High-Speed, High-Responsivity Ge Photodiode with NiSi Contacts for an Advanced Photonic BiCMOS Technology

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ABSTRACT

We will show that contacting a high-performance Ge photodiode with NiSi instead of $CoSi_2$ has no negative effect. This result strongly supports the development of an advanced photonic BiCMOS process where the RF performance of SiGe HBTs can take strong benefit from the “cold” NiSi.

INTRODUCTION

Recently, we introduced an advanced photonic BiCMOS technology, which monolithically combines state-of-the-art Si photonics, including Ge photodiodes (PD) with 70 GHz bandwidth, with a high-performance BiCMOS baseline offering SiGe heterojunction bipolar transistors (HBT) with f_T/f_{max} values of up to 240/290 GHz [1]. In this technology, cobalt silicide ($CoSi_2$) is used both for contacting photonic elements including the Ge-PD and several Si-based modulator structures, and BiCMOS devices, such as SiGe HBT, CMOS transistors, and polysilicon resistors.

However, it is known that SiGe HBT RF performance can strongly benefit when $CoSi_2$ is replaced by nickel silicide (NiSi) [2]. This is because a NiSi-based contact module allows for the reduction of the process temperature after the final BiCMOS anneal below 500 °C maintaining dopant activation better than in the $CoSi_2$ case with its typical process temperatures of 700° C or even higher. Consequently, introduction of NiSi in our photonic BiCMOS process as HBT performance booster is seen as desirable option too. However, a key question is there how the performance of the Ge-PD is affected by the Co silicide replacement. For the photodiode one could not necessarily expect performance improvement or at least immunity because it is integrated only after the final BiCMOS anneal, i.e. PD dopant activation is mainly determined by the thermal budget of the contact module. Thus, a particular concern was that the NiSi process could be even too cold for providing sufficient dopant activation, resulting possibly in a PD performance drop.

Here, we will demonstrate that the use of a “cold” nickel-silicide (NiSi) metallization process has no negative impact on the performance of the Ge photodiodes. This result paves the way for a photonic BiCMOS process with further advanced transistor RF performance.

GE PHOTODIODE FABRICATION

The approach for the integration of a waveguide-coupled Ge photodiode in a high-performance SiGe BiCMOS process and photodiode fabrication details were published elsewhere [3, 4]. Figure 1 (left) shows a schematic PD cross-section demonstrating its essential features, such as the lateral PIN structure and the tungsten contacts landing on lateral Si offshoots which are covered by a silicide layer. For the investigations of this work, photodiodes were fabricated only differing in the silicide module, $CoSi_2$ or NiSi. Note that our standard $CoSi_2$ module includes a 750 °C anneal step, while process temperatures of the NiSi module do not exceed 500 °C.

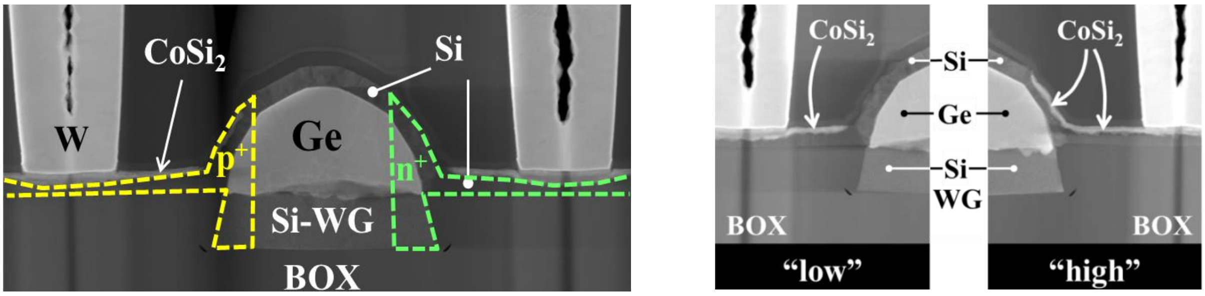

Fig. 1: X-section, perpendicular to direction of light incidence, of a lateral Ge PIN PD, coupled to a Si-waveguide (WG) (left). The right X-section illustrates two cases for PD sidewall silicide coverage [3]. It is shown because the coverage level (“low”, “high”) influences the PD performance. BOX denotes the buried SiO_2 layer of the SOI substrate used for fabrication. W contact plugs connect the PD with an AlCu metallization system (not shown here).

MEASUREMENT RESULTS

The following figures and the table compare characteristics and parameters of Ge photodiodes fabricated with the standard $CoSi_2$ module or the NiSi module. As can be seen that there are practically no differences between the diodes:

I-V (Fig. 2) and C-V characteristics (Fig. 3, right), frequency response behaviour (Fig. 3, left), and responsivity data (Table 1) are very similar for both cases. A maybe weak tendency to higher dark current at reverse voltage for the diodes with NiSi (Fig. 2, left) requires further investigation (more statistics). The relative big scattering of the PD dark currents at high forward bias (Fig. 2, right) results from differences in the diode sidewall silicide coverage (see Fig. 1, right), an effect described already elsewhere [3]. Differing sidewall silicide coverage is also responsible for scattering in the responsivity data. However, one can see that the use of NiSi obviously does not increase the scattering in both cases.

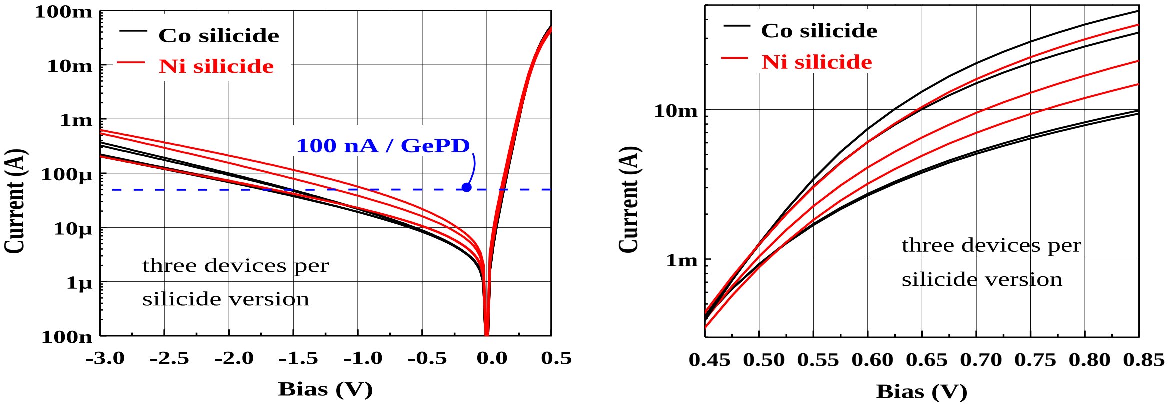

Fig. 2: Non-illuminated I-V characteristics of arrays with 500 Ge photodiodes in parallel (left) and forward I-V characteristics at high bias of single diodes (right). Devices were fabricated with $CoSi_2$ or NiSi module.

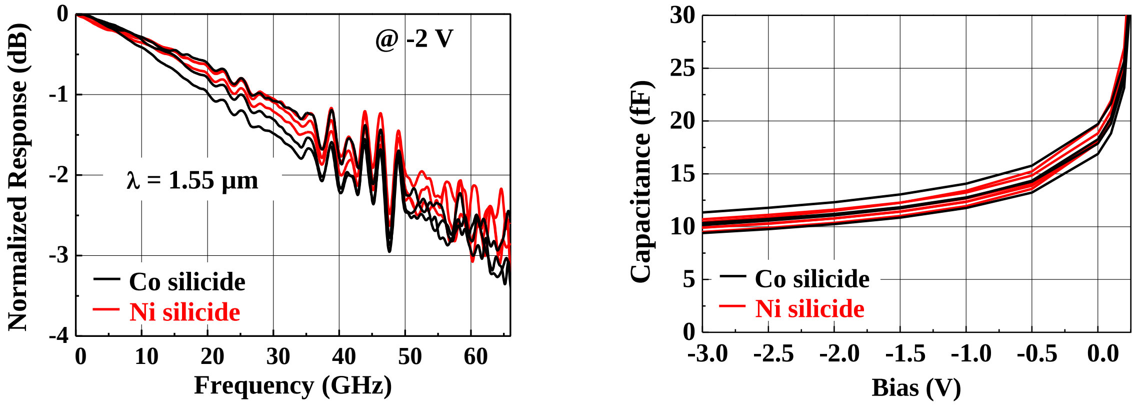

Fig. 3: O-E frequency response (left) and C-V characteristics of Ge-PD (right), fabricated w/ $CoSi_2$ or NiSi module.

Table 1: C-band responsivities, measured @ -2 V bias, of Ge-PD fabricated with $CoSi_2$ or NiSi module

Silicide module	Sidewall silicide coverage		
	low	medium	high
$CoSi_2$	> 0.9 A/W	> 0.7 A/W	< 0.7 A/W
NiSi	> 0.9 A/W	> 0.7 A/W	< 0.7 A/W

CONCLUSION

We demonstrated that contacting a high-performance Ge-PD with NiSi instead of $CoSi_2$ has neither a negative effect on the responsivity nor on the O-E bandwidth. This result paves the way for a photonic BiCMOS process with further advanced transistor RF performance enabling the fabrication of receiver ICs for data rates towards 100 Gbps or beyond.

ACKNOWLEDGMENT

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