iWoRiD 2022
23rd International Workshop on Radiation Imaging Detectors
26 – 30 June 2022
Riva del Garda, Italy

Contribution ID: **110** Type: **Oral**

3D integration approaches for Silicon Photomultipliers: from backside-illuminated to Through Silicon Via interconnections

Tuesday 28 June 2022 10:00 (20 minutes)

Silicon Photomultipliers (SiPMs) are Geiger-mode photodetectors largely used in scientific experiments of high energy physics as well as in medical imaging. Recently, SiPMs are also being considered the detectors of choice for autonomous driving based on light detection and ranging (LiDAR) systems [1].
In the last few years, Fondazione Bruno Kessler (FBK) has been working on the development of new 3D integration approaches for SiPMs, by using backside-illuminated (BSI) devices and Through Silicon Via (TSV) interconnections, to improve both performances and functionalities. To increase the photon detection efficiency (PDE) of the device and at the same time enable a direct 3D integration with the read-out electronics, FBK is developing two different technological approaches for near-infrared (NIR) and near and vacuum ultraviolet (NUV/VUV) light detection, respectively.
A BSI-SiPM design offers three principal advantages compared to the Frontside-illuminated (FSI) scheme: i) an enhancement of the fill factor (FF) of the single-photon avalanche diode (SPAD) to almost 100% because all the reflective and absorbing components (metal, quenching resistor) remain on the front side; ii) a possible light-trapping for NIR photons because the photons are reflected back and forth in the thin silicon layer and iii) high-segmentation access to SiPM output directly from the front-side (see Figure 1 a).
The same BSI approach used for NIR detection is not suitable for NUV/VUV light detection, since i) the carrier glass and the adhesive material used for wafer bonding are not transparent to wavelengths lower than 380 nm and ii) most NUV/VUV photons interact with the first tens of nanometers of the silicon. Therefore, our approach for FSI SiPM exploits the so-called "bulk-TSV"Via-Last. This TSV technology uses a portion of the silicon substrate as a conductive material, instead of metals, taking the advantage that most of the SiPM substrate is highly doped, except a few microns of an epitaxial layer. The silicon volume acting as a conductive interconnection is insulated by the rest of the bulk wafer using deep trenches filled with a dielectric material.
Experimental
The process flow of BSI SiPM for NIR starts with the fabrication of SiPM based on the conventional FBK SiPM-HD technology [2,3]. When the front-end is completed, the wafer is temporary bonded to a handling wafer. The device wafer is then thinned down to about 10 µm, i.e. a few µm larger than the nominal epi-layer thickness and the entrance window is fabricated on the backside. To make available the frontside contacts for the subsequent integration and, at the same time, provide mechanical stability to the structure, a glass support wafer (transparent to NIR photons) is permanently bonded to the backside and the handle wafer is debonded. The final device can work in both BSI and FSI configurations as shown in Figure 1 a).
On the other hand, the process flow of the NUV/VUV SiPM with TSV interconnections starts with the conventional FSI SiPM (with an optimized antireflective coating and passivation specific for NUV/VUV photons) [4]. Then, the wafer is temporary bonded to a glass carrier and thinned down to 150 µm. Subsequently, fully pass-through trenches are realized from the backside and filled with a dielectric material. Finally, the device wafer is debonded from the carrier glass, obtaining a SiPM with the contacts on the back and illuminated from the front. In this scenario, the 3D integration density is limited by the TSV dimensions (about 100 µm).
Results
FBK has been able to successfully fabricate and characterize the first batch of BSI-SiPM for NIR photon detection. The electrical characterization showed about 90% yield on the ultra-thinned wafers with a similar breakdown voltage and dark current compared to non-thinned wafers, proving that the thinning process it-

self does not degrade the electrical and noise performance. Using a hollow PCB, the PDE at 900 nm was measured on both configurations for the same chip and also compared with a SiPM device with a metal reflector on the front side, covering most of the active area. As shown in Figure 2, the last-mentioned device shows the highest PDE for every overvoltage mainly due to an effective light trapping mechanism.
Regarding the process fabrication of SiPM for NUV/VUV, results are promising: the first tests have shown proper electrical isolation of the TSV, as shown in the SEM image of Figure 1 b). Furthermore, the Front-end-of-line (FEOL) of the first prototypes has been successfully fabricated (as shown in Figure 3).
Conclusions
The first demonstrator of BSI SiPM for NIR photon detection has been developed at FBK. Compared to the FSI technology, the BSI sensors with metal reflectors show a clear increase in PDE at 900 nm. Ongoing work on the development of SiPMs for the detection of NUV/VUV photons is addressed by taking advantage of silicon bulk-TSV interconnections. We expect that the preliminary electrical and functional results will be available in the following months to be presented at the conference.
Bibliography
[1] R. Agishev et al., (2013).
[2] A. Gola et al., Sensors (Switzerland) 19 (2019).
[3] C. Piemonte et al., IEEE Trans. Electron Devices 63 (2016) 111-1116.
[4] M. Capasso et al., Nucl. Instruments Methods Phys., Detect. Assoc. Equip. 982 (2020) 1-4.

Primary author: PARELLADA MONREAL, Laura (Fondazione Bruno Kessler)

Co-authors: Dr ACERBI, Fabio (Fondazione Bruno Kessler); Mr FRANZOI, Alberto (INFN); Dr RUZARRIN, Maria (Fondazione Bruno Kessler); Dr GOLA, Alberto (Fondazione Bruno Kessler); Dr NAWAZ, Ali (Fondazione Bruno Kessler); Dr MERZI, Stefano (Fondazione Bruno Kessler); Dr FICORELLA, Andrea (Fondazione Bruno Kessler); Dr PATERNOSTER, Giovanni (Fondazione Bruno Kessler)

Presenter: PARELLADA MONREAL, Laura (Fondazione Bruno Kessler)

Session Classification: Sensors