Design of a 32Gbit/s O-band high sensitivity receiver

Senbiao Qin,[1,2] Laurens Bogaert,[1,2] and Gunther Roelkens[1,2]

[1] Photonics Research Group, INTEC, Ghent University - imec, Ghent, Belgium
[2] Center for Nano- and Biophotonics, Ghent University - imec, Ghent, Belgium

We propose a receiver design to achieve high sensitivity by minimizing the capacitance and improving the responsivity. Through micro-transfer printing, the trans-impedance amplifier can be compactly integrated side by side with the photodiode, which can significantly reduce the capacitance of the connection between the two. The interconnect capacitance can be as low as 9.6 fF with a connection length of 150 um taken into consideration. A short grating coupler with a length of 5 um and an efficiency of 80% is also designed on the imec SiN platform to support a small surface illuminated photodiode with an area of 30 um^2 and junction capacitance of 4.5 fF. Aiming at 32 Gbit/s non-return-to-zero On-Off keying in the O-band, the InGaAs absorption layer thickness is optimized to be 0.85 um, corresponding to a responsivity of 0.69 A/W. Implementation of a partially doped absorption layer can further enhance the photodiode for higher responsivity.

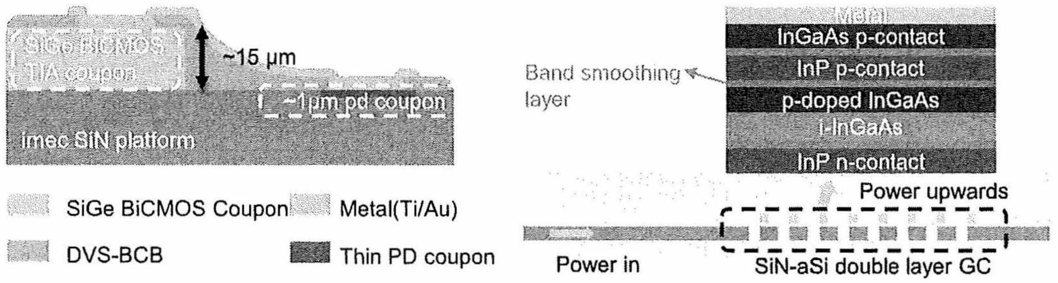
Introduction

From long-haul fiber links to on-chip photonics interconnection, optical systems are calling for a highly power-efficient solution. The SiN PIC platform is known for its low-loss waveguides, broad transparency window and absence of two-photon absorption in the telecom wavelength range, attracting lots of attention in the fields of optical interconnect, sensing, non-linear optics, etc. To realize fully integrated circuits on this platform, active components should be integrated onto it. Micro transfer printing is an emerging solution, by which a series of laser [1] and photodetector [2] integration on Si or SiN platforms have been demonstrated.

Optical receiver noise typically comes from the feedback resistor and feedback amplifier of the TIA front-end. The receiver sensitivity can be considerably improved by reducing the input capacitance for a low TIA input referred noise. In this paper, we present a high-sensitivity receiver design, including an InGaAs photodiode coupon and a SiGe BiCMOS trans-impedance amplifier coupon. The micro transfer printing of the SiGe BiCMOS electronic integrated circuits has recently been developed by X-Celeprint [3], which provides an excellent opportunity to bring the TIA chiplet close to the PD coupon, leading to an ultra-low interconnect capacitance and high sensitivity. A short grating coupler is also implemented to minimize the photodiode dimension to reduce the junction capacitance. In addition, the responsivity improvement of implementing a partially doped InGaAs absorption layer is also evaluated.

Receiver design

Figure 1a shows the schematic of the high-sensitivity receiver. Both the InGaAs photodiode coupon and the SiGe BiCMOS trans-impedance amplifier coupon can be integrated on the imec SiN photonics platform by micro-transfer printing. Thus, a compact layout is realized to minimize the capacitance from the metal leads. Spray-coated DVS-BCB helps to planarize the ~15 um height difference between the TIA coupon and the PD coupon for the metal connection. Figure 1b is a detailed schematic of the surface-illuminated photodiode. The optical power is coupled from the SiN waveguide to the PD coupon by a grating coupler. The dimensions of the PD coupon and the grating coupler are limited to reduce the junction capacitance of the photodiode. An additional aSi layer is implemented to increase the grating coupler strength to achieve a short coupling length with a decent coupling efficiency. The absorption InGaAs layer is partially doped, containing an intrinsic layer and another p-doped layer, which can boost the photodiode to a higher responsivity under a certain bandwidth requirement. When the p-doped InGaAs absorption layer thickness is set to zero, the layer stack returns to a normal p-i-n case.

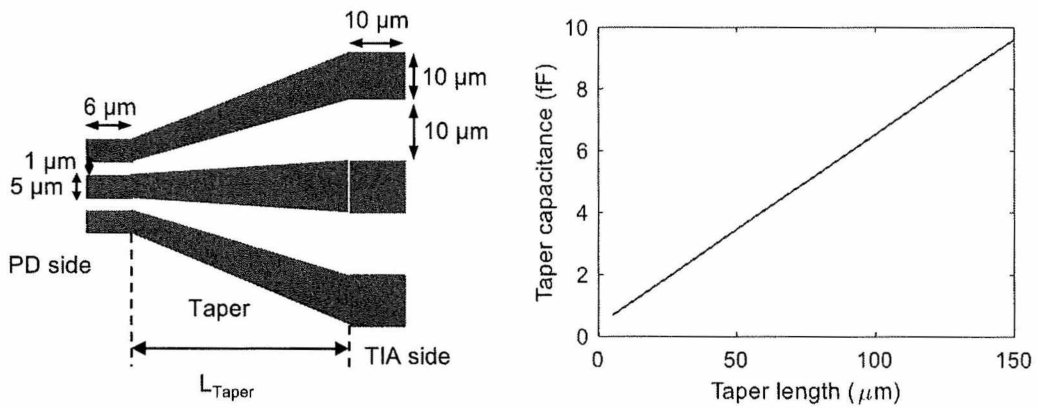


(a) Schematic of receiver (b) Schematic of the surface-illuminated photodiode

Figure 1: Plots of a) schematic of the high sensitivity receiver with SiGe BiCMOS trans-impedance amplifier coupon and InGaAs photodiode coupon transfer printed on imec SiN platform and b) schematic of the surface-illuminated photodiode containing 5 um length SiN-aSi double layer grating coupler and a partially doped InGaAs absorption layer

Capacitance and responsivity optimization

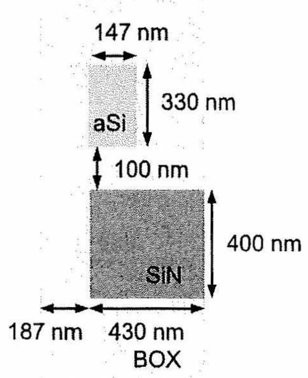
The capacitance introduced by the taper metal connection between the PD and TIA pads is studied as shown in figure 2a and 2b. In figure 2a, the dimension of the PD side GSG pads is 5 um × 6 um with 1 um gap, while for the TIA side it is 10 um × 10 um with 10 um gap. The metal connection is a taper structure, whose length varies from 5 um to 150 um. Figure 2b gives the simulated taper capacitance as a function of the taper length. Considering a taper length of 150 um, which should be a relatively relaxed condition for processing, the taper capacitance is still only 9.6 fF.



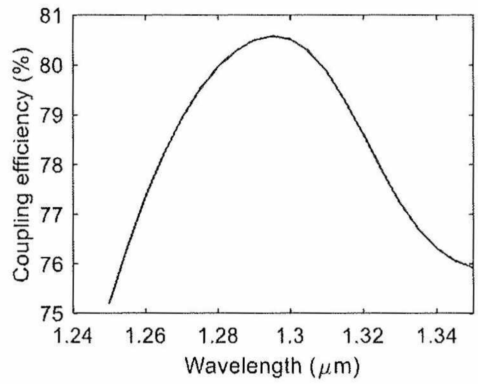
(a) Geometry of the taper metal connection (b) Taper capacitance

Figure 2: Plots of a) schematic of PD and TIA sides GSG pads and the taper metal connection and b) taper capacitance when the taper length is changed from 5 - 150 um

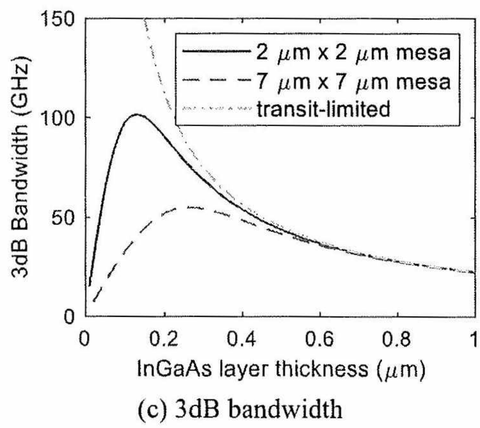
Junction capacitance, mainly determined by the geometric dimensions of the photodiode, also contributes to the total capacitance of the receiver. With the implementation of a short grating coupler, the PD length can be considerably limited, as well as the junction capacitance. As shown in figure 3a, the grating coupler is designed based on the imec 400 nm SiN photonics platform, which includes another 330 nm aSi layer. The grating pitch is 617 nm, with a SiN tooth width of 430 nm and an aSi tooth width of 147 nm. The coupling efficiency of this grating coupler is presented in figure 2b. A 5-um grating coupler with 8 periods can provide a coupling efficiency of 80% at a wavelength of 1.3 um. Using a thick InGaAs absorption layer can also reduce the junction capacitance. Figure 3c shows the bandwidth for different p-i-n type mesa sizes, compared with the transit-limited bandwidth. When the InGaAs layer is thicker than 0.6 um, the carrier transit time becomes the dominant factor. For this p-i-n photodiode, the maximum thickness of the InGaAs layer is 0.85 um due to the bandwidth requirement of 25 GHz for 32 Gbit/s. The simulation result of the junction capacitance as a function of InGaAs layer thickness is in figure 3d. Considering a small photodiode with an area of 30 um^2, the minimum junction capacitance is 4.5 fF.



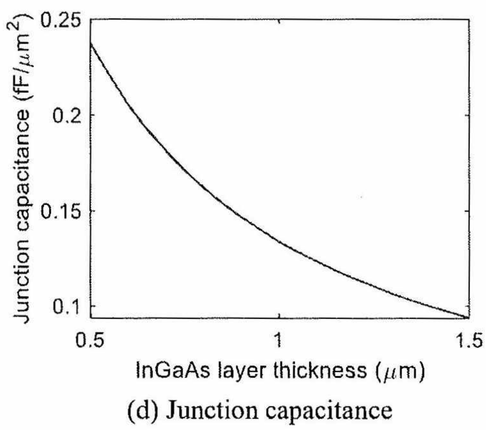
(a) One period of the grating coupler



(b) Coupling efficiency of the grating coupler



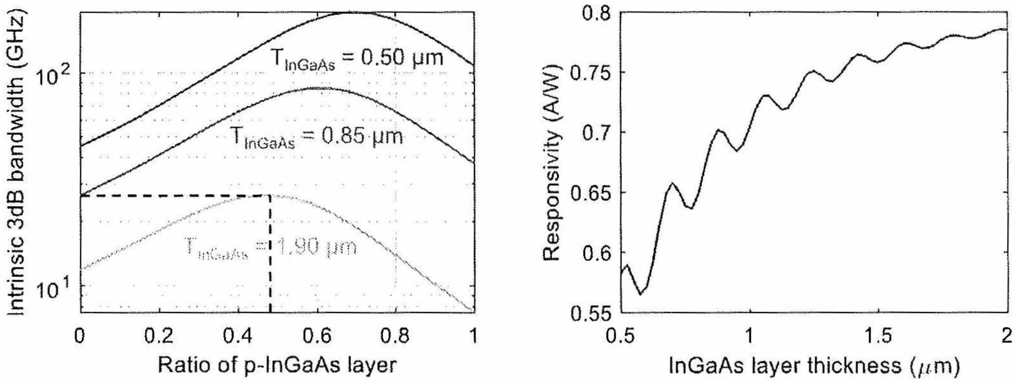
(c) 3dB bandwidth



(d) Junction capacitance

Figure 3: Plots of a) structural dimension of one period of the grating coupler, b) coupling efficiency as a function of wavelength, c) 3 dB bandwidth (assuming a 50 Ohm load) for 2 um × 2 um and 7 um × 7 um p-i-n type mesas when InGaAs layer thickness is changed and d) dependency of the InGaAs p-i-n photodiode junction capacitance on the InGaAs layer thickness

For the normal p-i-n photodiode with an InGaAs layer thickness of 0.85 um, the responsivity is 0.69 A/W. By implementing a partially p-doped InGaAs absorption layer, a 25 GHz bandwidth can be achieved with a thicker absorption layer thickness because neutral and depleted layers have different carrier transport mechanisms [4], which can further improve the photodiode to higher responsivity. As illustrated in figure 4a, the 1.90 um partially doped InGaAs absorption layer at the ratio of 0.47 has the same bandwidth as the 0.85 um intrinsic InGaAs absorption layer. In this case, according to the simulation results in figure 4b, the responsivity is enhanced to 0.78 A/W.



(a) Bandwidth versus ratio of p-InGaAs layer

(b) Responsivity

Figure 4: Plots of a) ratio of p-InGaAs layer dependence of bandwidth for different total InGaAs layer thicknesses and b) responsivity as a function of total InGaAs layer thickness

Conclusions

We put forward a high-sensitivity receiver design. The trans-impedance amplifier and photodiode can be compactly integrated on imec SiN platform to realize a metal lead capacitance of 9.6 fF for the connection length of 150 um. The SiN-aSi double-layer grating coupler can provide a decent coupling efficiency of 80% within a length of 5 um, which can support a small surface-illuminated photodiode with an area of 30 um^2 and junction capacitance of 4.5 fF. The adoption of a partially doped InGaAs layer helps increase the total absorption layer thickness from 0.85 um to 1.90 um while still meeting the 25 GHz bandwidth requirement. The corresponding responsivity is improved from 0.69 A/W to 0.78 A/W.

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