Directly modulated lasers on InP membrane platform

Directly modulated lasers on InP membrane platform: design and simulation

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Directly modulated laser (DML) design for InP membrane platform is proposed. In this platform, a stack containing contact layers and quantum wells is epitaxially grown on InP wafer, which is then adhesively bonded to Si substrate using BCB (benzo-cyclobutene). DML proposed makes use of weak tunable distributed Bragg grating to extend the modulation bandwidth by detuned loading and photon-photon resonance. Photonic crystal reflector is used to maximize Q-factor of the cavity. Up to 80 GHz 3dB bandwidth is obtained in simulation.

Introduction

The demand for low-price and high efficiency optical communication systems grows exponentially every year. Photonic integrated circuit (PIC) is a fast-evolving technology which allows to reduce footprint and fabrication costs and increase energy efficiency of the optoelectronic devices used in fiber communication systems. In short range communication, where fiber dispersion is negligible, directly modulated lasers (DMLs) are promising candidates for transmitter design [1]. Recently DMLs with 65 [2] and 108 GHz [3] bandwidth were demonstrated, which is comparable and even outperforming commercially available externally modulated lasers.

InP membrane on Silicon (IMOS) stands out as a novel fabrication technology for PICs, which potentially allows to achieve high density integration of passive and active optical components and connect them to driving microelectronic circuit within a single process flow [4]. In this paper, several designs of a DML on IMOS are proposed and studied in terms of their bandwidth, driving current and output power.

Bandwidth enhancement

For small-signal response, the modulation bandwidth of a DML is highly dependent on its relaxation oscillation frequency. The relaxation oscillation limited bandwidth might be enhanced by cavity design. One of the phenomena which helps to increase the bandwidth is photon-photon resonance (PPR) [5]. PPR can be generally achieved when a strong lasing mode of the main laser cavity becomes phase-matched with a low-power mode formed by reflection from outside the cavity, such as from cleaved facet, from output grating coupler or from DBR. In this case, a second peak appears in modulation response at the frequency corresponding to the frequency difference between the main lasing mode and the side-mode.

A simple schematic of laser cavity where PPR can be achieved, is shown on Figure 1. At one end of the cavity, a strong broadband reflector is used to reduce threshold gain for all modes. On IMOS platform, a building block with these properties is photonic crystal reflector (PhC) [6]. At the other end, a weak and long DBR grating is used as reflector and mode filter simultaneously.

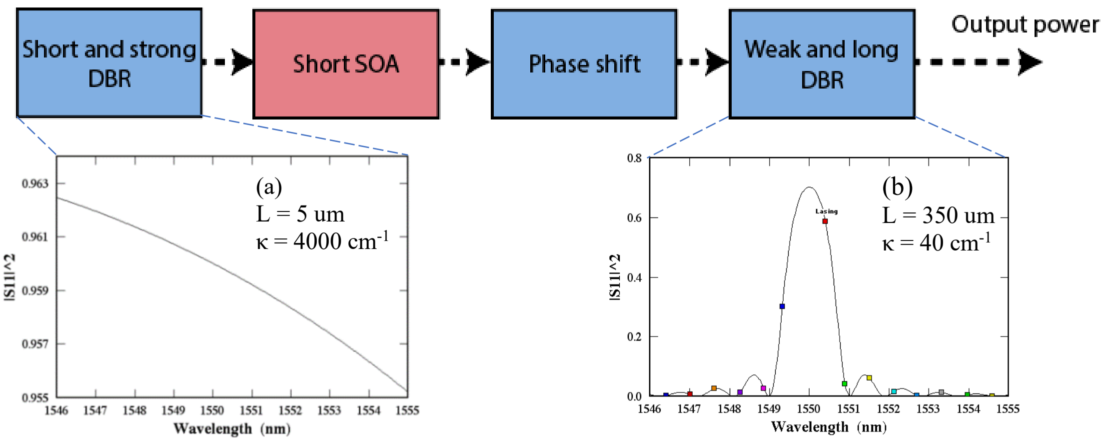

Figure 1. Top: laser cavity principal scheme. (a) Reflectivity spectrum of strong broadband reflector, used in current design. (b) Reflectivity spectrum of a weak DBR grating. Coloured dots are cavity modes. L is reflector length, κ is coupling constant.

The phase matching condition between the modes plays an essential role to obtain a pronounced second peak, and is generally difficult to achieve. In most of recent studies this was done in an uncontrolled way, which made devices with PPR suffer from low yield, and therefore not suited for mass production. In our design, two options for active phase control are investigated: 1) weak DBR grating fabricated on top of reverse-biased p-i-n junction; 2) a thermal phase shifter integrated between SOA and DBR.

Laser design

The design is mostly performed in the LaserMatrix™ software which is based on a traveling wave laser model (TWLM). DBR section of 350 um and $\kappa = 40$ cm^{-1} is used as mode filter, gain section of 120 um is used as SOA and DBR of 5 um and $\kappa = 4000$ cm^{-1} is used to emulate the PhC reflector. Values for the material gain, as well as for waveguide and SOA losses are taken from experimental data of previously characterized IMOS devices.

In IMOS, an SOA cross-section has an S-shape (see Figure 2a). The membrane approach allows to achieve a very high confinement of the optical mode inside SOA. The confinement factor is calculated as an overlap between mode field and quantum wells (QW). In our design, 8 QW are used, and the total confinement factor in simulation is 11%.

In Figure 2b it is shown how modulation response changes with different values of phase shift between SOA and DBR. The

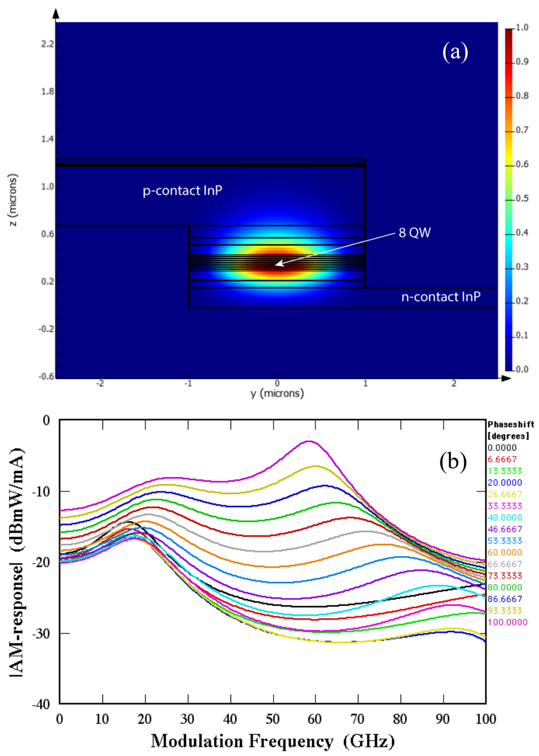

Figure 2. (a) Fundamental mode electric field in the SOA cross section. (b) Modulation response vs phase shift between SOA and weak DBR.

exact phase depends on actual optical length between reflectors, and, since mode effective index is quite high (n = 3.227), a small variation of the length due to fabrication error might result in significant change of the phase shift. Therefore it is necessary to include a mechanism for active phase tuning. In our design, two approaches to achieve this are studied. The first one is to build a weak DBR in a reverse-biased p-i-n junction, which is connected to SOA via butt-joint interface (Figure 3a). A passive waveguide section (made of intrinsic InGaAsP) is included between SOA and DBR for electrical isolation. Experimental data from similar stack on generic InP platform suggests that a phase shift of π can be achieved with V = -9 V in the modulator section of 1 mm [7]. In our laser design, the section length is limited by DBR reflectivity requirements, so from a section of 350 um a phase shift of $0.35\pi = 63°$ is expected. For $\lambda = 1550$ nm this means that the cavity length tolerance range is 84 nm, which is realistic to achieve with scanner lithography.

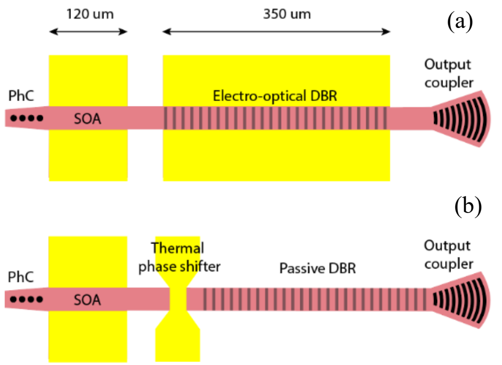

Figure 3. (a) Cavity design with 2 different mechanisms for active phase tuning: (a) with electro-optical DBR; (b) with thermal phase shifter. In yellow, electric contact pads are shown.

Another approach is to use a thermal phase shifter (Figure 3b), which was demonstrated in IMOS recently. The experimental data shows that a shift of 0.8π is achieved for a 2 um long phase shifter.

As seen from the Figure 2b, with the given cavity length the phase shift for the sharpest resonance is 100°. If the phase is shifted even more, the next adjacent cavity mode losses will reduce, causing possible mode hops, which will lead to laser output instability. At the chosen phase shift, the 3db bandwidth reaches 80 GHz at 80 mA driving current in simulation. The large signal simulation can be performed for this model, showing that 100 Gbps signal can be transferred with clear eye opening with a current swing of 10 mA.

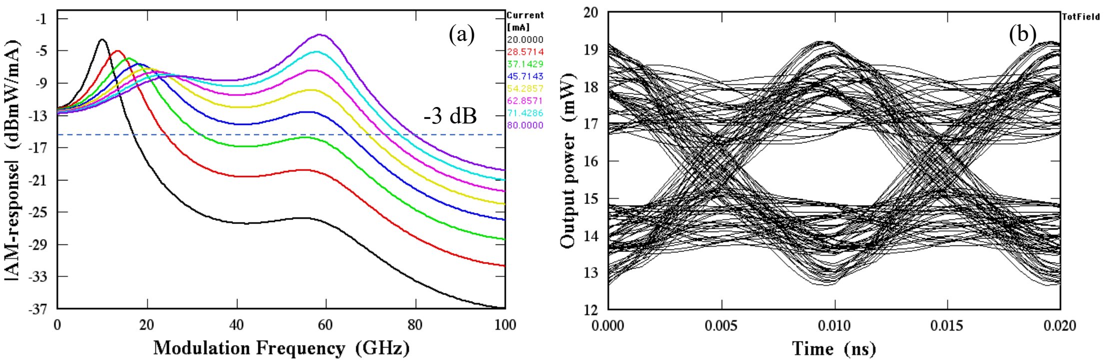

Figure 4. (a) Modulation response vs driving current. (b) 100 Gbps PRBS signal eye diagram

The driving current is relatively high, and this is due to the losses in DBR. It can be reduced significantly by adding a short strong DBR between SOA and weak DBR, to increase cavity quality factor and thus reduce the lasing threshold, as demonstrated in [2]. It will also allow to use shorter SOAs and shorter DBR. In our design, $L_{\text{short DBR}} = 15$ um and $\kappa = 640$ cm^{-1}. Output power in simulation is more than 10 mW. The cavity length is 380 um, which is 2 times shorter compared to the previously discussed design. The bandwidth reaches more than 60 GHz at driving current of 40 mA with relatively flat response.

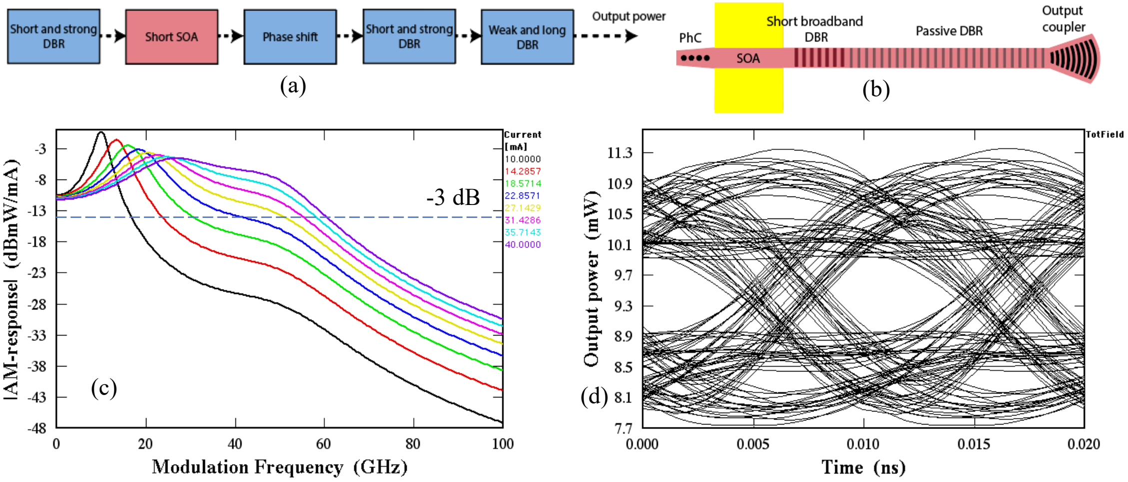

Figure 5. (a) Cavity scheme with 2-k DBR. (b) 2-k laser designed for IMOS. (c) Modulation response of 2-k DBR laser. (d) 100 Gbps eye diagram

Conclusion

Design of DML with bandwidth enhancement by photon-photon resonance is proposed. The mechanism for active control of the phase shift to achieve pronounced PPR peak is implemented. All designs demonstrate 3dB bandwidth comparable with state-of-the-art for DML (up to 80 GHz) and high output power of 10-19 mW. These designs are included in the upcoming IMOS active fabrication run, and will be fabricated soon.

Acknowledgements

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