High Efficiency/High Bandwidth Preamplified Receiver for High Speed Networks

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Abstract *We present a high efficiency preamplified receiver with a responsivity up to 160 A/W, a low noise figure close to 7 dB for very SOA current of 40 mA and a 3-dB bandwidth up to 55 GHz for future optical network.*

Introduction

The continuous growth of data traffic require very high speed detector to match the required bandwidth. Integration of a semiconductor optical amplifier with the photodiode allow to improve its sensitivity, especially in access network because of the limited speed of avalanche photodiode. We have demonstrated in the past very high efficiency SOA-UTC in C-band [1-2] and O-band [3]. If, for access network, O-band is the main center of interest, it has been demonstrated recently that using a SOA is very useful for photonic neural network, which can be used for long haul network in C-band [4].

In this paper, we present a new SOA-UTC design which achieve record responsivity and energy efficiency, with up to 160 A/W responsivity at 160 mA, and a large bandwidth up to 55 GHz.

Device design and fabrication

The SOA-UTC receiver is based on buried ridge SOA and passive waveguide for better optical and electrical properties and a deep ridge photodiode for high speed operation [1-3] and is represented in Fig. 1. The light is first coupled in a low confinement InGaAsP passive waveguide (depicted in green) to have low coupling losses with an optical fiber, then coupled to a high confinement passive waveguide (depicted in blue) using a spot size converter. Using butt coupling, light is directly transferred to the SOA active sections, before entering again the high confinement passive waveguide. All these waveguides are made using buried technology for high optical and thermal performances. Then the light is coupled to the deep ridge UTC photodiode [1-3]. The process involves butt joint regrowth, ebeam and stepper lithography and a mix of Ch4/H2 and Cl2 dry etching, associated with wet etching [1-3]. Several modifications and improvements has been made compared to previous designs:

- Use of MOVPE epitaxy for all the epitaxies instead of MBE epitaxy for passive, SOA and photodiode and MOVPE for buried regrowth. This will simplify industrialization and MOVPE systems are much more deployed than MBE systems in optoelectronics and have greater capacities.
- Use of input passive tapers to have a high injection efficiency in the SOA.
- Reduction of N doping for losses reduction.
- Improvement of contact design to keep low series resistance.
- Direct coupling between SOA and high confinement passive waveguide instead of using the low confinement fiber waveguide as an intermediate waveguide, which suppresses long spot size converters.

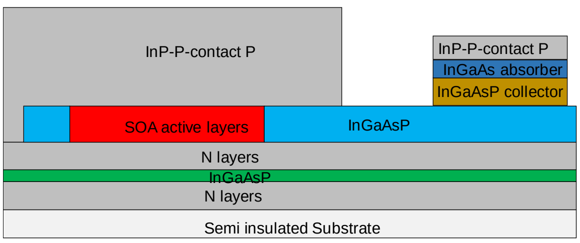

Fig. 1: schematic of the SOA-UTC receiver.

A photograph of the component is shown in Fig. 2 in which we see the input passive taper, the central SOA gain section, the passive transition and finally the UTC photodiode.

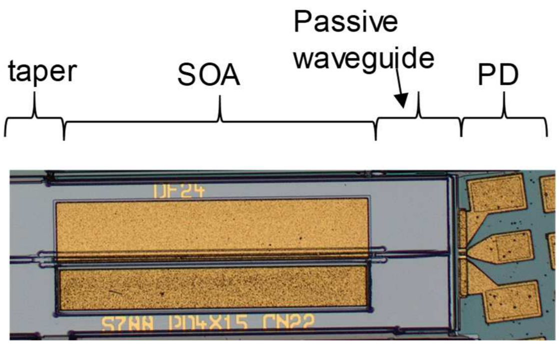

Fig. 2: Photograph of a SOA-UTC receiver.

Results and discussion

Responsivity of tests photodiodes without SOA was made to assess their intrinsic properties, including coupling losses with the fiber. We used a lensed fiber with a fiber mode diameter of

4.4 µm and the measurement was made at 1550 nm. The total losses for a 4×25 µm² photodiode is 3.4 dB compared to an ideal photodiode (R=1.25 A/W), which is consistent with our assumption of 1-1.5 dB coupling+taper

Tab. 1: Photodiode responsivity

Photodiode	R (A/W)	PDL (dB)
4×10 µm²	0.44	0.6
4×15 µm²	0.52	0.4
4×20 µm²	0.56	0.4
4×25 µm²	0.58	

losses and 1.5-2 dB loss in the PD. Polarization is around 0.5 dB for all photodiodes.

We then measure responsivity of SOA-UTCs at various wavelength, as shown in Fig. 3 and Fig. 4, using the same fiber. Peak wavelength was measured using amplified spontaneous emission (ASE) spectrum and was around 1565 nm. Using a SOA-UTC with 500 µm long SOA and a 5×25 µm² photodiode, we obtain a record sensitivity above 160 A/W at 160 mA drive current (Fig. 3). We also reach more than 80 A/W for a moderate current of 80 mA which help to reduce power consumption. Compared to previous design, the gain in energy efficiency is significant as we previously required more than 140 mA to achieve 80 A/W responsivity.

As responsivity of a photodiode is mainly driven by photodiode length, and with low wavelength dependence, we can assume that the losses due to optical coupling, taper, and photodiode internal efficiency is around 3.4 dB for a 5×25 µm² photodiode. Therefore, we can deduce that SOA internal gain is close to 25 dB for a 500 µm long SOA, which give a gain of around 5 dB/100µm SOA length. This high efficiency is due to the fact that there is no active taper but that current injection occurs only in straight section, in which efficiency is maximal. The PDL is moderate, around 1 dB, even at very high SOA gain (0.8 dB at 1565 nm and 100 mA, 1.2 dB at 1565 nm and 160 mA).

Noise figure is estimated using Eq. 1 as described in [3]. NF is around 8.5 dB at low SOA drive current (40-80 mA) and increase to around 9-9.5 dB at 160 mA [3].

$$NF = \frac{2n_{sp}}{\eta_e} = \frac{I_{ASE}(\upsilon)}{h\upsilon B_o R_{\max}} \times \frac{2}{1 + R_{\min}/R_{\max}} \qquad (1)$$

We also report results of a SOA-UTC with shorter SOA (400 µm) and photodiode (4×15 µm²) in Fig 4. The responsivity is lower (60 A/W maximum, corresponding to an SOA gain of around 20.5 dB. This is coherent with the 1st result as we obtain also obtain an SOA gain around 5 dB/100 µm. This also allow to obtain a better noise figure as the NF is estimated to be 7.2 dB even at a very low SOA current of 40 mA. This lower noise figure can be explained by the fact that shorter SOA are less affected by spatial hole burning which reduce the carrier density, and therefore the inversion factor, at the input and output of the SOA. Therefore, spatial hole burning increases the noise figure, especially because of the degraded performance at the input of the SOA. In the future, analysis of more SOA size to determine the threshold for the apparition of spatial hole burning and optimize the noise figure will be very interesting. We can also notice that the noise figure reaches its minimal value at very low current around 40 mA, which allow have a very low power consumption in the optimal operating condition. This very high efficiency can be explained by the fact that we used passive taper which are not injected and therefore current injection occurs only in the core part of the SOA (straight section with constant width) in which stimulated emission in the most efficient.

Finally, we measure the 3-dB bandwidth of SOA-UTC with 3 different diode size using an

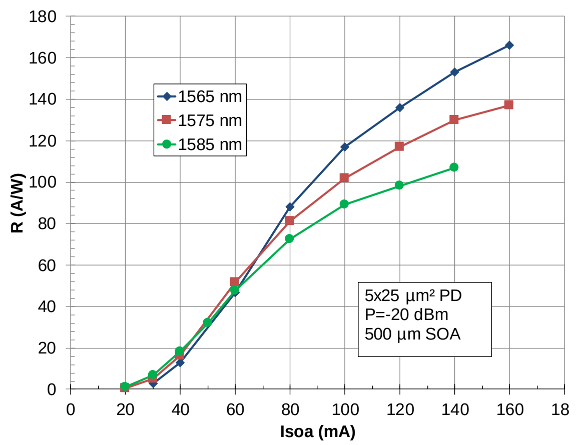

Fig. 3: responsivity of a SOA-UTC with 500 µm SOA and 5×25 µm² photodiode.

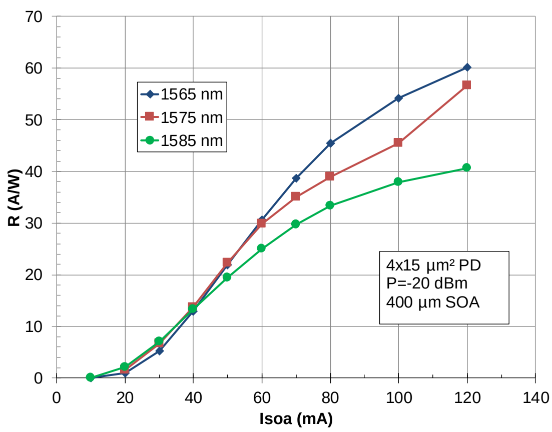

Fig. 4: responsivity of a SOA-UTC with 400 µm SOA and 4×15 µm² photodiode.

heterodyne setup. Measurements were done at a fixed photocurrent of 1 mA to have similar operating conditions on the UTC photodiodes for all the devices. Small photodiodes (4×10 µm², 4×15 µm²) present a similar bandwidth around 55 GHz. Therefore, we can deduce that photodiodes are transit time limited for diode area below 60 µm². For a 5×25 µm² photodiode, the bandwidth is still quite high at 42 GHz. We also changed photodiode bias but the effect on the bandwidth is negligible. These results are surprising because we demonstrated in [5] photodiodes with >70 GHz bandwidth using with the same absorber thickness but a thicker collector, which means they should have a longer transit time. We then investigate the doping profile of our photodiodes using SIMS and we found that the heterojunction (InGaAs/InGaAsP) at the absorber-collector interface is moderately P-doped. Therefore, electrons are not assisted by the electric field to pass through the energy gap at the heterojunction, which can explain a higher transit time. This modification of the doping profile can be explained by the decision to increase P doping in the most important part of the InGaAs absorber which lead to dopent (Zn) diffusion up to the InGaAs/InGaAsP interface.

Therefore, we expect to solve this issue in the next fabrication run and to achieved the same responsivity but with much higher bandwidth at least in the 70 GHz range.

Conclusions

In this paper, we present an improved design of our SOA-UTC for high speed communication. The new design allows to achieve record responsivity with a significant improvement of the energy consumption. 3-dB bandwidth is up to 55 GHz. The replacement of active taper by passive taper allows a much better injection efficiency which results in very high gain and low NF at low SOA drive current. The main limitation of these chips are the reduced bandwidth but we found its origin and we should achieve more than 70 GHz bandwidth in the next iteration.

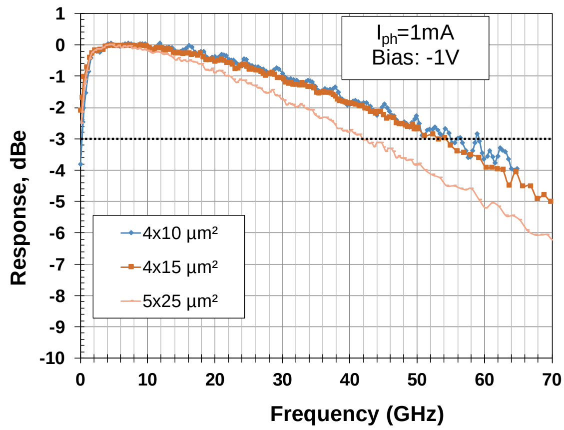

Fig. 5: Frequency response of SOA-UTC with 3 different photodiode area

Acknowledgements

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