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Modeling the frequency response of vertical and lateral Ge-on-Si waveguide photodetectors: Is 3D simulation unavoidable?

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Abstract: Using a 3D multiphysics model as a reference, we investigate the achievements and limitations of a simpler 2D drift-diffusion model to reproduce and optimize the electrooptical frequency response of vertical and lateral Ge-on-Si waveguide photodetectors.
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1. Introduction

Recent works on Ge-on-Si *pin* waveguide photodetectors (WPDs) based on vertical and lateral heterojunctions [1–3] have reported electrooptic cutoff frequencies well above 50 GHz, and in [4] the use of a finFET-inspired fabrication process has allowed to demonstrate a cutoff value larger than 240 GHz. In order to exploit the full potential of Ge-on-Si WPDs, an efficient physics-based simulation framework allowing a rapid exploration of the parameter space would be instrumental. Our modeling activity on vertical Ge/Si WPDs [5, 6] has already demonstrated encouraging agreement between measurements and 3D multiphysics simulations [7, 8]. Here, using our 3D model as a reference, we explore the encouraging results of a simplified 2D simulation approach, first showing the good match (at low input optical power) between 3D and 2D results for vertical WPDs, and then extending the application of the 2D model to lateral devices, leading to electrooptic responses very close to the measurements reported in [4].

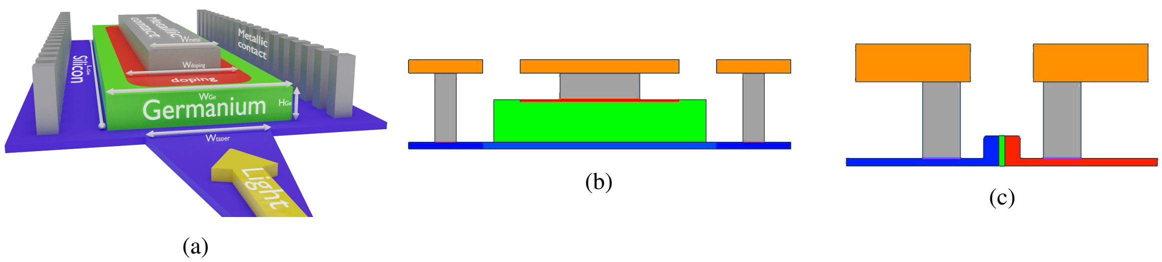
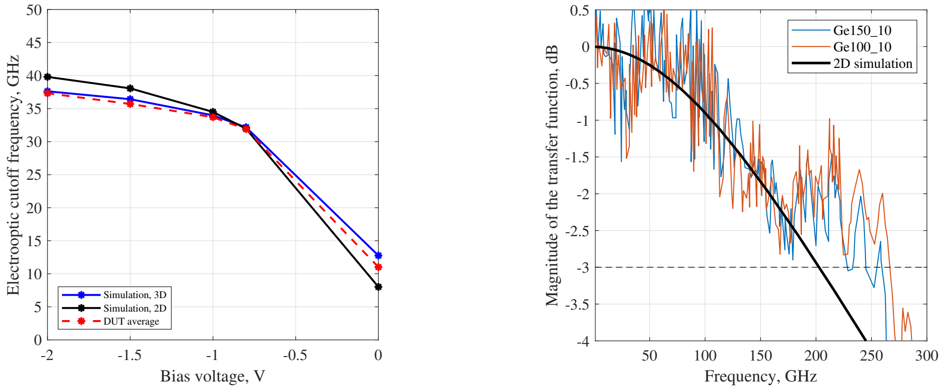


Fig. 1: (a) 3D perspective view and (b) 2D transverse cross section of the reference Ge/Si vertical WPD in [8]; (c) cross section of a lateral Si/Ge/Si WPD based on [4]. The Ge absorber is green, while red and blue are used for *n*-type and *p*-type regions, respectively. Tungsten is used for the metallic contacts, with a Cu layer on top.

2. Model

In [8], our reference 3D multiphysics model has been validated against electro-optical measurements of different Ge/Si vertical WPDs. The present work attempts a drastic simplification by replacing the full 3D structure with a 2D transverse cross-section. This choice still allows a detailed description of the doping profiles and of the material composition; the model includes the carrier transport equations [6], while the finite-difference time-domain optical simulation is supplanted by a uniform optical generation rate in the Ge region, corresponding to the peak value along the longitudinal direction of the 3D-simulated generation rate averaged across the WPD cross-section (see e.g. [8, Fig. 3]). The 2D model can be used to study the behavior of both vertical and lateral devices, with a decrease of the computation time from several hours to a few seconds for each simulation.



(a) (b)

Fig. 2: (a) Measurements and simulations (both 3D and 2D) of the cutoff frequency for the reference Ge/Si vertical WPD in [8]; (b) measured and 2D-simulated electrooptical response of a lateral Si/Ge/Si WPD based on [4].

3. Results and outlook

Figure (2a) reports the electrooptic cutoff frequency as a function of the applied bias for the vertical WPD studied in [7], showing an excellent agreement with both experiments and 3D simulations. Also when applied to the lateral devices presented in [4], the 2D model predicts a cutoff frequency above 200 GHz, very close to the experimental values, see Figure (2b). The proposed approach should allow a significant speed-up of the optimization time for both vertical and lateral WPDs with uniform longitudinal cross section, by allowing to study the effects of the details of transverse geometry and doping profiles that do not affect significantly the longitudinal distribution of photogenerated carriers.

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