Investigation of a novel zinc-diffusion process for the fabrication of InGaAs/InP single-photon avalanche diodes

Fraunhofer IAF

A. Wörl, F. Rutz, A. Bächle, J. Niemasz, and R. Rehm
Fraunhofer Institute for Applied Solid State Physics IAF,
Tullastrasse 72, 79108 Freiburg, Germany

P2.07

SWIR active imaging

Active imaging systems in the short-wave infrared (SWIR) have several advantages compared to their counterpart in the visible or near-infrared spectral range due to lower scattering losses and the availability of powerful, yet eye-safe lasers at 1550 nm. Further development of SWIR detector arrays down to single-photon level is however still an ongoing task. Funded within the European project ENLIGHTEN Fraunhofer IAF develops the technology for InGaAs/InP single-photon avalanche diodes (SPADs) and fabricates SPAD arrays for Non-Line-Of-Sight (NLOS) imaging applications (Fig. 1).

Fig. 1: Potential application for NLOS-imaging in the SWIR.

SPAD technology: Zinc-diffusion process development

- Important for fabrication
  - Confinement of high E-Field within active area
  - Planar process with double-well diffusion profile
- Zn-diffusion technology
  - Selective-area epitaxial overgrowth
  - Back-diffusion of Zn into underlying material (Fig. 2, left)
  - 2-step epitaxial overgrowth (Fig. 2, right)
  - Recess etch then 1-step epitaxial overgrowth (Fig. 3 & 4)

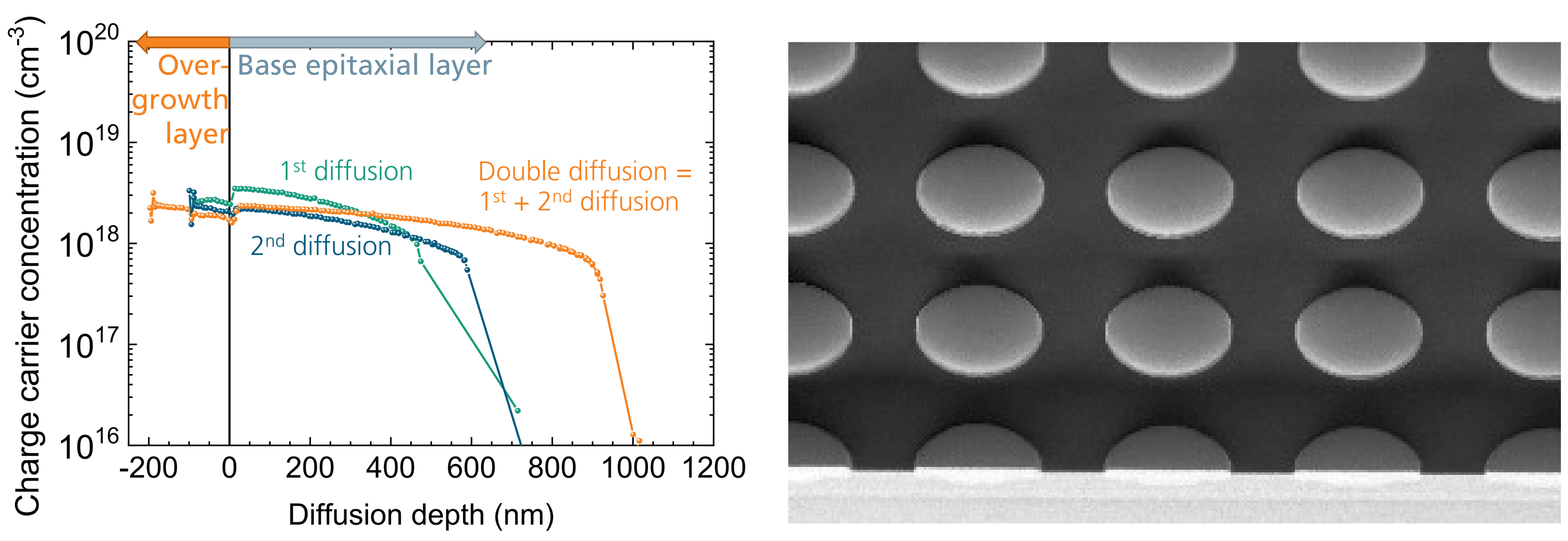

Fig. 2: Zn-diffusion depth analysis derived from ECV measurements (left) and SEM-image of a cross-sectionally cleaved part of a SPAD array fabricated via 2-step epitaxial overgrowth (right).

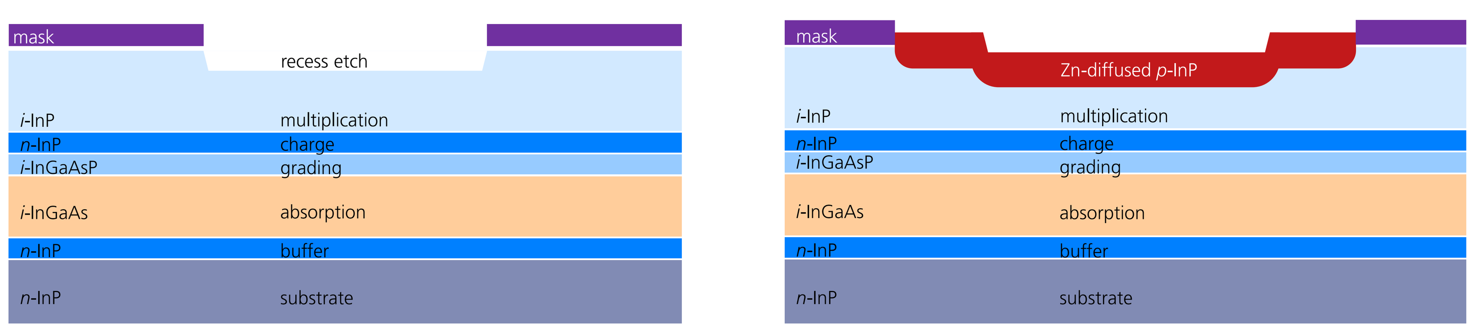

Fig. 3: Schematic of an InGaAs/InP SPAD after recess etch (left) and after 1-step epitaxial overgrowth for Zn-diffusion (right).

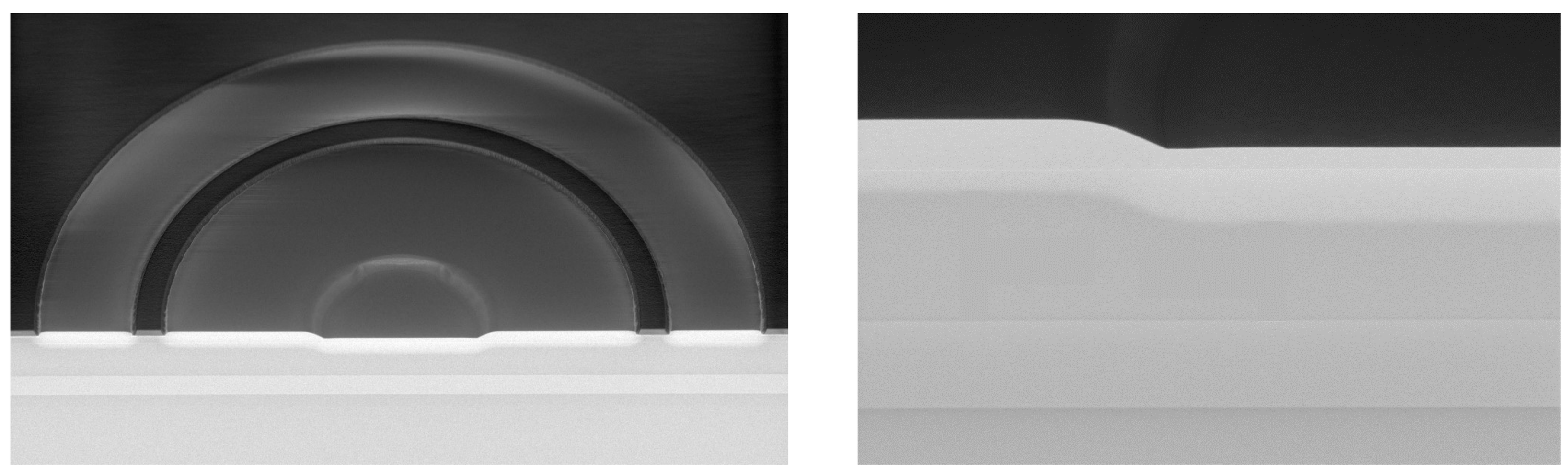

Fig. 4: SEM-image of a cross-sectionally cleaved InGaAs/InP SPAD with FGR (left) and a zoom-in to highlight the Zn-diffused double-well profile (right).

Device characterization: Proof-of-Concept

The dark count rate (DCR) over excess bias voltage and the spectral quantum efficiency below breakdown at unified gain of an exemplary detector demonstrate the suitability for active imaging at 1550 nm, and, as a proof-of-concept, the ability to operate the InGaAs/InP SPADs in Geiger mode beyond breakdown (see Fig. 5).
Next steps are the optimization of SPAD devices regarding geometry and doping levels.

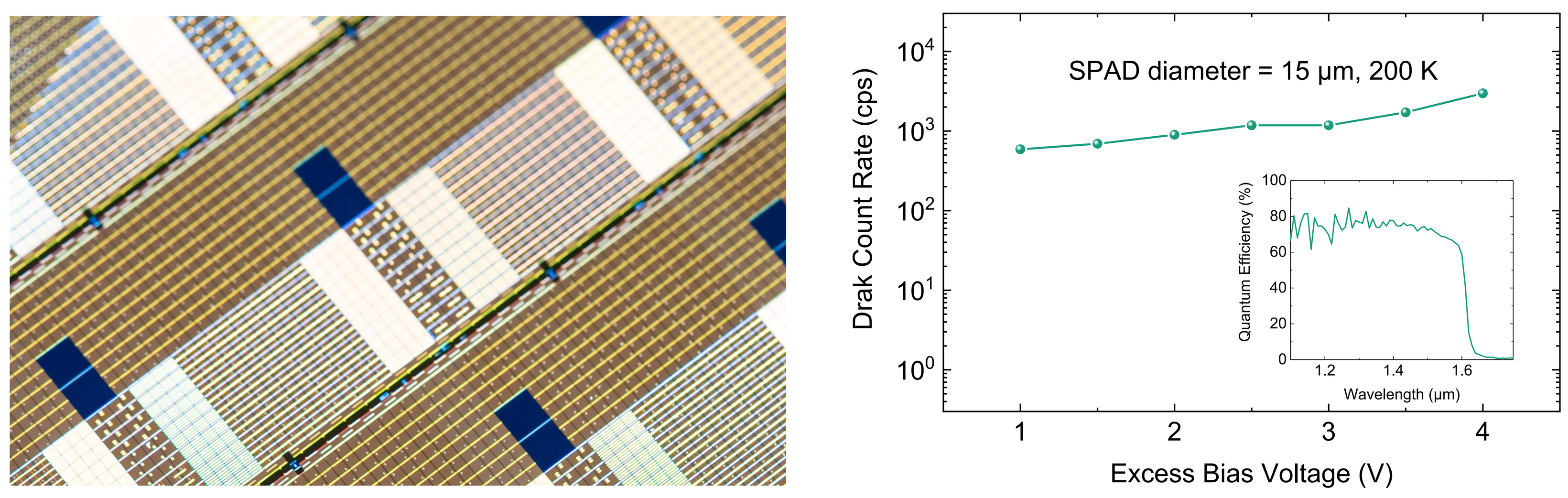

Fig. 5: Close-up of a 3-inch InGaAs/InP SPAD wafer (left) and DCR over excess bias voltage with QE over wavelength at unity gain inserted (right).

Advantages of the novel Zn-diffusion process

- Prevention of unwanted Zn contamination in MOCVD
- Faster and more stable process runs
- Well-defined difference in diffusion depths

Contact

Andreas Wörl, Fraunhofer IAF, Optoelectronics,
andreas.woerl@iaf.fraunhofer.de

ENLIGHTEN
»European Non-Line-of-Sight Optical Imaging« *ENLIGHTEN*, EDF project 101103242.

Co-funded by the European Union

Federal Ministry of Defence