SWIR GaSb Photodiode integration on Si Photonics through Micro-Transfer-Printing

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We investigate the possibility to integrate GaSb photodiodes on a Ge-SOI platform via micro-transfer printing. The germanium layer is used as an intermediate waveguide/taper to couple light from the underlying silicon waveguide to the III-V active region. We have successfully transfer-printed GaSb photodiode coupons and electrical measurements are performed.

Introduction

The short-wave infrared (SWIR) wavelength range and especially the 2-2.5 µm range is of particular interest for spectroscopic sensing applications [1]. Various molecules including glucose, lactate, urea and ethanol have absorption peaks in this spectral region. Therefore SWIR lasers and photodiodes are of great interest.

In recent years, GaSb, as the 4th generation of the III-V material, has proven its excellent electrical and optical properties in the SWIR range [2-4]. GaSb and its related alloys are able to efficiently cover a spectral range from 1.7 to 3 µm, which is in line with the absorption bands of multiple molecules. Compared to the InP system, the current most mature choice in the near-infrared, GaSb can probe further into the SWIR and has better performance diode lasers in the 2-2.5 µm range [5].

Here, we present a GaSb based p-i-n photodiode that fits the target spectral range (2 to 2.5 µm). We integrate the GaSb photodiode on a Ge-SOI platform via micro-transfer printing technology [6, 7]. This technology allows for the efficient use of III-V materials and enables pre-testing of the devices on the source wafers and the integration of a wide range of materials/devices on wafer scale in a massively parallel way.

Design & Fabrication

The GaSb p-i-n photodiodes are integrated on a Ge-SOI platform, where 500 nm germanium is grown on top of standard 220 nm SOI wafers. The schematic of the device is depicted in Fig. 1. The germanium and silicon waveguides are patterned by Electron-beam lithography (EBL). After EBL patterning the germanium and silicon layer are etched by Reactive-ion etching (RIE).

The GaSb epitaxial layer is supplied by Brolis Sensor Technology. The GaSb photodiode structure consists of a 200 nm thick highly-doped GaSb p-contact layer and cladding, a pair of AlGaAsSb SCH layers, an active region with quantum wells separated by AlGaAsSb barriers and a 275 nm n-GaSb contact layer. A 1.5 µm thick intrinsic InAsSb layer is used as the release layer for the transfer printing. The overall thickness of the III-V layer stack that is printed onto the target photonic circuit is around 4 µm.

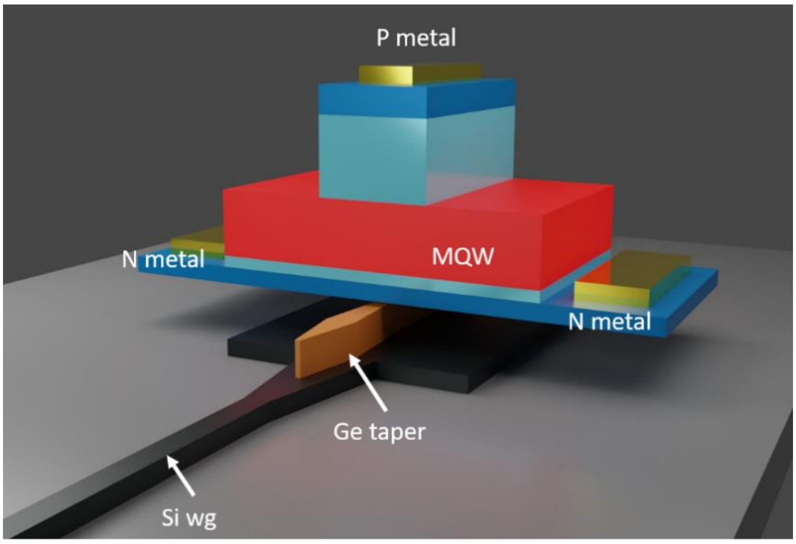

Figure 1: Rendering of the layout of the GaSb on Ge-SOI Photodiode.

The III-V process flow is described in Fig. 2. It starts by depositing a SiN hard mask. The hard mask is then patterned using optical lithography to define the mesa of the photodiode. The III-V is then etched through Inductively Coupled Plasma (ICP) etching (Fig 2(a)). This mesa etch defines the III-V waveguide and it is stopped before the quantum wells are reached. After this, a second mesa is defined to pattern the quantum well region (Fig. 2(b)). The dry etch process stops when the n-GaSb contact layer is exposed. Subsequently, a layer of 400 nm SiN is deposited to protect the side walls of the mesa. This protective layer is then patterned by optical lithography, followed by ICP etching to make the vias for metallization. Ti/Pt/Au contacts are formed on p-GaSb and n-GaSb contact layers simultaneously through a lift-off process (Fig. 2(c)). At this stage the GaSb photodiode is formed on the native source sample and will be followed by steps to make it transfer-printable. A SiN layer is again deposited as the hard mask to define the boundaries of the transfer-printable coupon (Fig 2(d)). The etching stops at the release layer. Afterwards, the release layer is etched through the same method: mask deposition, optical lithography and dry etching (Fig. 2(e)). After over-etching 200 to 300 nm into the GaSb substrate, a 650 nm SiN layer is deposited and patterned to form tethers that will hold the device after the under-etching of the release layer (Fig. 2(f)). In order to form a flat-top surface for the transfer-printing step, a thick photoresist of 4.2 µm is spin-coated on the sample and patterned to encapsulate the device. To mitigate the attack from the etchants during the under-etching, the photoresist also requires a hard bake at 150° for 5 minutes to get better chemical stability. Afterwards, a citric acid solution is used to under-etch the InAsSb release layer. This wet-etching process is performed at 60° C which gives an etching rate of 25 µm per hour. The coupons at this point stand on the SiN tethers as the anchors.

These coupons are fabricated in a dense array with a vertical pitch of 110 µm and the length of the coupon varies from 200 to 400 µm with a step of 100 µm, where the lengths of the III-V waveguide are 120 µm, 220 µm and 320 µm respectively.

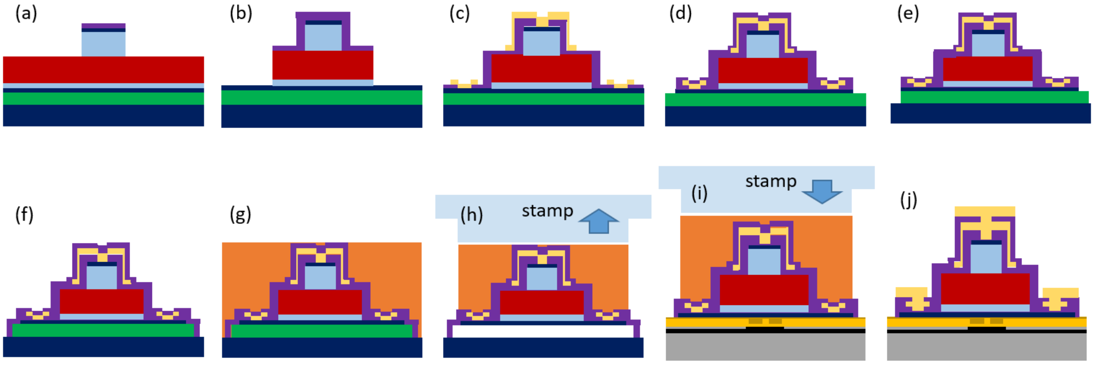

Figure 2: Process flow of the integration of GaSb photodiode coupons via micro-transfer printing.

Fig. 3(a) shows the top view of patterned and released coupons on the GaSb source sample, where the coupons have a width of 45 µm. In the current design there are two variants of our coupons: one with two n-contacts on both sides and the other with only one n-contact at the side. To transfer-print these coupons, PDMS stamps with a post of 200, 300 and 400 × 50 μm^2 in size are used for the corresponding size of coupons, using an X-Celeprint μTP-100 tool. The photodiode coupons are printed on a Ge-on-SOI photonic waveguide circuit. The Germanium layer is 500 nm thick and the waveguides are etched 300nm deep.

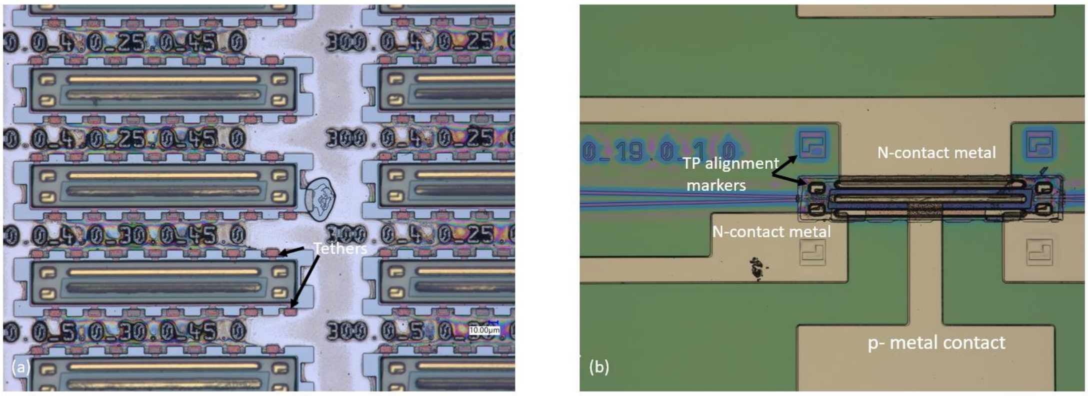

Figure 3: Microscope top images of GaSb coupons (a) before transfer-printing; (b) after transfer-printing and post-process.

To ensure a high printing yield, the target sample is spin-coated with a DVS-BCB: mesitylene 1:4 solution at 3000 rpm, followed by a soft bake at 150°C and cooling down to room temperature. Both the GaSb source sample and the Ge-on-SOI target sample are loaded into the micro-transfer-print tool after preparation. The source and the target samples need to be aligned before the actual transfer-printing. Once they are aligned and all the parameters are set properly, the stamp can pick up the coupons from the source sample and print them on the target sample (Fig. 2(h) and 2(i)).

One of the advantages of micro-transfer-printing is that all III-V processes are carried out on the native sample, which simplifies the process and allows us to know the quality of the III-V devices before transfer-printing by putting testing structures on the source sample (for example TLM structures). The first step of post-processing is removing the encapsulated photoresist using an oxygen plasma RIE. After that, the DVS-BCB bonding layer is fully-cured at 210° C for 9 hours. Then, metal vias is made by etching the SiN layer to expose the p-contact metal and n-contact metal. As the last step of the whole process, a final lift-of process is executed to form a Ti/Au metal stack as the electrical contacts for probing, as shown in Fig. 3(b).

Device characterization

So far we characterized the test structures on the source sample and performed *I-V* measurements. The testing structures were characterized at room temperature using electrical contact probes and a Keithley 2400A voltage-current source. As shown in Fig. 4, a dark current below 1 μA was measured at a reverse bias voltage of 2 V for all 3 test photodiodes with a maximum length of 320 μm. The next step is to measure the real transfer-printed photodiode.

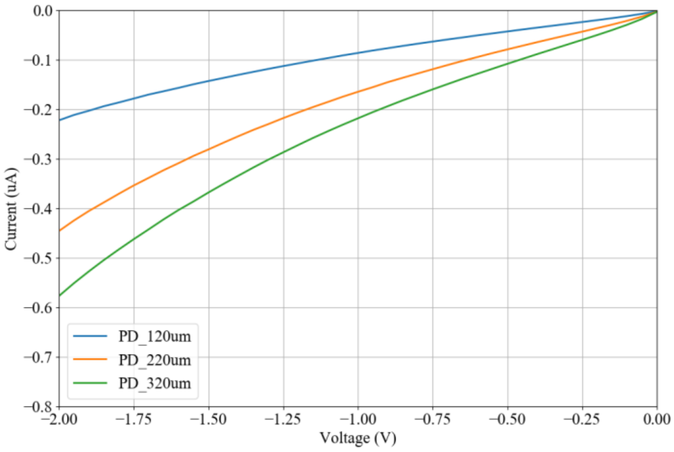

Figure 4: Measured dark currents of testing PD devices

References

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