Back-side Illuminated PDs

Thinned and Back-side Illuminated Silicon Photodiodes

Wafers with PREMA Photodiodes consisting of pn-junctions close to the upper surface have been back-grinded to 20 µm, 35 µm, 60 µm and 100 µm. The spectral sensitivity of singulated photodiodes was measured with back-side illumination. Related to the thickness of the photodiodes, a shift of the spectral sensitivity to longer wavelengths was found. The spectral sensitivity has been increased by a metal cap above the photodiodes. Here, photons that have not been absorbed are reflected.

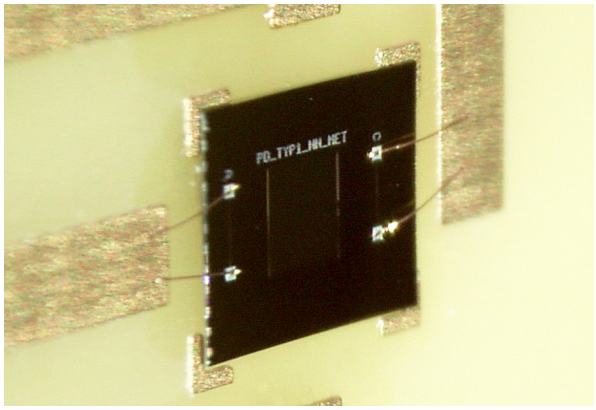
FEATURES

- Photodiodes with different thicknesses
- Varied spectral responsibility
- Additional metal cap for light reflexion
- Efficiency is only reduced to about 35 %

APPLICATIONS

- Retina Implant
- Photodiode-Arrays

COB-PHOTODIODE



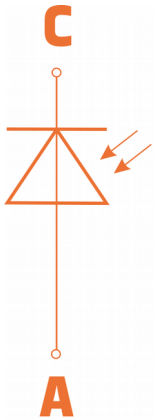
Note: For back-side illumination, the PCB has a hole underneath the die

KEY CHARACTERISTICS

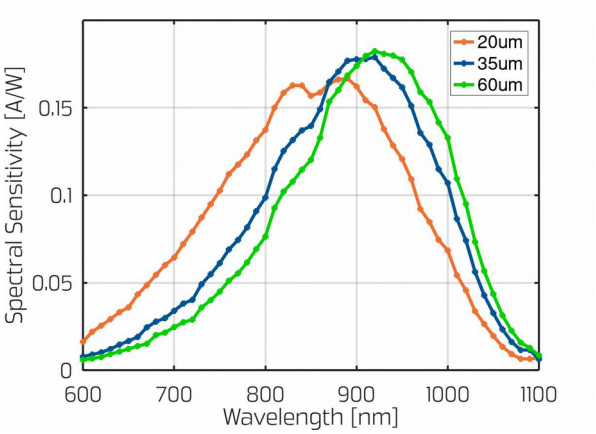
Parameter	Typ.	Unit
Die size*	2,0 x 3,2	mm^2
Photodiode size*	1,0 x 1,5	mm^2
Peak wavelength	820-950	nm
Peak sensitivity	0,18	A/W
Dark current @ 40°C / Vr = 1 V	< 0,1	nA
Capacitance @ Vr = 2 V	120	pF

* sizes can be changed for individual applications

CIRCUIT



SPECTRAL SENSITIVITY

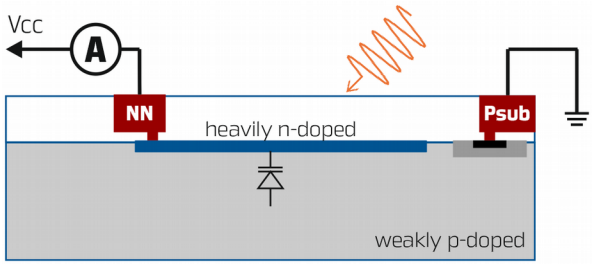


Thinned and back-side illuminated photodiodes with metal cap (thicknesses as given in the explanation)

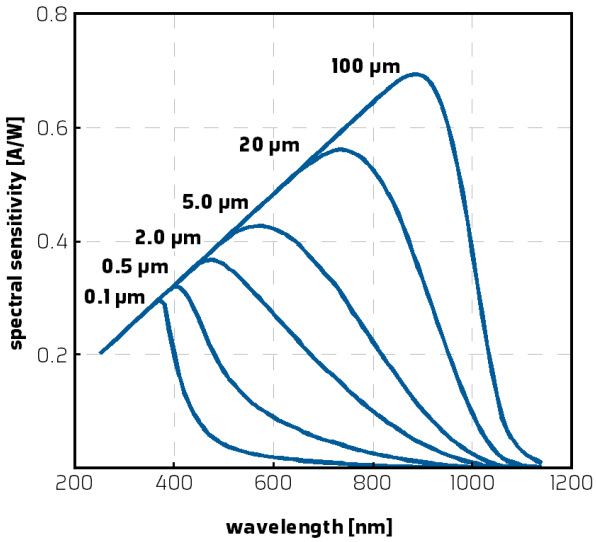
Back-side Illuminated PDs

Introduction - Front-side Illumination

PENETRATION DEPTH OF PHOTONS



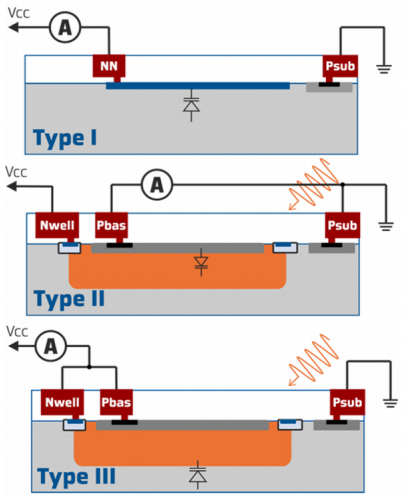
Using PREMA Photodiodes, the major light absorption happens in weakly p-doped silicon. Here, an indirect bandgap of 1.1 eV is utilized. Therefore, light with wavelengths less than ~1135 nm is able to generate electron-hole pairs. The probability of a photon to be absorbed depends on the wavelength of the photon. Photons with longer wavelengths can penetrate deeper into the silicon. Here, the diagram shows the calculated spectral sensitivity for several absorption thicknesses.



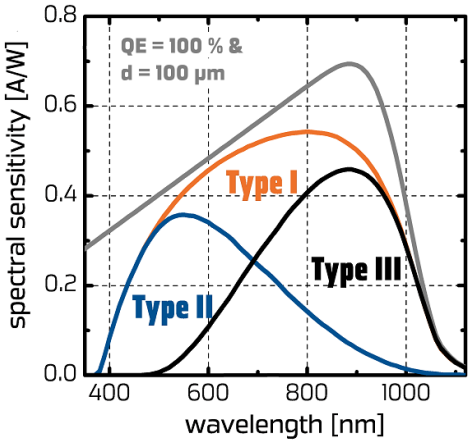
Whereas the absorption of the ultraviolet light already happens in the initial tenths of microns, there is a wide range of thicknesses still exhibiting significant variations in the spectral absorption.

PREMA PHOTODIODES

The PREMA fabrication process allows to combine photodiodes with integrated circuits on the same die.



Using a low energy implantation process, the Type I photodiode has a spectral response as given in the diagram (orange). Next to the implementation of a simple pn-junctions a used for Type I photodiodes, the PREMA wafer fab also includes a high ion implantation process to generate n-doped wells. Using the n-doped well to collect photo-electrons either within or below the well gives the two varied spectral sensitivities of the Type II (blue) and Type III (black) photodiodes, respectively. Please note that the structure of Type II and III is identical. Therefore, the PREMA process allows to fabricate a single photodiode with two different spectral sensitivities utilizing the wavelength dependence of light absorption in silicon.



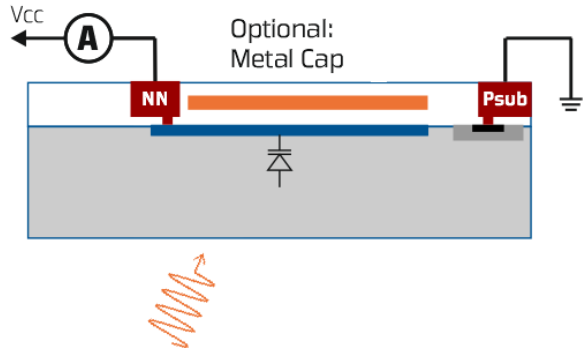
Back-side Illuminated PDs

Back-side Illumination

CROSS SECTION

Wafers with Type I Photodiodes were fabricated in the PREMA wafer fab. Two different versions were made with variations in the backend:

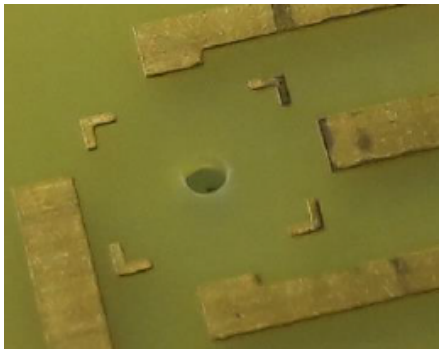
1. with metal cap (orange)
2. with passivation layer



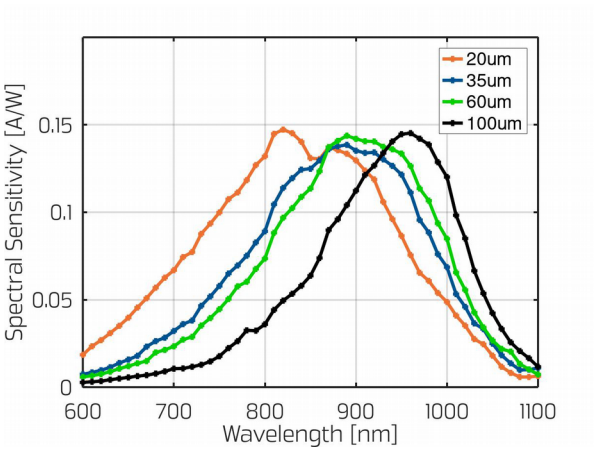
In addition to the passivation layer, an isolated metal layer is deposited over the photodiode to reflect photons that have not been absorbed while passing the thinned silicon. Photons are reflected back, towards the pn-junction. Therefore, the absorption length for photodiodes with a metal cap is about twice as long. 4 wafers were back grinded to the following thicknesses:

- 20 µm
- 35 µm
- 60 µm
- 100 µm

After back grinding and singulation the photodiodes were mounted on PCBs with holes below the photodiodes to enable back-side illumination.



SPECTRAL SENSITIVITY WITH PASSIVATION LAYER



As shown in the diagram, the spectral sensitivity of the photodiodes depends on their thickness. With a thickness of only 20 µm, the most sensitive type at short wavelengths has been measured. Here, the pn-junction is the closest to the back-side of the photodiode. Light with even shorter wavelength generate photoelectrons only close to the back-side so that they recombine before reaching the pn-junction. According to the explanation, going to thicker photodiodes the spectral sensitivity is shifted to higher wavelengths.
Because photons with bigger wavelengths are also partially absorbed right after entering the photodiode, the peak height is not increased for thicker samples.
For varied thicknesses, the spectral sensitivity is also different at higher wavelengths. The spectral sensitivity of the photodiode with only 20 µm decreases first because here the most photons are not absorbed. The higher the wavelength, the higher is the probability for a photon to leave the photodiode at the front-side. This probability decreases with the thickness of the photodiodes.
To prevent this effect photodiodes having an isolated metal cap on top of the photodiode are made for comparison. Results are discussed below.

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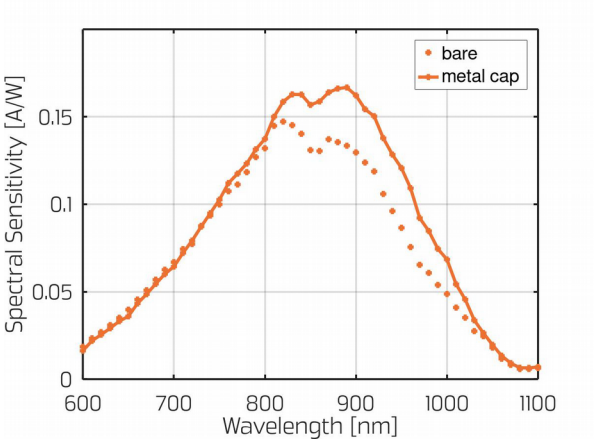
Back-side Illumination – with Metal Cap

SPECTRAL SENSITIVITY WITH METAL CAP

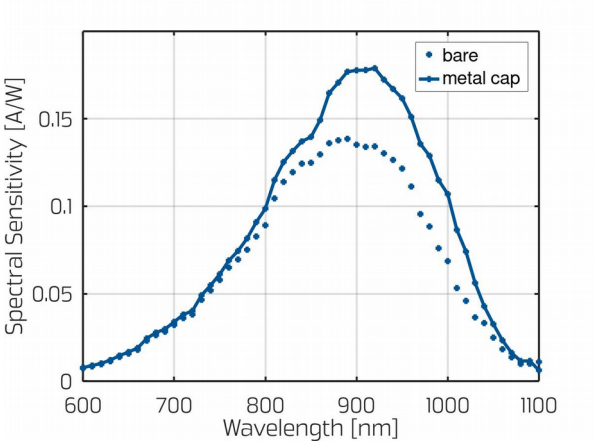
Two different photodiodes have been fabricated. One set of samples is capped by a passivation layer that is also utilized for front-side illuminated photodiodes and labelled as 'bare'. To enhance the spectral sensitivity of back-side illuminated photodiodes a second set of samples additionally capped by an isolated metal is made (labelled as 'metal cap').

Die Thickness: **20 µm**



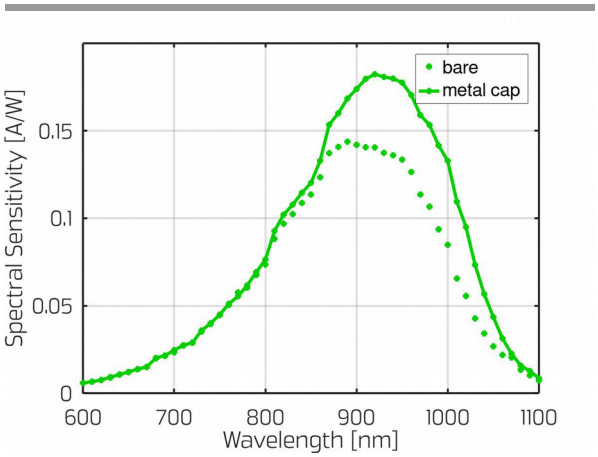
At small wavelengths identical spectral sensitivities are measured for 'bare' and 'metal capped' photodiodes because here all photons are already absorbed and the pn-junction is not reached.
As longer the wavelength as bigger is the probability of the photon to be non-absorbed. In metal capped photodiodes non-absorbed photons are partially reflected at the embedded metal-insulator-interface.

Die Thickness: **35 µm**



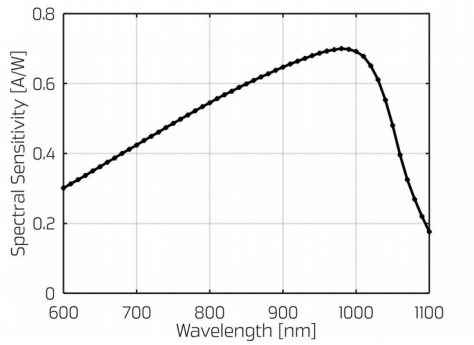
Therefore, the effective volume to detected photoelectrons is enhanced by the metal cap. Compared to 'bare' photodiodes the spectral sensitivity increases further and the maximum is shifted to bigger wavelengths. The described effect is similar for all die thicknesses.

Die Thickness: **60 µm**



REFERENCE PHOTODIODE

The spectral sensitivity of a common front-side illuminated PIN-photodiode is shown. Thereby, for thinned and back-side illuminated photodiodes a reduction of the spectral sensitivity to about 25 % has been found. Compared to identical Type I photodiodes from PREMA but front-side illuminated (see page 2), the spectral sensitivity is only reduced to about 35 %.



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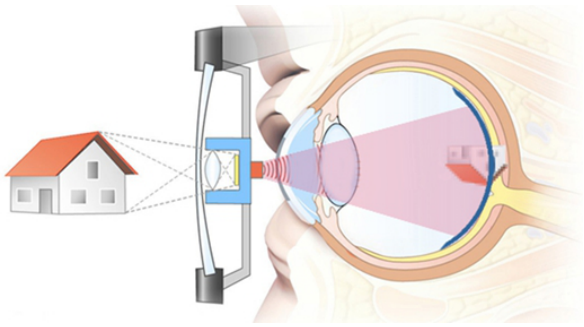
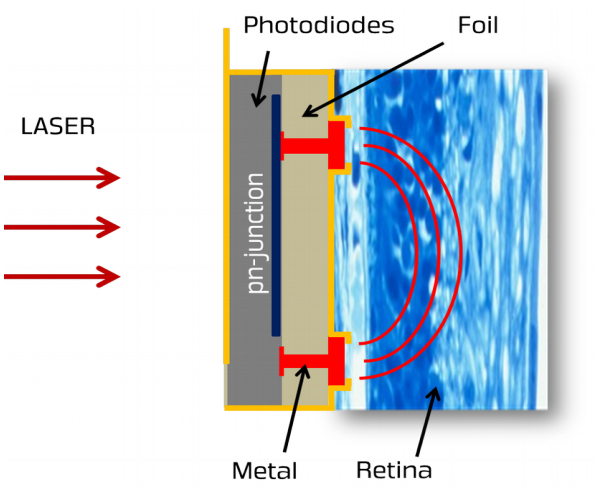
Application

RETINA IMPLANT

For people suffer from Retinitis Pigmentosa a retina implant is developed. Epi-retinal implants replace the functionality of photoreceptors by a direct electrostimulation of the ganglion cells.



As illustrated in the image, the surrounding is received by a camera. The information is transferred by a LASER that emits mono-chromatic light directly into the eye. Using a scanner, a small light spot can be deflected somewhere on the retina implant. Next to information the energy transferred to implant is high enough for electrostimulation. Thus, compared to other techniques here no other external energy supply is needed. Because it is aspired to create a larger visual field, the size of the implant is a lot larger than existing solutions. In total about 5000 photodiodes are connected to a flexible foil that can adapt to the curvature of the eye.



A cross section that has been simplified shows the principle functionality of the implant. Here, a single photodiode is illustrated that is covered by a foil with vias and metal contacts. While the photodiodes are illuminated from the back-side, the electric contacts from the top-side of the wafer can be used.

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