Tunable Integrated Pulse Shaping Devices

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We report on the design and fabrication of tunable integrated pulse shaping devices. These devices are realized in the InP/InGaAsP material system and contain an arrayed waveguide grating pair and an array of phase modulators. An arbitrary discrete phase profile can be applied to a pulse propagating through the pulse shaper. The bandwidth of the pulse shaper and the AWG channel spacing are chosen to be able to compress chirped picosecond pulses down to 300fs. Further integration with a modelocked laser source then allows for the realization of a femtosecond pulse source. Different geometries for the device are presented.

Introduction

State of the art modelocked monolithic semiconductor laser sources are able to produce pulses with widths down to 2ps and with a good extinction ratio. In semiconductor mode-locked lasers reported up to now, the self-phase modulation (SPM) in the semiconductor material limits the attainable pulse duration. Bulk and fiber optics have been used in combination with a semiconductor optical amplifier (SOA) to manage the chirp of the pulse by intra-cavity or extra-cavity dispersion compensation. Using the latter technique pulse durations below 300fs were produced [1].

To be able to develop an integrated monolithic femtosecond semiconductor laser (IFSL), we need to be able to control the phase profile or dispersion of the pulse. In the first step towards a full realization of an IFSL we present the design and realization of an integrated monolithic dispersion compensating or pulse shaping device.

Design

Simulation and experimental results show that pulses produced by passive modelocking (PML) are upchirped [2,3]. The excess of bandwidth can be used to compress the pulses towards the femtosecond regime, using a suitable amount of dispersion. Such a dispersive element or pulse shaper can be realized in an integrated circuit and added to a PML ring laser using an arrayed waveguide grating (AWG) pair with tunable delay lines as depicted in Fig.1. This pulse shaping device is based on a similar design presented by Tsuda et al. [4], extended with phase modulators (PHMs) that can be tuned between 0 and 2π phase shift. As a result the total dispersion of the pulse shaper can be tuned.

The output pulses of the PML laser are simulated to have a duration of 1ps to 2ps with an upchirp of 1THz to 2THz [3]. The bandwidth of these pulses is sufficient to compress them down to 300fs by applying a suitable amount of dispersion. However satellite pulses might arise as a result of the non-flat transmission spectrum of the AWG channels.

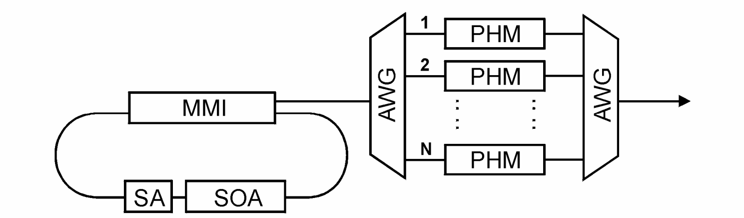

Fig. 1. A pulse shaping device based on an AWG-pair is added to the output of a PML ring laser. The PML laser consists of an SOA, a saturable absorber (SA) and a multimode interference coupler (MMI) to couple out the light. The pulse shaping device has two AWGs and N delay lines with PHMs in between that can be individually tuned between 0 and 2π phase shift.

We have designed a set of pulse shapers, specifically tailored to achieve 300fs-500fs pulses. This means that a bandwidth of approximately 1.5-2THz is needed. We made designs with 4 delay lines spaced at 400GHz, 16 delay lines spaced at 100GHz and 20 delay lines spaced at 200GHz (see Fig. 2 for the last two designs). The PHMs in the delay lines have a length of 5mm. For this length the phase of TE polarized light can be shifted over 2π radians by applying a 5V reverse bias voltage. To decrease the formation of satellite pulses the transmission spectrum of the AWG channels has to be flattened. This is done by adding MMI inputs to the free propagation region of the AWG (Fig. 2, inset 1 and Fig. 3). To obtain devices that are not sensitive towards the central wavelength of the pulse, the free spectral range has been designed to be equal to the number of channels times the channel spacing.

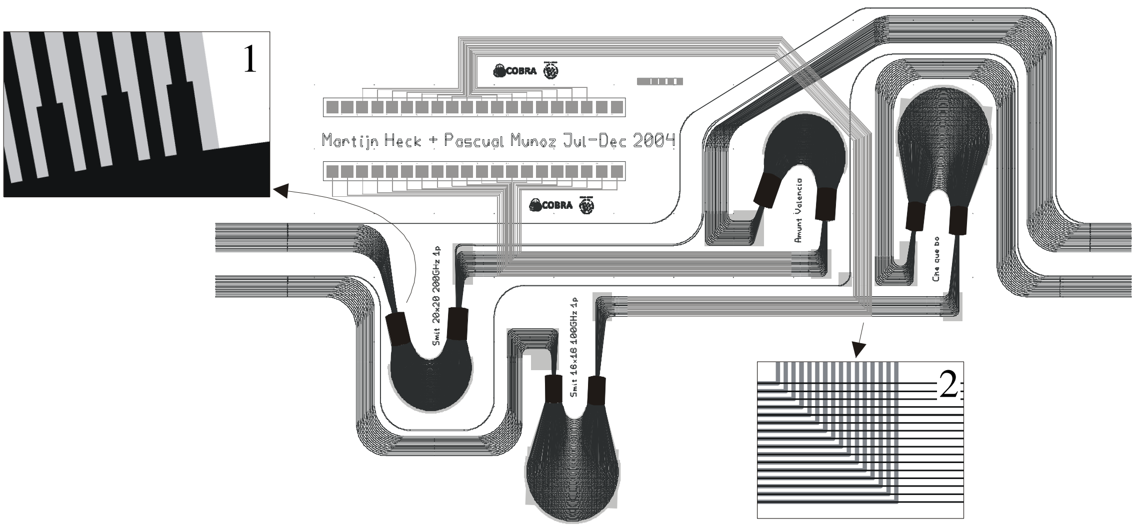

Fig. 2. Mask design for the fabrication of a 20x200GHz (upper) and 16x100GHz (lower) pulse compressor. The PHMs can be individually tuned using a (20 pin) multiprobe (Inset 2). Inset 1: The design of the alternate Gaussian and flat-top inputs and outputs. The waveguides are given in black, where waveguides in the light grey areas indicate deeply etched (high-contrast) waveguides. The metal contacts and access lines are given in dark grey.

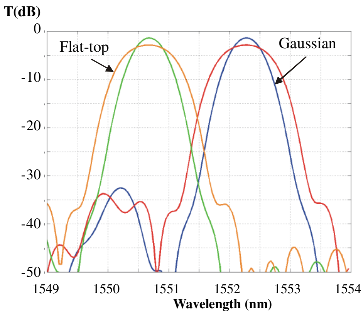

Fig. 3. Simulation of the Gaussian and flat-top (MMI) transmission spectrum of the 200GHz AWG channels that are used in the design in Fig. 2.

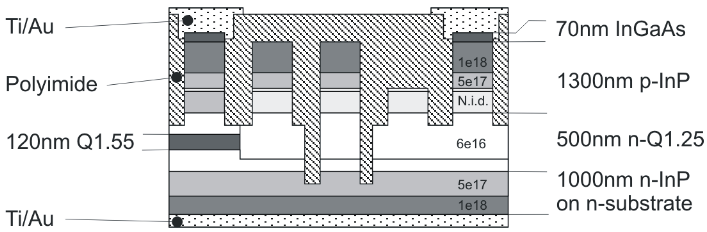

Fig. 4. Active-passive integration technology [5], showing from left to right an active (SOA), a shallow (low-contrast), a deep (high contrast), an isolation and a PHM waveguide cross-section. Doping levels are given to the right. The pulse shaper does not utilize active waveguides, but they are given for reference. Q1.25 and Q1.55 denote InGaAsP with bandgaps corresponding to wavelengths of λ=1.25μm and λ=1.55μm respectively.

Technology

The pulse shapers are realized in a MOVPE grown layerstack compatible with the active-passive technology ([5], Fig. 4). The waveguides are etched in two steps using an optimized CH_4/H_2 etching and O_2 descumming reactive ion etching process. Hereafter different layers of polyimide are applied to cover and planarize the surface. The polyimide is locally etched back using a CF_4/O_2 isotropic etching process to create contact openings for the PHMs. The polyimide passivates the sidewalls of the PHMs. Finally Ti/Au metallization is applied by e-beam evaporation and etched to create the electrical contacts. As both the layerstack and processing of the pulse shapers are compatible with the active-passive technology, the pulse shapers presented here can be integrated further with PML ring lasers to create an IFSL.

First Results

The devices have been realized according to the processing technology mentioned above. The waveguides have a decreased width with respect to their designed value due to an overexposure in the lithography step. Furthermore the process used for etching back the polyimide causes trenching of the polyimide along the PHM sidewalls. As a result the sidewalls are partially bared, leading to a possibly reduced passivation and increased leakage current.

Measurements on the leakage current show that the polyimide still shows good sidewall passivation, resulting in currents of less than 30nA at 5V reverse bias voltage, the designed operating point for modulating the phase by 2π radians [Fig. 5]. Furthermore the polyimide passivation shows good uniformity, with leakage currents ranging from 18nA to 30nA for 5V reverse bias for an array of PHMs.

Non-uniformities in the processing over the wafer surface result in a detuning of the two AWG channel transmission spectra with respect to each other. As a result part of the optical power will be emitted from an adjacent output. In Fig. 6 it can be seen that the power injected into a 4x400GHz device is more or less equally divided over two adjacent output channels, indicating a severe detuning of around 200GHz.

The decreased waveguide width decreases the bandwidth of the AWG channel transmission spectrum and causes it to be more peaked. As a result the pulse shaper peak transmission is more sensitive towards detuning of the AWGs.

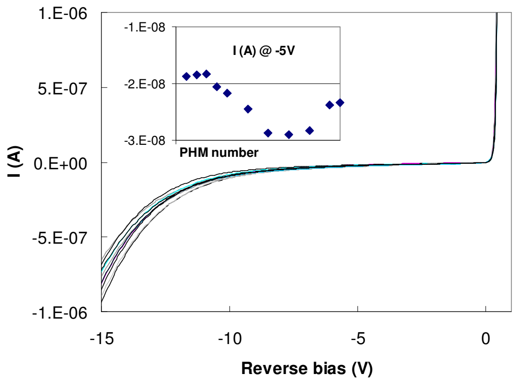

Fig. 5. IV curves for an array of PHMs in the 16x100GHz device.

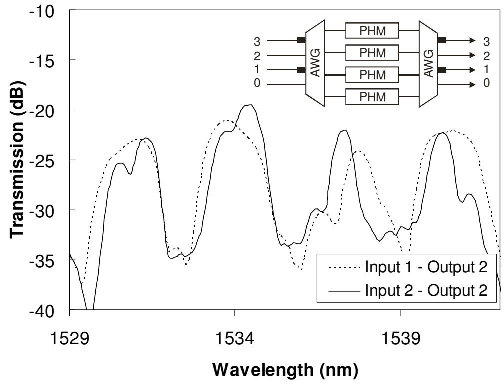

Fig. 6. On-chip losses for a 4x400GHz device; the inset shows the input-output configuration.

Conclusion

Pulse shaping devices have been fabricated using a processing technology that allows for further integration with PML lasers. Although our first results compare well with similar work [6], they clearly show the importance of relative tuning of the AWGs with respect to each other, either by uniform wafer processing or by active tuning of the AWG channel transmission spectra by e.g. temperature control.
Issues in the processing technology with respect to the optical properties of the pulse shaper have been identified and solved for a future new realization to decrease the on-chip transmission losses. However the first results for the 4x400GHz device show the possibility of pulse transmission and pulse shaping experiments, which will be carried out next.
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