# Heterogeneous balanced photodetector on silicon nitride with 30 GHz bandwidth and 26 dB common mode rejection ratio

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**Abstract:** We demonstrate InGaAs/InP balanced photodiodes on $Si_3N_4$ waveguides with record-high 3-dB bandwidth of 30 GHz, 0.72 A/W responsivity, and high common mode rejection ratio (CMRR) of 26 dB at 30 GHz. 

## 1. Introduction

As a CMOS-compatible platform, silicon nitride $Si_3N_4$ photonics has attracted significant research efforts over the past years. $Si_3N_4$ waveguides can have ultra-low propagation loss and high optical power handling capability, and numerous high-performance passive and nonlinear photonic components have already been demonstrated [1, 2]. Recently, progress in III-V/$Si_3N_4$ heterogeneous integration has also enabled active photonic components including high-speed photodiodes (PDs) [2–8].

For heterodyne detection schemes and applications that require enhanced signal-to-noise ratio, balanced PDs are beneficial since they can suppress common mode noise. In this paper, we demonstrate a heterogeneously integrated balanced photodetector on $Si_3N_4$ with a record-high bandwidth of 30 GHz and a high CMRR of 26 dB.

## 2. Experimental

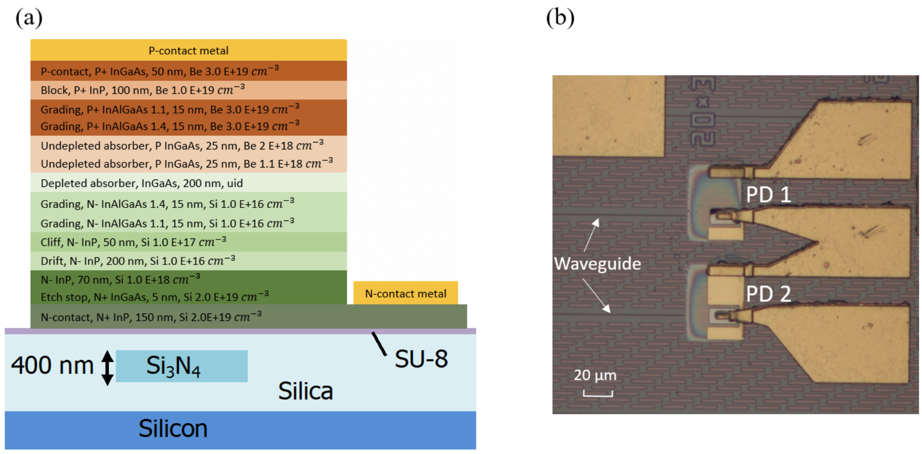


Fig. 1: (a) Cross section with epitaxial layer structure, (b) fabricated balanced PDs on $Si_3N_4$ waveguides.

The epitaxial layer structure and cross section of our balanced PDs are shown in Fig. 1 (a). The waveguide consists of a $Si_3N_4$ core with 400-nm thickness, 2-$\mu m$ width and 100-nm thick silica cladding. In contrast to our previous work [6], we used a modified uni-traveling carrier PD structure that results in n-down after bonding. This design is advantageous since high n-type doping levels ($> 10^{19} cm^{-3}$) can be reached in the InP contact layer which ensures low sheet resistance [9]. The PD fabrication starts with III-V die to $Si_3N_4$ wafer bonding using SU-8 in a low-temperature adhesive bonding process [6]. The III-V substrate is then removed by selective wet etching and double-mesa PDs are formed by a combination of dry and and wet etching processes. Radio frequency (RF) probing pads are deposited and connected with the contact metals by electro-plated air-bridges. Fig, 1 (b) shows a fabricated balanced photodetector with its two $Si_3N_4$ input waveguides.

Fig. 2 (a) shows the I-V curves of a pair of balanced PDs with dark currents below 100 nA at 3 V reverse bias. Considering 1.5 dB fiber-chip coupling loss, the (internal) responsivity was measured to be 0.72 A/W at 1550 nm wavelength.

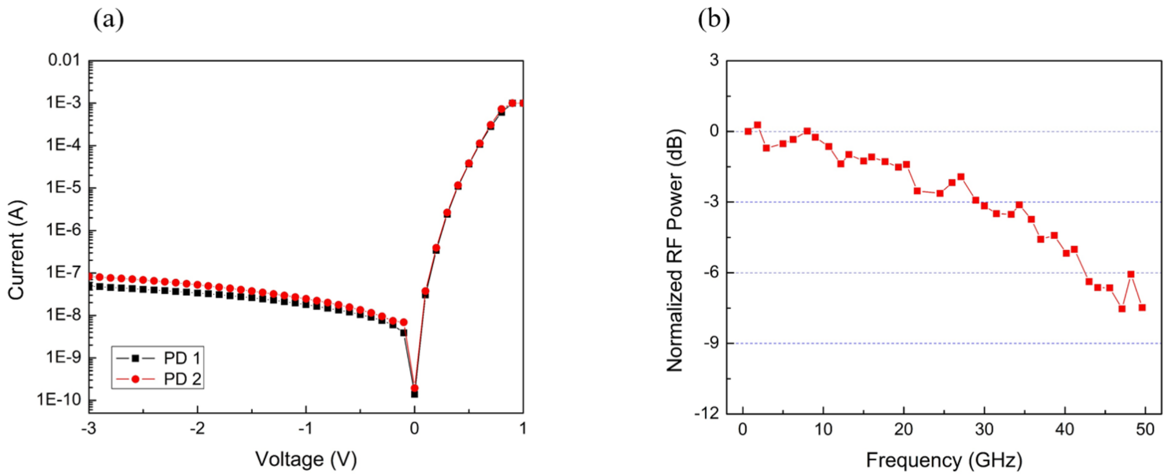


Fig. 2: (a) Dark I-V curves and (b) frequency response.

The frequency response was measured in differential mode using an optical heterodyne setup with nearly 100% modulation depth (Fig. 3). The optical signal was split into two branches and we used an optical delay line to adjust the signal phase before reaching the lensed fiber array. The PDs were reverse-biased at 3 V by two DC voltage sources through a custom-designed RF probe with integrated capacitors. The measured 3-dB bandwidth of a balanced PD pair, each with an active area of 200 $\mu m^2$, is 30 GHz (Fig. 2 (b)). Based on the total capacitance of 94 fF and a series resistance of 7 $\Omega$ we estimated a resistance-capacitance (RC) bandwidth of 29.7 GHz which indicates that our balanced photodetector is RC-limited. We believe that the bandwidth performance can be further improved by decreasing the PD areas.

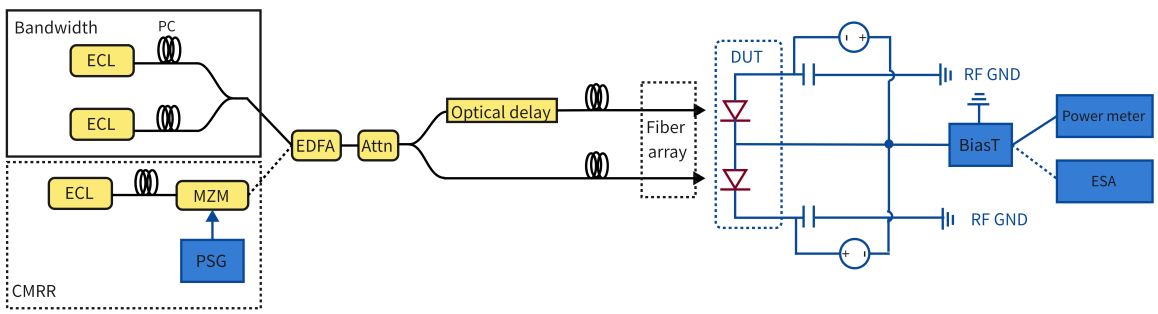


Fig. 3: Experimental setups for bandwidth and CMRR measurements (ECL: external cavity laser, PC: polarization control, PSG: RF signal generator, MZM: Mach-Zehnder modulator, EDFA: erbium doped fiber amplifier, Attn: optical attenuator, DUT: device under test, ESA: electrical spectrum analyzer)

Another key parameter of a balanced photodetector is CMRR, i.e. the ratio of differential-mode RF output power to common-mode output RF power. To measure CMRR, the optical heterodyne setup was replaced with single ECL laser and a MZM driven by an RF signal generator. Fig. 4 (a) and (b) show the differential and common mode signals as measured with the ESA. High CMRRs of 39 dB and 26 dB were achieved at 20 GHz and 30 GHz, respectively.

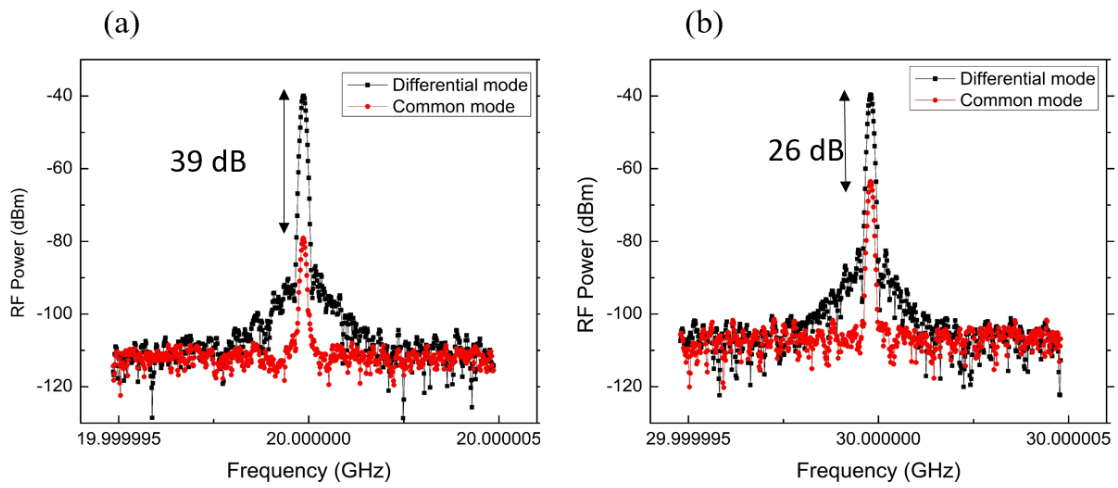


Fig. 4: CMRR at (a) 20 GHz, and (b) 30 GHz.

## 3. Summary

High-speed balanced PDs heterogeneously integrated onto $Si_3N_4$ waveguides were fabricated and characterized. The balanced PDs show an RC-limited bandwidth of 30 GHz and high CMRR of over 26 dB. The reported device has potential applications in photonic integrated circuits that require improved noise performance and large bandwidth.

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