Integrated Waveguide Device for Picosecond Pulse Amplification and Spectral Shaping

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We report on the simulation, design and characterization of a new device, named IRIS. It is designed for increasing the optical bandwidth of picosecond pulses to enable further pulse compression or shaping. The IRIS device consists of a concatenated array of semiconductor optical amplifiers and saturable absorbers. It is realized in the InP/InGaAsP material system for the 1550nm range.

Simulations and measurements on the realized IRIS devices show increased spectral broadening as compared to an SOA of equivalent length. Moreover simulations show that pulse peak amplification is over two times higher and ASE output levels are lower by about two orders of magnitude, making it a promising short pulse amplifier.

Introduction

Pulsed lasers with a coherent broad optical spectrum are attractive sources for use in arbitrary waveform generators [1], dense wavelength division multiplexing systems, optical code-division multiple-access (O-CDMA) systems [2] and frequency comb generation. Such systems can be realized on a single photonic integrated circuit when semiconductor mode-locked lasers (MLLs) are used as the pulsed source. Nowadays monolithic MLLs are able to produce pulses with durations down to 1-2ps, having a corresponding spectral width of up to 2nm [3]. By changing the design or operating conditions the spectrum can be broadened, leading to non-transform limited pulses [4,5].

To increase the optical bandwidth of picosecond pulses further, amplification and highly non-linear fibers are often used. In a photonic integrated circuit a semiconductor optical amplifier (SOA) is a possible option, though at the expense of increasing the noise in a system and the broadening that can be achieved is limited.

In this paper we present our IRIS device [6] which we have designed to add bandwidth to an optical picosecond pulse, for applications as mentioned above. We compare the performance of a number of configurations of the IRIS device with an SOA of the same length, both theoretically and experimentally.

IRIS device

The IRIS device consists of a series of equal pairs of one SOA section and one saturable absorber (SA) section, as schematically depicted in Fig. 1(a). Such devices have been realized using InP/InGaAsP bulk gain material, operating at wavelengths in the region of 1.55μm. The sequence of SOAs and SAs is fabricated by etching a shallow ridge waveguide of 2μm width in the bulk gain material. To suppress lasing, the waveguide is oriented at the Brewster angle for the fundamental mode with the facets which have also been antireflection coated. To create electrical isolation between the SOAs and SAs, the most highly doped part of the p-cladding layers is etched away using a dry RIE etch process. The isolation section between the SOA and SA has a length of 10μm (shorter SAs) to 20μm (longer SAs). Two gold metal pads alternately contact the waveguide sections to create two common contacts for the SOAs and SAs respectively (as can be seen in the photograph in Fig. 1(b)). Amplification and absorption are realized by a forward or reverse electrical bias of the diode respectively. We have designed and realized a number of different device configurations with a varying length ratio between the SOA and SA (up to 50%) and number of SOA/SA pairs (5, 10 or 20). We have added SOAs on the same chip for reference purposes. The fabrication technology of the IRIS device is fully compatible with the technology to fabricate MLLs as presented in [4]. This allows for further integration of the MLLs with the IRIS device.

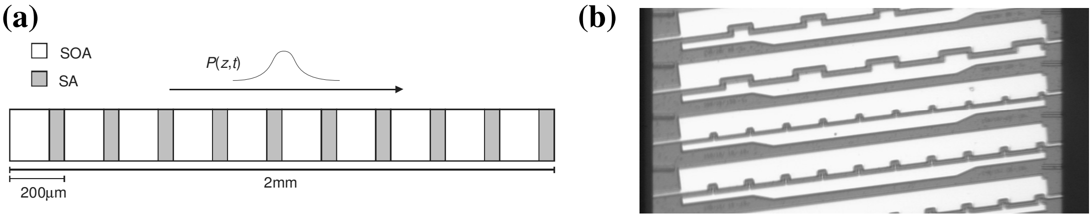


Fig. 1: (a) Schematic overview of the IRIS configuration used in the simulations. An input pulse (denoted by $P(z,t)$) enters from the left side, entering an SOA and exiting from the right-hand side. The ratio of the SOA and SA length within the 200μm section is varied. (b) Photograph of the realized devices, showing different configurations.

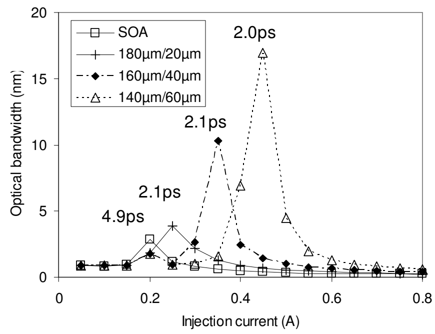
Simulation results

We have simulated the IRIS configuration as pictured in Fig. 1(a). In the simulations the ratio between the SOA and SA lengths is varied, but the number of SOA/SA pairs is fixed at ten. Isolation sections in between the SOA and SA are not taken into account. Input pulses have a duration of 2ps and a peak power of 0.1W, which are representative values for pulses generated by semiconductor MLLs. The pulse repetition rate studied here is ‘long’ as compared to the carrier recovery time (i.e. propagation of a single pulse is simulated).

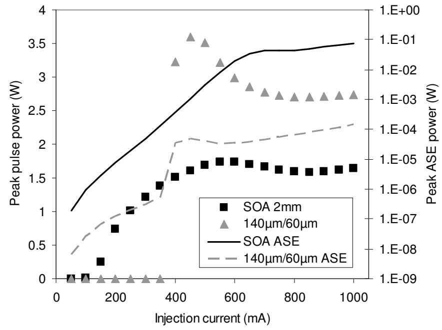
To simulate picosecond pulse propagation through the device we use the model we have presented in [5], extended with ASE fields. The model is made bidirectional, to simulate ASE and laser fields propagating in both directions, and assumes zero reflection at the facets.

After propagation of the pulses through the IRIS device, the simulated spectra of the output show an increase in bandwidth compared to the simulation result of an equally long SOA. This is presented in Fig. 2(a). In Fig 2(b) the detailed evolution of the spectrum as a function of total SOA current is presented for the device that produces the highest bandwidth (140μm/60μm configuration) in Fig. 2(a). The increase in spectral broadening for this device is over five times, i.e. 17nm as compared to a maximum of 3nm for an SOA. The main reason for this increase in broadening is that under these operating conditions the temporal broadening of the pulse in the IRIS device is minimized, much like the situation in a passively mode-locked laser. Because of this the change in the carrier depletion takes place in the shortest time. As a result the self-phase modulation is maximized [5]. A second important result is that the ASE level in the output is reduced by about two orders of magnitude as compared to the output from an SOA (Fig. 2(c)). The gain depletion due to the ASE is therefore also significantly reduced. These features make the IRIS device a promising candidate for a short pulse optical amplifier.

(a)



(c)



(b)

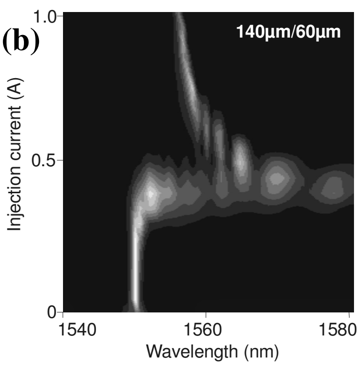


Fig. 2: Simulation results for IRIS devices where input pulses have a duration of 2ps and a peak power of 0.1W. The input pulses are transform limited. (a) Calculated spectral broadening (FWHM) of three configurations (10 pairs of SOA/SA with respective lengths as mentioned in the inset) compared to an SOA of 2mm length. (b) A picture of the development of the shape of the spectrum of the 140µm/60µm configuration as a function of the injection current. The spectral intensity in (b) is normalized and coded from black up to white. In (a) corresponding output pulse durations at maximum broadening are shown. (c) The calculated peak pulse transmission of the 140µm/60µm configuration compared to that of an SOA and their respective maximum ASE levels.

Experimental results

Spectra of short pulses that have propagated through one of several designs of IRIS devices have been measured. Most results were obtained with the devices with 20 pairs of SOA/SA sections, so this set is presented here. The TE polarized input pulses have a peak power of approximately 0.08W, a duration of 2.5ps and a repetition rate of 10GHz. The experimental results are presented in Fig. 3(a) and agree qualitatively with the simulated results in two aspects. First the total SOA current values at which the increase in spectral broadening of the device output starts to occur, increases with longer SA lengths. Secondly, the spectra obtained with the IRIS devices show increased maximum broadening for the shorter SA lengths (60µm/10µm and 55µm/15µm configuration, Fig. 3(a)) when compared to an SOA, namely 4nm and 3nm respectively. As our devices are not packaged, the injection current is pulsed to avoid excessive heating of the device. Additional spectral broadening is expected for the devices with longer SAs at higher injection currents (above 660mA, which was the limit of our setup), as predicted by the simulations. The experimental results in Fig. 3 do not show the spectral narrowing at higher injection currents, as predicted by the simulations results presented in Fig. 2(a,b). Experimentally we observed the dependency of the spectrum on the reverse bias voltage on the SA sections. In the simulations this voltage dependency is not taken into account explicitly [5]. Increasing the voltage on the SA decreases the modulation depth in the spectra (Fig. 3(b)). This feature makes the spectrum more suitable for applications as mentioned above. The equalization of the spectrum needs less intensity modulation, either by absorption or by amplification of the separate spectral components.

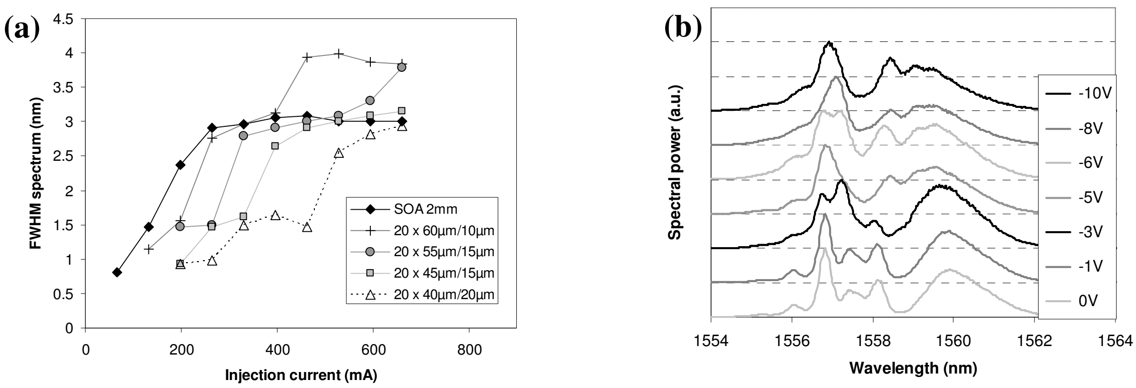


Fig. 3: (a) Measured spectral widths (FWHM) for different IRIS configurations with 20 SOA/SA pairs. The applied reverse bias on the SAs is -1V. The injection current is supplied by a pulsed source, using 300ns pulses and 1% duty cycle. (b) Normalized output pulse spectra after propagation through a configuration with short SAs (20x 60µm/10µm), applying different reverse bias voltages.

Conclusion

We have theoretically and experimentally investigated a new device concept, called IRIS, which we have designed for adding bandwidth to a short pulse. The fabrication and processing technology can be compatible with that of a MLL, which enables monolithic integration of a MLL with an IRIS device.

Simulations show that the device performance with respect to adding bandwidth to picosecond pulses is better than that of an SOA of equivalent length, with calculated bandwidths of up to five times as large (17nm as compared to 3nm). Measurements on realized devices agree qualitatively with our simulations, showing increased performance (4nm compared to 3nm), but the measured range of injection currents is limited by the current source.

Furthermore the simulations show that in the process of amplification a picosecond pulse can be compressed inside the IRIS device, whereas these pulses broaden inside an SOA. Moreover ASE noise levels are suppressed about two orders of magnitude, making the IRIS device a promising short pulse amplifier.

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