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Design Effects on the Performance of High-Speed Ge Photo Detectors

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ABSTRACT

We investigate design effects on the opto-electrical frequency response of waveguide-coupled, lateral Ge p-i-n photodiodes to estimate the sensitivity of this response to diode fabrication tolerances and, in particular, to improve our understanding how diffusion of photo carriers acts on the response behavior.

INTRODUCTION

Ge p-i-n photodiodes (PD), coupled to a Si waveguide (WG), are the most widely used light detecting elements for Si-based photonic or electronic-photonic integrated circuits. Meanwhile, such diodes are available with opto-electrical (OE) bandwidths beyond 60 GHz [1–4]. That "slow" photo carrier diffusion can have an essential effect on the OE frequency response of high-speed Ge-PD was discussed recently [3, 4] and taken into account for diode modelling too [5]. Here, we investigate design effects on the OE frequency response of WG-coupled Ge lateral p-i-n photodiodes, to estimate the sensitivity of this response to diode fabrication tolerances and, in particular, to improve our understanding how diffusion of photo carriers acts on the response behavior.

EXPERIMENTS

Construction and fabrication details of the diodes investigated here are described in [3] and [4]. Note also that a diode version providing > 60 GHz bandwidth is already a key component of IHP's photonic BiCMOS process [6].

Figure 1 illustrates the PD design variations investigated here. At a fixed width ("X") of the SiN pedestal, which is used for self-aligned doping and thus controls the PD depletion layer width, three basic designs were realized: 1) PDs with equally wide n^+ and p^+ doped Ge regions where each of which is ~2 times wider than "X" (left). 2) PDs with equally wide doped Ge regions where each of which is much narrower than "X" (center). Width of the doped regions ("Y") was varied here. 3) Asymmetrical diodes with either wide n^+ or wide p^+ doped Ge regions (right).

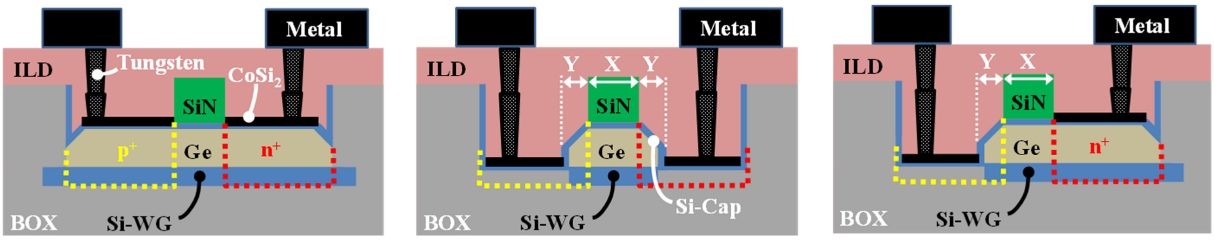

Figure 1: Schematic cross sections of lateral Ge p-i-n photodiodes differing in the width of the doped Ge regions **at a fixed depletion layer width** (controlled by the width of SiN pedestal "X"): Width of equally wide doped Ge regions is either large (left) or small, compared to "X" (center). One of the doped Ge regions is much wider than "X" (right). Cut is perpendicular to the direction of light incidence.

We focus first on the middle structure to study the effect of a stepwise increased enclosure "Y". It is, even for biggest "Y", still 2x smaller than "X". Change of "Y" by design emulates here fabrication-related variations which can result from small width variations of the SiN pedestal and the Si-WG. Figure 2 (left) shows that increasing "Y" deteriorates the OE frequency response behavior. Because 248 nm lithography is used both for defining Si-WG and SiN pedestal, variations in "Y" can well be kept under the 50 nm level where degradation of the response behavior is still weak. Diode I-V and C-V characteristics (Fig. 2, center and right) indicate that the observed "Y" dependency of the frequency response can't result from RC or photo carrier drift effects: Series resistance lowers with increasing "Y", due to increasing $CoSi_2$ coverage [3], and capacitances, i.e. depletion widths do not show any "Y" effect. We thus conclude that only photo carrier diffusion effects can be responsible for the observed response behavior.

Next, we compare the behavior of a PD with narrow doped Ge regions (Fig. 2, center, std. "Y") with that of the other designs depicted in fig. 1. Big differences in the response behavior can be seen (Fig. 3, left), which also can only result from photo carrier diffusion effects (see Fig. 3, center and right). First, we see that response degradation continues when "Y" becomes a multiple of "X" (Fig. 3, left, black vs. blue). Interesting is the behavior of the asymmetrical diodes, where widening of n^+ Ge regions much more degrades the response behavior than widening the p^+ side (Fig. 3, left, black vs. red and green, resp.). It indicates that holes diffusion in the n-doped Ge region has much more influence than diffusion of electrons on the other side. Also catches the eye that the asymmetrical diode with wide n^+ region behaves worse than the PD with equally wide doped Ge regions (Fig. 3, left, red vs. blue). This effect and the “Y”-dependency of frequency response can be understood when one considers that increasing “Y” or making diodes asymmetrical changes the ratio between carrier generation in high-field and non-depleted Ge regions.

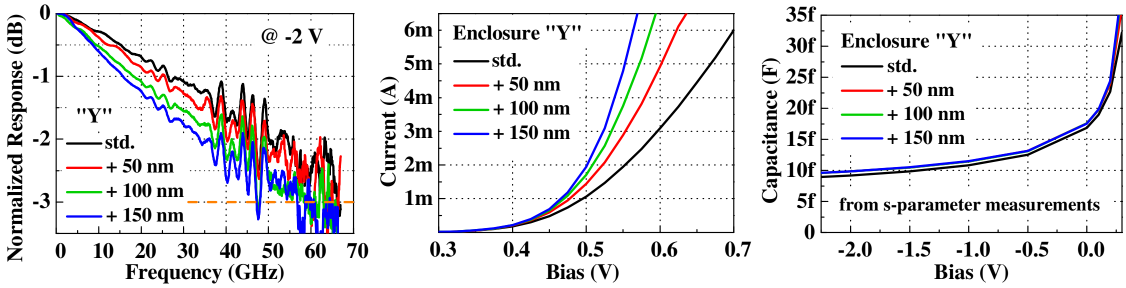

Figure 2: Normalized OE response vs. frequency (left), forward I-V (center) and C-V characteristics (right) for Ge-PD differing in “Y”.

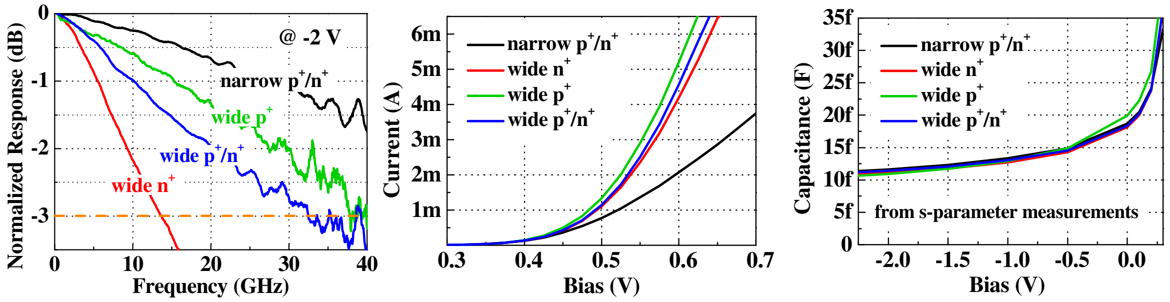

Figure 3: Normalized OE response vs. frequency (left), forward I-V (center) and C-V characteristics (right) for Ge-PD with narrow p^+ and n^+ doped Ge regions (Fig. 1, center), wide p^+ and n^+ doped Ge regions (Fig.1, left), and either wide n^+ or p^+ Ge regions (Fig. 1, right).

SUMMARY

Design effects on the OE frequency response of high speed lateral p-i-n Ge photodiode have been presented, pointing out the importance of a proper layout. Further, our results clearly indicate the importance of a separate treatment of the photo carrier diffusion contribution for both carrier types and of weighting photo carrier generation in high-field and non-depleted Ge regions in a photodiode equivalent circuit model.

ACKNOWLEDGEMENT

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