overshoot current is applied, to cool it down, a reverse overshoot is applied. See figure 4 for the simulated behaviour of overshoot and bias driving. The maximum current that can be applied is limited, due to the destruction of the heaters at high powers. The use of a bias will therefore cause a smaller modulation depth, but the modulation will be faster, since the time needed for cooling down is reduced. Figure 4 shows that the overshoot-and-bias driving signal causes a faster response in both heating and cooling.

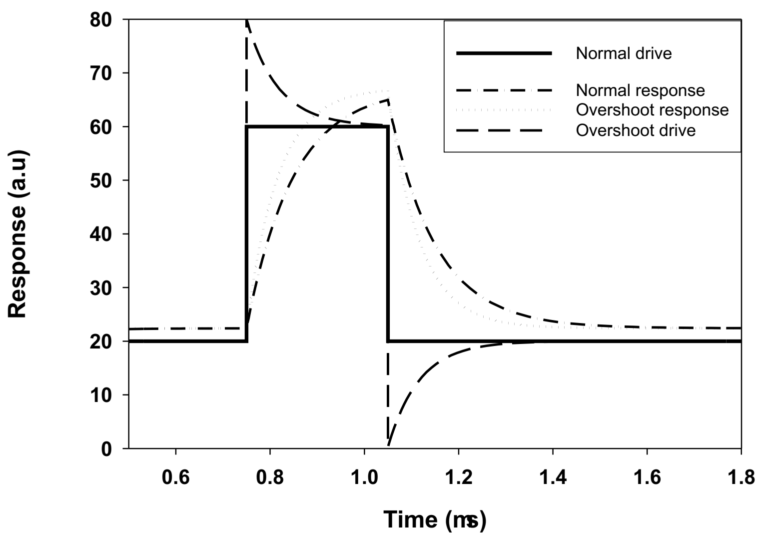

Figure 4: Simulated result of modulated output driven by normal block wave and overshoot-and-bias signal

Results

Measurements have been done on a single MR based on SiO_2/Si_3N_4 with a chromium heater. A modulating signal was applied to the heater. The wavelength of the incoming light source is chosen such that is it placed an the slope of the resonator response. Figure 5 shows the measured responses of the system with and without the overshoot in the driving

signal at 500 Hz. The overshoot response reaches its maximum value faster and the slope is steeper for the rising case. The response in the falling slope did not change since in this case no overshoot was applied for the falling slope. Furthermore the steady state value of the overshoot driving signal is less then the normal driving signal. The same modulation depth in output response was reached with 44% less power.
The measurement shown in figure 6 also shows the result of the use of a bias. Now an overshoot has been applied on the falling slope as well. It can be seen that not only the rising slope is steeper than the normal response, but the falling slope as well. The modulation depth in this measurement is somewhat reduced, since the steady-state values for high and low were chosen the same, to investigate only the effect of the overshoot and bias on the slope behaviour.

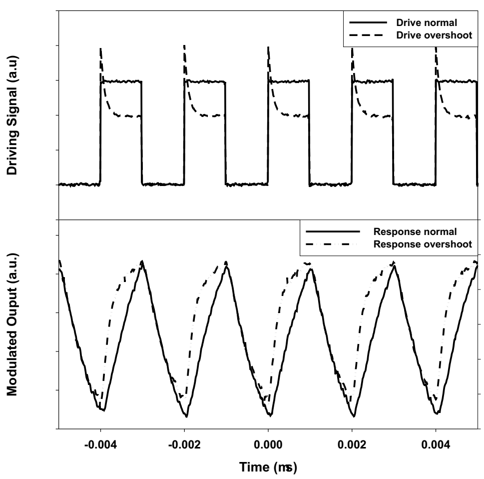

Figure 5: Measurement of response with normal and overshoot drive

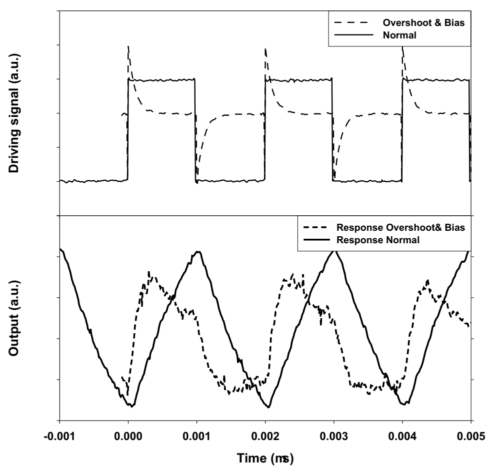

Figure 6: Measurement of response with normal and overshoot-and-bias drive

Conclusion

The optimization of the driving signal for a thermally modulated MR has been described. The application of a overshoot-and-bias signal to the heater structure enhances the speed of the modulated output. A 44% decrease in needed driving power is measured. Both the rising and the falling slope of the modulated response are improved.

References

[1] P. Rabiei et al, ”Tunable polymer double micro-ring filters”, *Photonics Technology Letters*, Vol. 15(9), pp 1255-1257, 2003.

[2] D.H. Geuzebroek et al., ”Wavelength tuning and switching of a thermo-optic microring resonator”, *Proc. ECIO*, 2003, pp 395-398.

[3] E.J. Klein, ”Wavelength selective switching using thermally tunable microring resonators”, Msc Thesis, Univeristy of Twente, 2002.

[4] Y. Jay Min et al., ”Transient thermal study of semiconductor devices”, *IEEE Trans. Comp., Hybrid, Manuf., Technol.*, vol 11, pp 485-492, 1990.