Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research A 583 (2007) 149–152
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Electro-optical measurements of 3D-stc detectors fabricated at ITC-irst

Andrea Zoboli[a,*], Maurizio Boscardin[b], Luciano Bosisio[c], Gian-Franco Dalla Betta[a], Claudio Piemonte[b], Alberto Pozza[b], Sabina Ronchin[b], Nicola Zorzi[b]

[a] *INFN and Department of ICT, University of Trento, via Sommarive, 14 - 38050 Povo di Trento, Italy*
[b] *ITC-irst, Microsystems Division, via Sommarive, 18 - 38050 Povo di Trento, Italy*
[c] *INFN and Department of Physics, University of Trieste, via A. Valerio, 2 - 34127 Trieste, Italy*

Available online 1 September 2007

Abstract

In the past two years 3D silicon radiation detectors have been developed at ITC-irst (Trento, Italy). As a first step toward full 3D devices, simplified structures featuring columnar electrodes of one doping type only were fabricated. This paper reports the electro-optical characterization of 3D test diodes made with this approach. Experimental results and TCAD simulations provide good insight into the charge collection mechanism and response speed limitation of these structures.

PACS: 29.40.Gx; 29.40.Wk; 85.30.Kk; 85.40.Bh; 85.60.Dw

Keywords: Radiation detectors; 3D silicon detectors; Device modeling

1. Introduction

A new architecture of silicon radiation detectors, usually referred to as 3D detectors, was proposed by Parker et al. in 1997 [1]. These sensors feature columnar electrodes of both doping types penetrating through the substrate, so that low depletion voltages and fast charge collection times can be achieved by properly choosing the inter-column pitch, while maintaining a standard wafer thickness (which corresponds to the active depth). As a result, these detectors are more radiation hard than planar detectors and represent a promising solution for future particle physics experiments, e.g., super-LHC, for which fast hadron fluences of about $10^{16}\,cm^{-2}$ are foreseen in the inner part of the silicon trackers [2]. Unfortunately, 3D detectors require a rather challenging fabrication process, involving micromachining technology, which could be a problem for the large scale production of such detectors.

In the past two years, 3D detectors have been developed at ITC-irst (Trento, Italy) in the framework of an R&D program supported by the Italian National Institute for Nuclear Physics. In particular, a slightly different version of 3D detectors (called 3D-stc), having electrodes of one doping type only (namely, n-type columns in a p-type high-resistivity silicon substrate) which are not etched all through the substrate, were fabricated and tested. The obvious advantage is a simplified fabrication process. The drawback is that, once full depletion between columns is reached, the electric field cannot be increased further by increasing the bias voltage [3]. As a result, wider low-field regions are present with respect to standard 3D detectors, possibly affecting the charge collection properties. Nevertheless, these devices are a useful test vehicle to study the critical steps of the technology and the basic electrical characteristics.

This work reports the electro-optical characterization of 3D-stc diodes aimed at investigating the response speed and the charge collection efficiency. Measurements are compared to numerical device simulations, providing good insight into the detector operation.

2. Device description

Experimental results reported in this paper are relevant to 3D-stc test diodes fabricated at ITC-irst on p-type

*Corresponding author.
E-mail address: zoboli@dit.unitn.it (A. Zoboli).

0168-9002/$ - see front matter
doi:10.1016/j.nima.2007.08.227

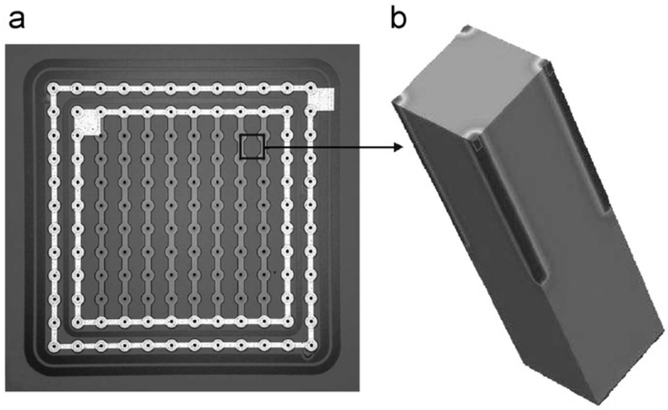

Fig. 1. (a) Photograph of a 3D diode and (b) 3D view of the simulated cell.

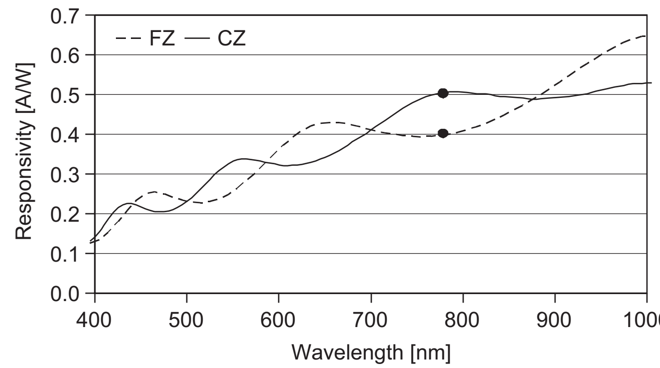

Fig. 2. The 3D-stc diode spectral responsivity at 15 V reverse bias.

high-resistivity silicon substrates from two ingots: Czochralsky (CZ) wafers, 300 μm thick, and Float Zone (FZ) wafers, 500 μm thick. The substrate doping concentration is approximately $2 \times 10^{12}\,\mathrm{cm}^{-3}$ for both CZ and FZ wafers.

The 3D diodes (see Fig. 1a) are made of a matrix of 10×10 n^+ columnar electrodes, having a 10 μm diameter and a 150 μm depth (hole etching performed at CNM, Barcelona, Spain [4]). All columns are shorted by surface n^+ diffusion and/or metal strips, depending on the details of a particular device. The pitch between columns is 100 μm, so that the active area is $1\,\mathrm{mm}^2$. A 3D guard-ring (square frame of columns) surrounds the diode. Surface isolation between diode and guard-ring and around the guard-ring is provided by p-stop implants. More details on the layout and the fabrication technology can be found in Ref. [5].

In order to gain insight into the detector's dynamic behavior, numerical device simulations have been performed with Synopsys Sentaurus [6]. As explained in Ref. [3], 3D simulations are required for these structures. The simulation domain (see Fig. 1b) is the basic 3D cell composing the diode structure, with dimensions: $(x, y, z) = (100, 100, 300$ or $500\,\mu\mathrm{m})$. In the simulation four n^+ columns are placed one at each corner of the structure, and a p^+ back-side implant is used as an ohmic contact to the p^- substrate.

3. Results and discussion

3.1. Static measurements

Current–voltage and capacitance–voltage measurements in reverse bias have been carried out to check the device quality and to estimate the depletion properties. For both diode types, lateral depletion between the columns was achieved at a voltage of 6–7 V. However, due to different thickness, the CZ device is fully depleted at about 35 V, whereas for the FZ device a full depletion voltage of about 190 V was estimated from the $1/C^2-V$ curve. Such a value could not be measured directly because of early breakdown in the diode at 20 V. As for the leakage current, it was lower than 30 pA at full depletion in the CZ diode, whereas it was in the order of 100 pA at 20 V (before the onset of breakdown) in the FZ diode.

Spectral responsivity measurements in the wavelength range from 400 to 1000 nm (with 5 nm steps) have been performed at different voltages. The optical power curve at different wavelength has been determined by means of a calibrated photodiode. Both for the calibrated photodiode and the device under test, the light spot was entirely focused onto the active area. As an example, Fig. 2 shows the responsivity at a reverse bias of 15 V. Oscillations in the curves are due to light interference in the surface passivation layers (SiO_2 and Si_3N_4). Different positions of peaks and valleys are observed for the two diode types because of the different thickness of the passivation layers. In particular, at 780 nm, i.e., the wavelength of the laser used for dynamic tests, the responsivity of the CZ diode was higher than that of the FZ one by about 20%. It should also be noted that no bias effect has been observed in these static measurements: because of the good substrate quality in terms of recombination lifetime, an effective charge collection also from the undepleted portions of the device is obtained.

3.2. Dynamic measurements

TCT[1] measurements have been performed with an infrared pulsed laser of 780 nm wavelength, for which the absorption length in silicon is about 10 μm. The pulse duration was 6 ns at a frequency of 100 Hz, and the beam was collimated onto an area of approximately $0.5\,\mathrm{mm}^2$, so that half of the active area was illuminated. The circuit used to drive the laser was operated to yield a maximum power of about 2 mW. The detector was connected to a transimpedance amplifier, having a gain of 2500 V/A and a bandwidth larger than 3 GHz. The output of the amplifier was monitored with a digital oscilloscope. The system was placed inside an aluminium box to shield it from

[1]Transient Current Technique.