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

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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. 6x6mm^2. Fabrication has been carried out in the framework of EuroPIC multi-project wafer run.

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 [1] and optical waveform synthesis for bio-imaging systems [2] 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 [3]. 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. The pattern is basically determined by the Fourier transform of the desirable shaped pulse. A shaped output pulse is obtained after the spectral components are recombined by a second lens and grating.

Control of the spectral phase/amplitude pattern of optical pulses has been achieved through using acoustooptic modulators, liquid crystal modulators and holographic masks. Programmable liquid-crystal modulator arrays are most commonly used and allow independent, simultaneous control of both spectral amplitude and phase [4].

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 [5]. The chip presented in this paper is fabricated on an InP-based manufacturing platform which is available in the framework of EuroPIC [6]. A key advantage of this platform is the active-passive integration scheme which allows direct integration of active components (such as semiconductor optical amplifiers (SOAs) and photo detectors), and passive elements (such as waveguides and arrayed waveguide gratings (AWGs)) on a single chip.

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. Characterization of the chip is still ongoing at the time of publication. Further details on full functionality will be published elsewhere.

Operation Principle and Chip Design

The pulse shaper device is to be combined with our (quantum dot) mode-locked lasers which have a spectral bandwidth of up to 8nm [7]. 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 again 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. Microscope image the realized chip is presented in Fig.1.

To achieve the highest possible detailed phase control the input signal from the mode-locked laser will be split using a 50GHz channel spacing AWG; this is the maximum 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 aim of amplification is to control the relative amplitude of each part of the spectrum. To equalize path lengths in the 20 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. Passive waveguide sections are deeply etched and active sections use shallow etching. Total on-chip loss (double-pass, excluding gain of SOAs) is in the order of 20dB. Total size of the AWG is 1×3.5 mm^2, and the gap between input/output waveguides of the AWG is 0.4μm.

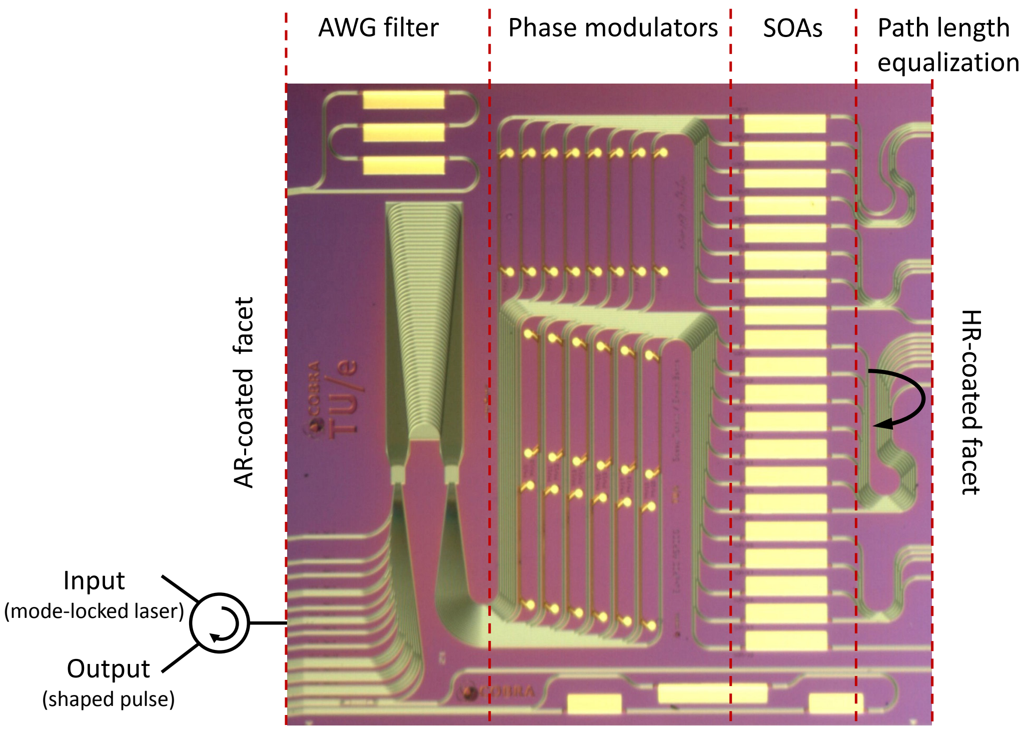

Fig.1. Microscope image of the realized pulse shaper chip. The light reflects back on the HR-coated facet and passes the optical circuit twice making the system more compact. The total size is 6x6mm^2.

Table 1. Basic building blocks used in design of the pulse shaper chip

	Required elements	Specification	Comments
1	Passive straight waveguide	width=1.5µm	Deeply etched, 5-6dB/cm loss Total length~ 9.2mm
2	Passive curved waveguide	min radius=150µm	Physical offset used when required
3	AWG	Size 1×3.5 mm^2	8nm (~1THz) FSR 20 channels, 50GHz spacing
4	EO phase modulators	width=1.2µm length=1mm	operating voltages: ~3.5(V) → π
5	SOA	width=1.9µm length=750µm	Shallowly-etched Max operating current: 55(mA) → 7dB gain Total power~20×55(mA)×2(V)=2.2(W)
6	Transition elements		Deep-shallow taper Active-passive transition

AWG: Spectral Filter

The designed AWG is cyclic and is designed for 50GHz (0.4nm) 3dB channel width. SOA components may be used as on-chip broadband sources to characterize the AWG. We bias the SOA in channel 11 at I_{SOA}=30mA and record the optical spectrum at the chip edge. Fig.2 demonstrates recorded optical spectra at each of the chip input/output waveguides. Measured amplified spontaneous emission (ASE) from a similar test SOA is shown. We note that the single pass on-chip loss is around 10dB. FSR is 8nm and the AWG passband is flat within 3dB. The spectral modulation around 1536nm is due to reduced ASE spectral power.
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. There is less than 1dB difference in height of each peak. We are currently investigating this effect and we think it could be caused by unwanted reflections and/or strong coupling between AWG in-/output waveguides. In the following section we investigate the effect of polarization dispersion and show that it does not contribute to this observation.

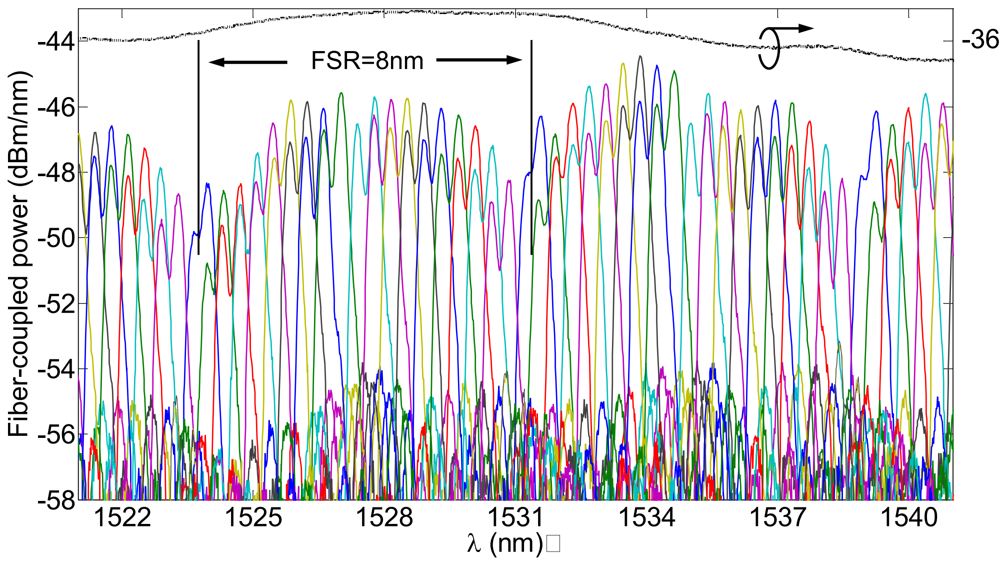

Fig.2. Fiber-coupled optical spectral power measured at the 20 output waveguides of the cyclic AWG. Resolution bandwidth used on the optical spectrum analyzer is 0.1nm. The SOA in channel 11 is biased at 30mA; generated ASE is shown (dotted curve, right axis). Channel 10 is missing due to a damaged facet.

Polarization Dispersion

Regarding the relative height of the two lobes, it is rather unlikely that the previously described shape of AWG channels is due to polarization. Measurements on a 750μm-long SOA shows that the ratio of generated TE/TM ASE light is over 15dB. Nevertheless, the curved waveguides and, most importantly, the AWG contribute to polarization conversion. In order to verify the effect of polarization conversion, we use an external light source with defined state of polarization to inject light to the chip. Furthermore, we apply reverse bias on the PM in channel 11 and use it as an on-chip photo detector. We used a tunable laser source (TLS) with narrow linewidth, i.e. 100kHz, and sweep the wavelength and then record the current through the PM.

Fig.3 shows the recorded photo current vs TLS wavelength. When the polarization is defined as TE, the AWG channel 11 is at 1527nm. When the polarization is perfectly rotated to TM the channel position shifts to 1522nm. If we use a mixed polarization state, both polarizations are excited and we observe multiple pass bands. The AWG is clearly polarization sensitive and this effect is attributed to polarization dispersion. Increased photo current through the PM at shorter wavelengths is mainly attributed to higher efficiency of absorption.

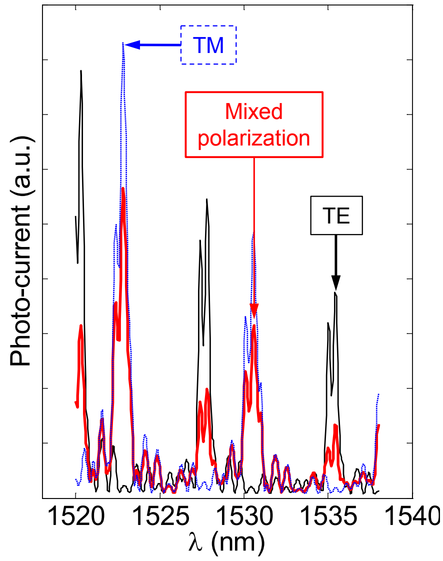

Fig.3. Photo-current (a.u., linear scale) though the PM in channel 11 while wavelength of an external light source is swept and coupled to the chip via input channel 9. State of polarization of the injected light is defined by a polarization controller. TE: solid thin; TM: dashed; mixed: solid thick.

Acknowledgments

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References

[1] H. Tsuda, K. Okamoto, T. Ishii, K. Naganuma, Y. Inoue, H. Takenouchi, and T. Kurokawa, "*Second- and third-order dispersion compensator using a high-resolution arrayed-waveguide grating*," IEEE Photon. Technol. Lett., vol. 11, no. 5, pp. 569–571, May 1999.

[2] A.C.W. van Rhijn, M. Jurna, A. Jafarpour, J.L. Herek, H.L. Offerhaus, "*Phase shaping strategies for coherent anti-Stokes Raman scattering*," Journal of Raman Spectroscopy, 25 March 2011, DOI: 10.1002/jrs.2922.

[3] S.T. Cundiff1 and Andrew M. Weiner, "*Optical Arbitrary Waveform Generation*" Nature Photonics, vol. 4, pp. 760–766, Nov. 2010.

[4] A. M. Weiner, "*Femtosecond Pulse Shaping using Spatial Light Modulators*," Rev. Sci. Instr. Vol. 71, pp. 1929–1960 (2000).

[5] For details see: http://europic.jeppix.eu/

[6] Heck, M. J. R. et al., "*Design, fabrication, and characterization of an InP-based tunable integrated optical pulse shaper*," IEEE J. Quant. Electron. Vol. 44, pp. 370–377 (2008).

[7] M. J. R. Heck, et al. , "*Passively mode-locked 4.6 GHz and 10.5 GHz quantum dot laser diodes around 1.55 μm with large operating regime*," IEEE J. Sel. Top. Quant. Electron. Vol. 15, pp. 634–643 (2009).