Crosstalk reduction in a tunable PHASAR

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An optimization method for crosstalk reduction in a tunable PHASAR has been developed, implemented and experimentally verified. The crosstalk reduction experiments were performed using a tunable PHASAR with 48 array arms that are each provided with a voltage-controlled phase-shifting section. Finding the proper settings for each phase shifter was done with a genetic algorithm.

Introduction

PHASAR (de)multiplexers are key components in Wavelength Division Multiplexing (WDM) optical communication systems. Some of the challenges in optimizing the performance of the PHASAR are the reduction of the crosstalk generated by the device and the tuning of the absolute operating wavelength of the PHASAR. Both problems can be addressed by using a PHASAR of which the optical length of each arm can be tuned. An eight-wavelength channel InP-based PHASAR provided with 48 electro-optical phase-shifting sections on the array waveguides has been realized by Maat *et al.* [1]. Here we report on a method to select the proper tuning voltages for each of the phase-shifting sections. The method is based on a genetic algorithm.

Crosstalk

Figure 1 shows a photograph of the tunable PHASAR. Crosstalk in PHASAR (de)multiplexers is caused mainly by random phase errors in the transmission through the waveguide array. These errors are due to imperfections in the fabrication process, such as variations in the layer thicknesses of the wafer material and small deviations in the width of the array waveguides. The length of an array arm is typically several thousands wavelengths, while a phase error of only 10 degrees already results in a crosstalk floor of approximately −25 dB, which is a typical value for InP-based devices. The tunable PHASAR used in this experiment has the additional length of the phase-shifting sections in

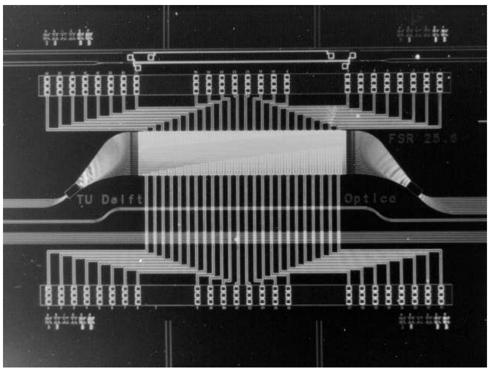

Figure 1: *Photograph of the tunable* PHASAR*, showing the curved waveguide array, the 48 phase-shifting sections and the electrode patterns.*

each arm which contributes significantly to the crosstalk of the device: without applying a voltage on the electrodes the initial crosstalk level is as high as −14 dB.
The voltages for each of the waveguide arms are generated by an 8-bit D/A converter and the allowable range corresponds to a phase shift ranging from 0 to (at least) 2π.

Phased array simulator

In order to facilitate the development of an algorithm for reducing the crosstalk, we used a software module for simulating the tunable PHASAR. Parameters that describe the characteristics of the simulated PHASAR are set such that the response of the simulated device is similar to that of the real device. The module approximates the modal fields with a gaussian beam and uses a paraxial approximation for the simulation of the starcoupler. It does not take into account the material or waveguide dispersion. These approximations do not significantly change the simulated response of the PHASAR, but do greatly reduce the simulation time. The effect of a voltage over the phase-shifting sections is simulated by changing the refractive index of a straight waveguide in the PHASAR with a value corresponding to a phase shift of a little more than 2π at maximum voltage. The initial crosstalk in the device is simulated by assigning a gaussian distributed random phase error to each of the 48 array arms.
In Figure 2 we give an example of a simulated transmission spectrum. The 'peak area' is defined by the region with a width of twice the channel spacing around the peak transmission value. The difference between the peak level and the maximum transmission level in the region outside the peak is what we define to be the crosstalk of the PHASAR, which is approximately −21 dB in this example.

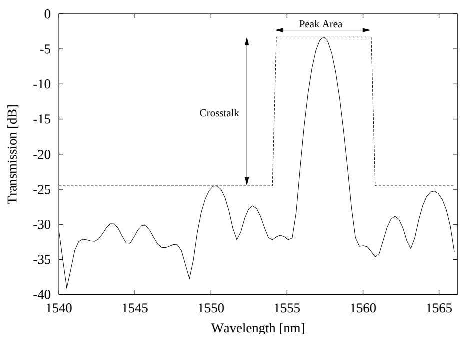

Figure 2: *Definition of crosstalk and 'peak area'. The crosstalk is determined by the highest value outside the peak area.*

Crosstalk reduction with a genetic algorithm

The genetic algorithm is implemented using publically available library from TU-Berlin[1]. The algorithm is called genetic because of the analogy with biological genetics. In our implementation, the voltage on each of the 48 arms of the PHASAR is coded as an 8-bit variable and is one *gene*. Each *individual* has one chromosome containing 48 genes so in total 384 bits. A *population* contains many individuals. This concept is visualized in Figure 3. For each individual, the *fi tness*, in this case the crosstalk, can be calculated. The fittest individuals in each population will reproduce. In our model two parents generate one or more children using a random *crossover* position on the parent chromosomes (see Figure 4). Offspring genes can be altered by random bitflips (*mutation*) as is illustrated in Figure 5. User settable parameters specify variables such as the population size and the mutation rate.

[1] evoC V2.0 ©TU-Berlin 1992-95, Bionics&Evolutiontechniques, K. Trint, U. Utecht

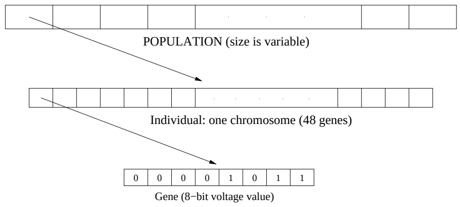

Figure 3: *Each gene holds an 8-bit value that is the voltage on one phase-shifting section. Each individual has one chromosome containing 48 genes. A population contains several individuals.*

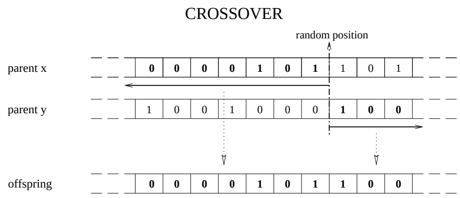

Figure 4: *Two parents create a child via a random crossover position on the parent chromosomes.*

The algorithm gives good results. Starting from an initial crosstalk value of -18 dB, like in the real device, the algorithm usually arrives to final crosstalk values between -35 and -40 dB and sometimes as low as -45 dB.

Experimental verification

Figure 6 shows the experimental setup. We use an EDFA as a broadband light source. The light is coupled into one input of the PHASAR using a microscope objective. Because the tunable PHASAR is polarisation dependent, a polariser is used to select only TE polarised light. After traversal through the PHASAR, a tapered fibre collects the light from one output and couples it into an optical spectrum analyser.
The setting of the voltages on the tunable PHASAR is controlled by a PC, that is connected by a serial line to a microprocessor controlling the D/A converters that provide the actual voltages on the electrodes on the chip. Two different processes manage the experiment: the tuning program that implements the genetic algorithm and a *LabVIEW* routine that instructs the microprocessor about the required the voltages on the electrodes and interprets the data from the spectrum analyzer. Both processes are synchronized by writing

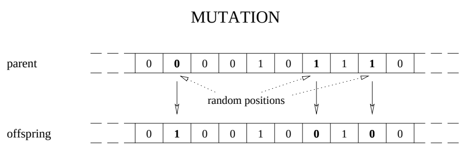

Figure 5: *Offspring genes can be altered by random bitflips.*

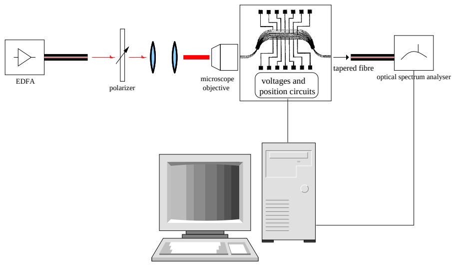

Figure 6: *Organisation of the experimental set-up.*

and reading a file that specifies the 48 voltage values and a second file that holds the spectrum.

During the experimental testing we discovered that less than half of the once-working phase shifters were still functional: 19 arms are good, 4 arms work but the change in the transmission spectrum is marginal and the remaining 25 do not introduce any change in the spectrum. Because of the grouping of the non-functional phase-shifting sections, we believe that three out of the six D/A converters are not working. Despite this we were able to show that the optimization procedure works.

The initial crosstalk in the device was -14.2 dB. With only 19 functional phase-shifting sections we arrived at a final crosstalk of -18 dB: still an improvement of almost 4 dB. Figure 7 shows both the initial and the optimised spectrum. The reduction of the peak transmission of 1 dB in the optimised spectrum is caused by a reduced in- and/or out-coupling efficiency during the experiment. The total number of iterations in the optimization procedure was 1801 and the experiment took 2 hours and 48 minutes.

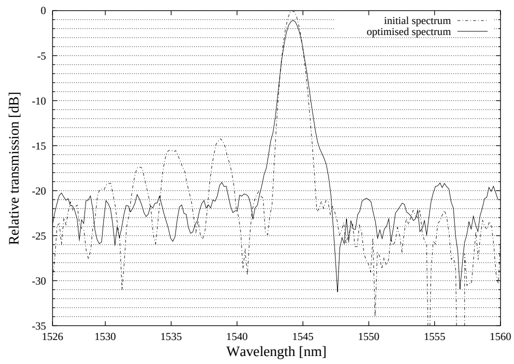

Figure 7: *Comparison between initial and optimised transmission responses.*

Conclusions

We developed a genetic algorithm for reducing the crosstalk in a tunable PHASAR. The simulations show that the algorithm works and the results have been experimentally verified. Even though less than half of the phase-shifters were functioning properly we could still achieve a 4 dB reduction of the crosstalk. The method will be applied again once an improved device is available.

References

[1] D.H.P. Maat, F.H. Groen, R.C. Horsten, Y.C. Zhu, P.E.W. Kruis, C.G.P. Herben, X.J.M. Leijtens, and M.K. Smit, "Tunable phased array demultiplexer on InP featuring wide-range tuning and pass-band shaping," in *Proc. 9th Eur. Conf. on Integr. Opt. (ECIO '99), postdeadline papers*. April 14–16 1999, pp. 25–28, Torino, Italy.