Design and Fabrication of a Monolithically Integrated AWG-based Optical Pulse Shaper

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Abstract— **We present design, fabrication and first characterization results of an InP-based integrated optical pulse-shaper. An AWG with 50GHz channel spacing is designed to split the input signal from a mode-locked laser. The AWG has 20 output channels and covers 8nm bandwidth. The phase and amplitude in each channel is controlled using electro-optic phase modulators and SOAs. The light reflects back on a facet end with an HR-coating, is recombined in the AWG and returns through the input waveguide. The double-pass design makes the chip size compact, i.e. 6×6mm^2.**

Keywords- Photonic Integration; Optical pulse-shaping; Multi-project wafer run.

I. INTRODUCTION

An optical pulse train is composed of a series of equally spaced spectral components in the frequency domain. For many applications it is necessary to control the relative spectral phase and amplitude of optical pulses. Dispersion compensation in high-speed optical communications and optical waveform synthesis for bio-imaging systems are two examples. In general, it is possible to (almost) arbitrarily shape the optical pulses by controlling the phase and amplitude of each and every spectral component [1]. In the so-called line-by-line shaping approach, the incident optical pulse is decomposed into its constituent spectral components by a spectral disperser element which is usually a grating. The phase and amplitude of the spatially dispersed spectral components are then modulated according to a required pattern. A shaped output pulse is obtained after the spectral components are recombined by a second lens and grating.

Programmable liquid-crystal modulator arrays are most commonly used to allow independent, simultaneous control of spectral phase/amplitude pattern of optical pulses. To explore the possibilities to bring the many advantages of photonic integration to this field, we have designed a monolithically integrated AWG-based optical pulse-shaper. An instance of a previously demonstrated tunable integrated semiconductor optical pulse shaper is presented in [2]. The chip presented in this paper is fabricated on an InP-based manufacturing platform which is available in the framework of EuroPIC multi-project wafer runs.

The current design includes a total number of 20 SOAs as well as 20 phase modulators. In the following sections, we discuss the chip design and present characterization of the 50GHz AWG element and phase modulators. Characterization of the chip is ongoing at the time of publication.

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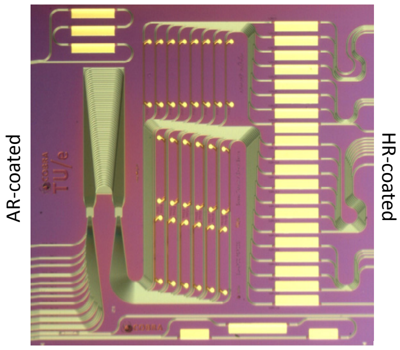

Fig.1. Microscope image of the realized 6×6mm^2 pulse shaper chip.

II. CHIP DESIGN AND CHARACTERIZATION

The pulse shaper device is to be combined with our (quantum dot) mode-locked lasers which have a spectral bandwidth of up to 8nm. The purpose of the chip is to compensate the chirp profile over optical pulses and any dispersion in the optics after the device. The light from the mode-locked laser is injected to the pulse shaper chip on an AR-coated facet. The light passes through an AWG which decomposes the spectral components. Filtered spectral components pass through electro-optic (EO) phase modulators (PMs) and SOAs and then reflect back on a facet end with an HR-coating. Frequency components are then recombined in the AWG and return through the input waveguide. The reflection geometry is used to make the system more compact. The two directions are separated in a circulator outside the chip.

A microscope image of the realized chip is presented in Fig.1. To equalize path lengths in the AWG arms as much as possible, optical path length differences in different channels are calculated and extra sections of waveguides are added to each channel. Some specifications of basic building blocks used to design the current photonic chip are listed in Table 1. Total on-chip loss (double-pass, excluding gain of SOAs) is in the order of 20dB.

Table 1. Building blocks in design of the pulse shaper

Required elements	Specification
Passive straight/ curved waveguide	Width=1.5µm, min radius=150µm, deeply etched, 5-6dB/cm loss, total length~ 9.2mm
AWG	Size 1×3.5 mm^2, 8nm (~1THz) FSR, 20 channels, 50GHz spacing
EO phase modulator	Width=1.2µm, length=1mm
SOA	Width=1.9µm, length=750µm, shallowly-etched
Transition element	Shallow-deep taper, active passive transition

A. AWG: Spectral filter

To achieve detailed phase control, the input signal from the mode-locked laser will be split using a 50GHz channel spacing AWG; this is the minimum number which is currently practically manageable. The AWG has 20 output channels and a free spectral range (FSR) of 8nm. Each channel includes a PM and an SOA. The designed AWG is cyclic and is designed for 0.4nm 3dB channel width. To characterize the AWG, SOA components may be used as on-chip broadband sources. We bias the SOA in channel 11 at I_{SOA}=30mA and record the optical spectra at the input waveguides at the AR-coated facet. Fig.2 shows recorded optical spectra at each of the input/output waveguides. The single pass on-chip loss is around 10dB. FSR is 8nm and the AWG passband is flat within 3dB.

The spectral shape of AWG channels is not as expected. Each channel seems to consist of two lobes which have 50GHz 3dB bandwidth and are separated by 0.4nm. Therefore, the channel width is effectively doubled. There is less than 1dB difference in height of each peak. Regarding the relative height of the two lobes, it is not possible that the shape of AWG channels is due to polarization. Measurements on a 750µm-long SOA shows that the ratio of generated TE/TM amplified spontaneous emission (ASE) light is over 15dB. Nevertheless, the curved waveguides and, most importantly, the AWG contribute to polarization conversion. We have investigated the effect of polarization dispersion of the AWF in [3].

B. PhaseModulators

The PMs on the pulse shaper chip are used to apply a certain phase mask on the frequency components of the input pulse. To increase the phase shifting efficiency, the PMs are oriented parallel to the wafer major flat. Therefore, the linear EO effect adds to the quantum-confined Stark effect (QCSE) shift which is generally regarded as quadratic in nature resulting in a nonlinear phase tuning characteristic.

The 1mm-long PMs are operated by applying a reverse bias voltage. The dark current is measured to be 2.5nA to 4nA for reverse bias V_{PM}=0 to V_{PM}=–5V. Fig.3 (right axis) shows the I-V curve of a PM in presence of the ASE light generated by the SOA which is biased at I_{SOA}=30mA. The current through the PM is I_{PM}=2µA at V_{PM}=0V and increases to I_{PM}=21µA at V_{PM}=–5V. The increased reverse current is caused by higher light absorption in presence of the external electric field due to QCSE. To quantify the amount of induced excess losses, we have measured the optical power at the AR-coated facet for several values of V_{PM}. The result is shown in Fig.3 (left axis). Up to a reverse bias of V_{PM}=–4V, the excess loss is lower than 1dB which is tolerable.

In order to characterize the phase tuning performance of phase shifters, we have made use of the spectral filtering behavior of the AWG. The neighboring channels of the AWG are designed to have 3dB overlap at FWHM. Therefore, if an external light signal with a wavelength in between the central wavelengths of two adjacent channels is injected to the chip, the power is effectively split between the two channels. In each arm, the light will pass through the PM and SOA, reflect back on the HR-coated facet and then recombine by the AWG to return to the input waveguide. This structure forms an interferometer which is used to characterize the phase shifters.

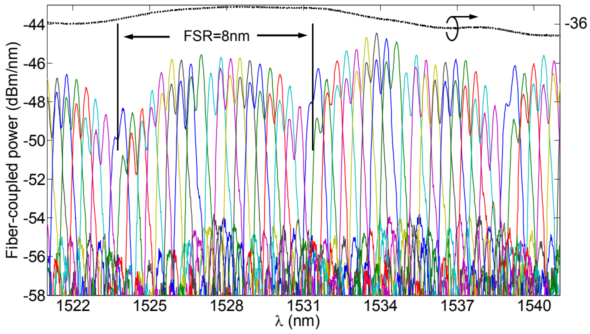

Fig.2. Fiber-coupled optical spectral power measured at input/output waveguides. The SOA in channel 11 is biased at 30mA; generated ASE is shown (dotted curve, right axis).

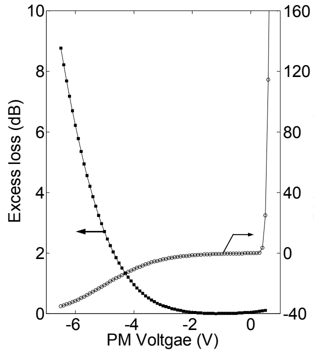

Fig.3. Induced excess loss (dB, left axis) and current through the phase shifter (µA, right axis) vs. applied voltage on a 1mm-long phase shifter.

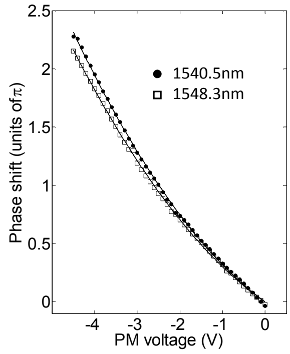

Fig.4. Measured phase shift (circles at λ=1540.5nm, open squares at λ=1548.3nm) and quadratic polynomial fitted curve (solid line).

Changing the bias voltage on a phase shifter in one arm induces a phase difference and thus changes the return optical power due to interference. In order to increase the signal to noise ratio, we have used the lock-in technique by modulating the SOA in one arm. The measured values of induced phase shift (circles at λ=1540.5 and squares at λ=1548.3) vs. the applied voltage are shown in Fig.4. The quadratic polynomial fitted curve is shown as a solid line. The required voltage for a 2π phase change (double-pass) is approximately 2.5V.

III. CONCLUSIONS

We have presented characterization of the AWG spectral filter and phase modulators on an integrated pulse shaper chip. The chip will be employed in combination with our quantum-dot mode-locked laser source to compensate the spectral chirp of the generated optical pulses. The settings of the phase modulators for pulse compression can be derived from the known spectral phase of the optical pulses from the quantum dot laser source. Measured phase tuning behavior of phase modulators is required for calculation of control signals.

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