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Systematic electro-optical study of photodiodes in intrinsic material (lowly doped) with backend stack optimization

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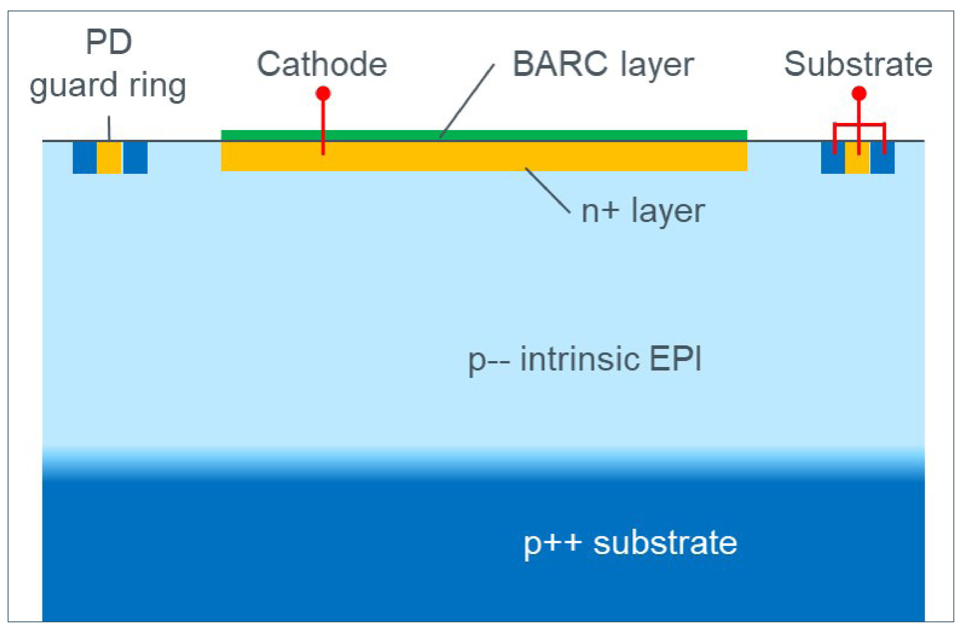
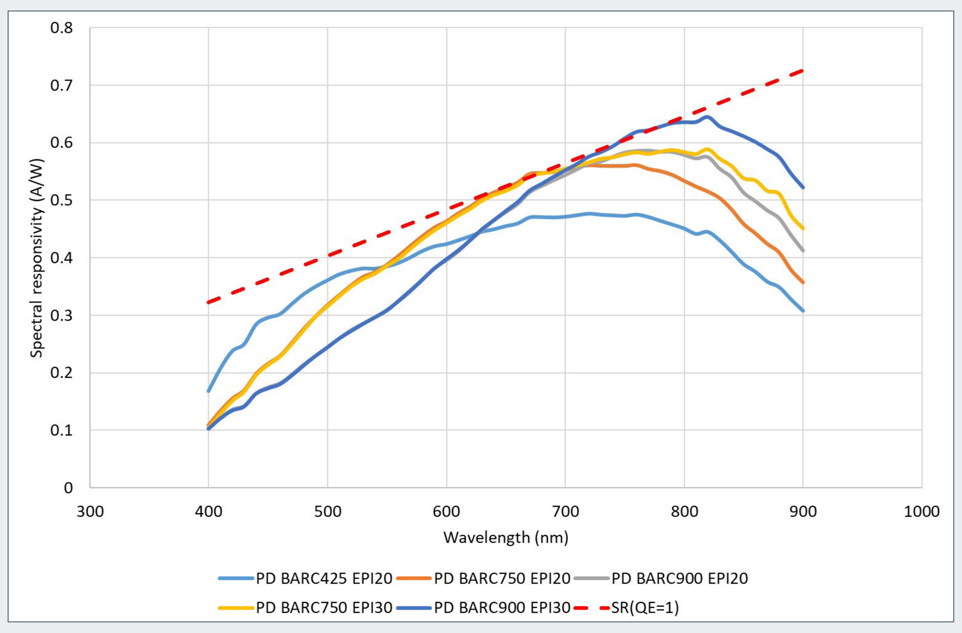
A photodiode is a device based on a p-n junction collecting photocurrent generated in the substrate. The combination of reverse biasing and large depletion area are necessary for improving the quantum efficiency of the photodiode [1] because of the reduction of the transit time of the carriers in the substrate. A way to enlarge the depletion area of the photodiode is the use of low-doped intrinsic material thus forming a PIN photodiode. The low-doped intrinsic material additionally reduces the recombination rate of the photo carriers, thus improving the efficiency of the device. The photodiode can be tuned to be sensitive to specific wavelengths by using appropriate p-n junctions as well as a Bottom Anti-Reflective Coating (BARC) layer of wavelength dependent thickness. The impact of the different intrinsic p-type EPI layer thicknesses and photodiode designs are analyzed with respect to optical and electrical performances of circular and square photodiodes.



PIN photodiode structure

- PIN structure with n+ type well on intrinsic p-- epitaxial layer (iEPI) (400 Ohm.cm)
- Substrate p++ type (10 mOhm.cm)
- PNP guard ring for anode connection and crosstalk reduction
- n+ well with circular shape and various diameters Ø=360µm, up to Ø=1066µm
- n+ well with fixed width square shape (W=200µm) placed in arrays 1x1, 4x4, 7x7 and 11x11
- Bottom Anti-Reflective Coating (BARC) layer optimized for λ=425nm, λ=750nm and λ=900nm wavelengths

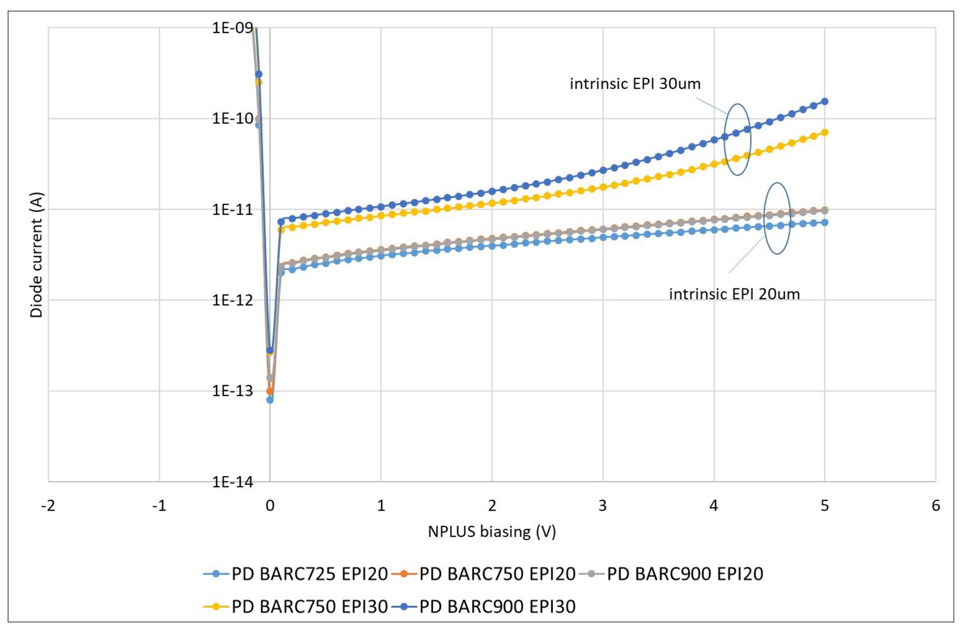


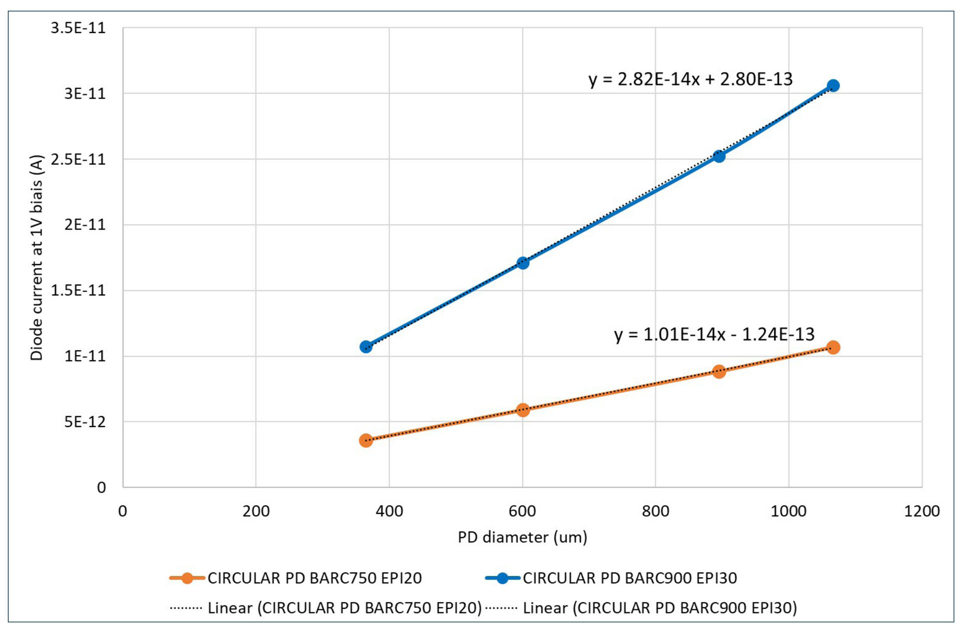
Impact of intrinsic EPI thickness on Photodiode's Spectral Responsivity:

- Increase of near infrared responsivity due to longer silicon absorption depth
- 0.63A/W at 800nm for a 30µm iEPI (0.58A/W for a 20µm iEPI)

Impact of wavelength optimized BARC layer:

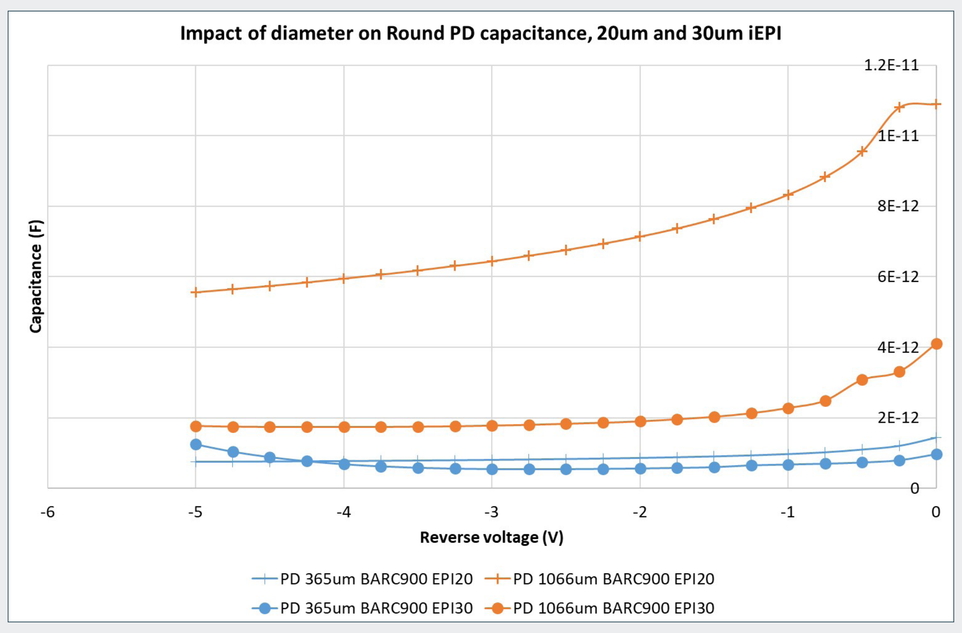
- Quantum Efficiency of 100% for BARC layers optimized for λ=750nm and λ=900nm between 650 nm and 800nm
- Quantum Efficiency of 82% for BARC layer optimized for λ=425nm wavelengths.

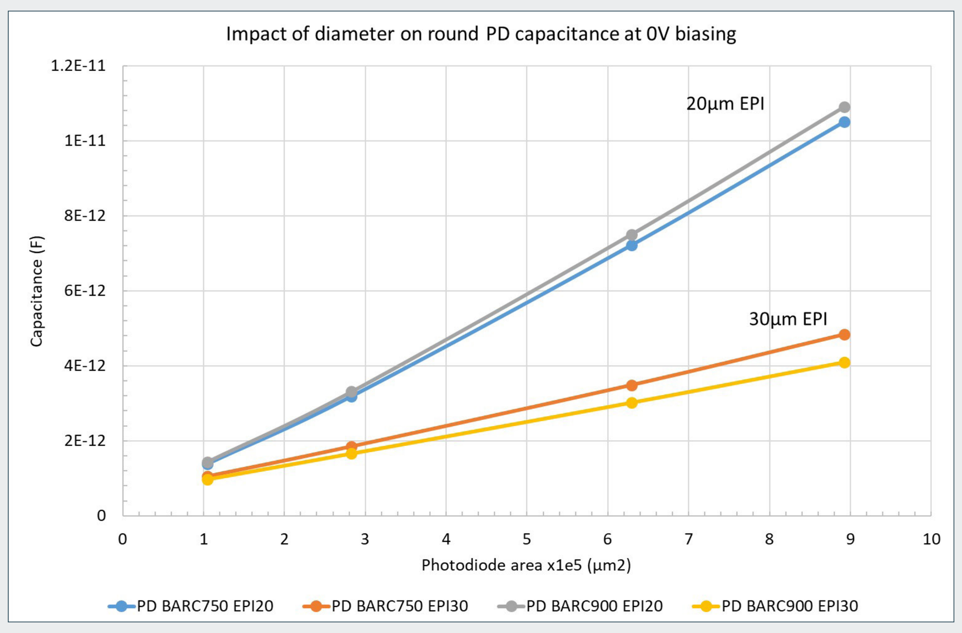




Photodiode Leakage current is a function of:

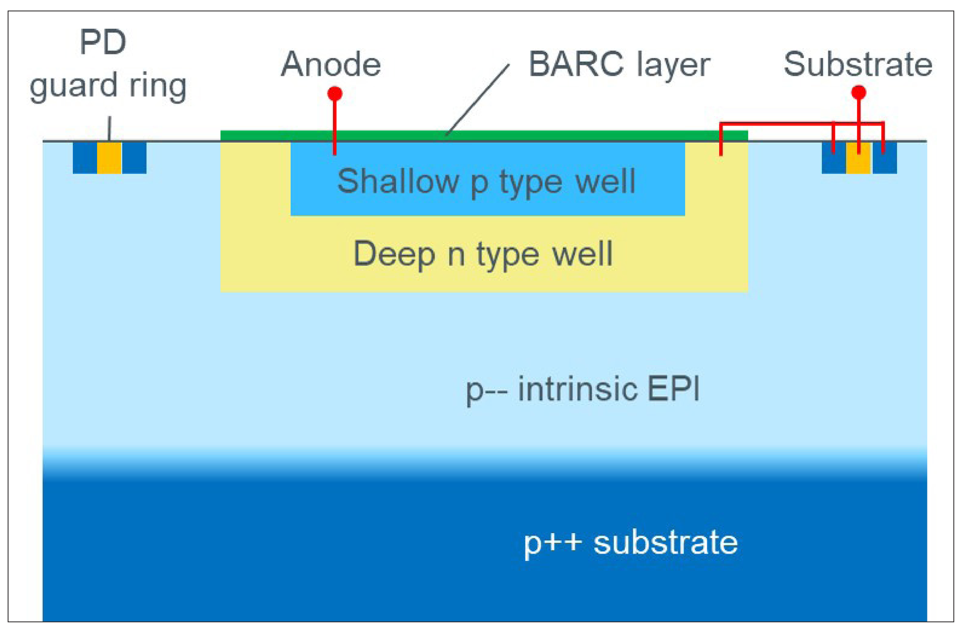
- iEPI thickness and doping due to the extension of space charge width
- Photodiode diameter with a strong correlation to photodiode's perimeter
- Photodiode's distance to the guard ring with space charge reaching n+type contact of guard ring at high bias
- Limited impact of BARC layer deposited

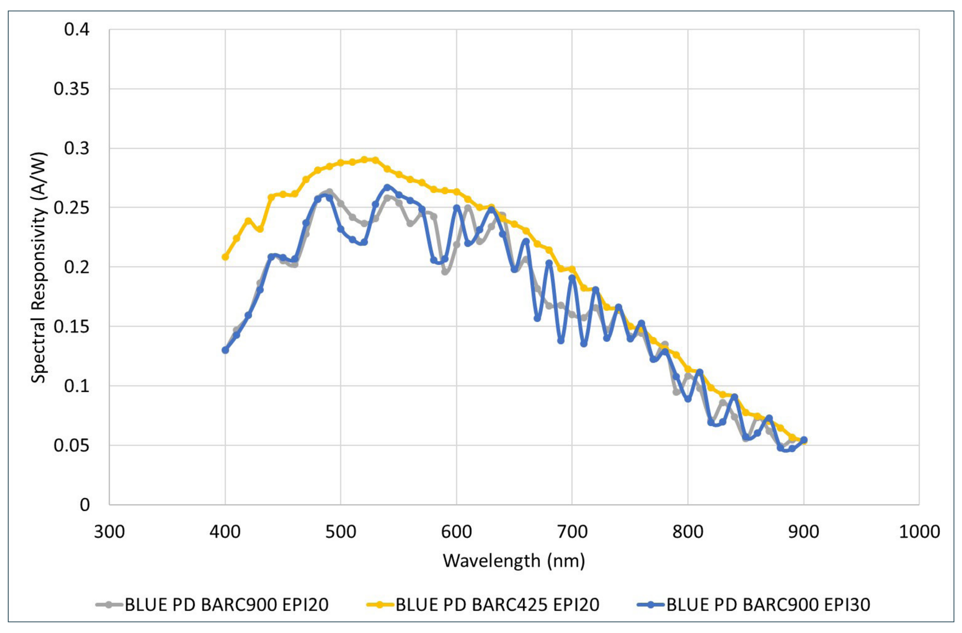




Photodiode Capacitance is a function of:

- iEPI thickness
- Photodiode's surface





Blue wavelengths optimized photodiode structure:

- P+ well in N+ Well shortened to substrate
- PNP guard ring for anode connection and crosstalk reduction
- Photodiodes designed in a square geometry with various widths

Blue wavelengths optimized photodiode Spectral Responsivity:

- No impact of iEPI thickness due to surface collecting layer of photon
- Reduced spectral responsivity in near Infrared wavelengths
- BARC layer optimized at λ=425nm improves photodiode's quantum efficiency

Summary:

In this paper, we have presented the impact of low-doped intrinsic p-type epitaxial (iEPI) thicknesses (20µm and 30µm) and bottom antireflection coating (BARC) on the optical (spectral responsivity) and electrical (leakage current and capacitance) performances of various PIN photodiodes. PIN photodiodes (n+ in intrinsic p- epitaxial layer) reach a spectral responsivity of 0.63A/W and 100% quantum efficiency with the deposition of BARC layers optimized for λ>750nm in combination with 30µm iEPI thickness. The leakage current is larger with thicker iEPI thickness and varies from 3.5pA (20µm iEPI) to 10pA (30µm iEPI) for a circular PIN photodiode (Ø 365µm). Their capacitance is reduced for larger iEPI thickness and varies from 0.97pF (20µm iEPI) to 1.43pF (30µm iEPI). Optimized blue photodiodes are not sensible to iEPI thicknesses and have a leakage current of 10pA for a 150µmx150µm square photodiode.