32 GHz Germanium Bipolar Phototransistors on Silicon Photonics

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Abstract: We present designs and simulations for a 32 GHz fT 3-terminal germanium bipolar phototransistor for high-sensitivity 10 GB/s receiving. We also experimentally demonstrate a preliminary, non-optimized phototransistor with 14 GHz fT built on silicon photonics.

I. Introduction
Ultra-low capacitance photodiods are becoming increasingly important for future optical interconnect technology[1], [2]. However the sensitivity gains achieved through capacitance reduction in the photodiode can be easily erased by the 0.2 fF/µm capacitance of the wire connecting it to the amplifying receiver circuit. To solve this one can simply eliminate the wire between photodiode and first stage transistor by creating a phototransistor. Several groups have recently attempted this in germanium demonstrating MOSFET[3], JFET[4], and bipolar phototransistors[5]. Unfortunately all have so far suffered from drawbacks related to low gain or low bandwidth. By taking advantage of the compact geometry afforded by waveguide integration, we can engineer a high-speed bipolar phototransistor. We present a design for a 3-terminal germanium bipolar phototransistor on silicon photonics with a simulated 32 GHz fT for 10 GB/s receiving. We also demonstrate our preliminary efforts, consisting of a non-optimized floating base germanium phototransistor with a measured fT of 14 GHz, and 3dB bandwidth of nearly 5 GHz.

II. Device Design and Simulation Results
Figure 1 shows a schematic of the proposed photoBJT, showing emitter, base, and dual collector contacts, with a thin body to compromise between low current crowding in the transistor and fast optical carrier collection. The device is 0.35 x 2.5 x 10 µm long, and butt-coupled to a 0.21 x 0.5 µm Silicon waveguide. Optical FDTD simulations show upwards of 70% optical absorption at 1550 nm from the waveguide. The silicon photonics are dry etched with a two-step process to enable grating couplers. A thin oxide (20 nm) is grown with a small hole wet etched for an isolated silicon seeding area. Germanium is deposited via LPCVD and dry etched in to thin strips, then coated with oxide and melted at 1050°C for 1 s in rapid melt growth crystallization[6]. The contact areas are etched open, and boron and phosphorus are implanted and activated at 500 °C for 30 s. Finally aluminum contacts are deposited and patterned.

Figure 1. Schematic of 3-terminal germanium photoBJT on SOI with silicon waveguide (WG) butt-coupled to the device. A cross section shows the junction profile and background doping level.

Figure 2. (a) Scanning Resistance Probe (SRP) measurements of implants made into germanium with the simulated profile overlaid. (b) Using the implant profile with 2E17 cm⁻³ uniform background doping, the AC gain curves are simulated.
Figure 2(a) shows scanning resistance probe (SRP) measurement results from implants for the simulated 3-terminal device, showing a 60 nm deep emitter region with $3 \times 10^{18}$ cm$^{-3}$ activated phosphorus and a $3 \times 10^{17}$ cm$^{-3}$ base region. The SRP results are superimposed over the simulated implants in Sentaurus. The simulation results in Fig. 2(b) show a peak $f_T$ of over 32 GHz, with a current gain of 10 (20 dB). By tuning the amount of bias applied to the base, the gain and 3dB frequency can be tailored to suit the given application, such as reducing the gain in order to extend the 3dB frequency, making the device suitable for 10 GB/s operation.

III. Preliminary Experimental Results

Figure 3(a) shows a non-optimized preliminary floating base photoBJT that is 1.7 µm wide and 8 µm long with a unique coupling mechanism where it is wrapped around the silicon waveguide[7], while fig. 3(b) shows the measurement. This device has skipped the background implant step, and has a rather wide lateral base region, resulting in a long but highly depleted base region. With 5 µW of incident light at 1550 nm, the device shows a photocurrent gain of 11.3 (21 dB) with a 3dB bandwidth of 700 MHz for a measured peak $f_T$ of 14.6 GHz at 3V collector-emitter bias. At higher optical input of 375 µW, the bandwidth is 4.8 GHz, but with a reduced gain of only 1.8 (5 dB) which is an $f_T$ of only 8 GHz.

IV. Conclusion

We have designed and simulated a 32 GHz $f_T$ 3-terminal photoBJT for highly sensitive 10 GB/s receiving. Our preliminary demonstrations with non-optimized doping and geometries have demonstrated $f_T$ of over 14 GHz.

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