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"Matching" of Photodetectors Integrated in a 0.18 µm Modular CMOS Foundry Technology

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Summary:
Matching is a design parameter for analog CMOS applications which describes the statistical device differences between pairs of identical designed and used devices [1]. This is common for transistors but not (yet) for photodiodes. Its significant impact on common optical detection tasks is explained related to extracted values from three photodiodes manufactured in the XS018 CMOS technology.

Keywords: Matching, Photodiodes, CMOS, Spectral Response, Dark Current, Capacitance

The Hidden Power

Matching or the synchroneity of devices has the power to make or break the function of an integrated circuit. People carefully check performance parameters but often forget to think about the limitations in the system aspect that are caused by asynchrony of variations between parts. In sensor technology, the most important thing is to extract the signal in the noise. Improved matching reduces the noise, increases the working range, the sensitivity and last but not least the yield.

Description of the Devices and the Test

Exemplarily three typical junction diodes are used for the investigations. *doa* is a deep n-well in p-epi (substrate) with a broad-spectrum response, *dob* is adding an electrically shorted p-well into the deep n-well resulting in a cutoff for the short wavelength. *doa* and *dob* are preferably used as pair when two distinct spectral functions are needed, with little as possible other differences in the device behavior (see Fig. 2 & 3). Finally, *doe* is an n-well in p-epi (substrate) diode with a broad-spectrum response, like *doa*, but with less process effort and the potential of higher fill factor due to simpler layout and tighter design rules.

To cover several use cases, three major layout options have been investigated for each diode.

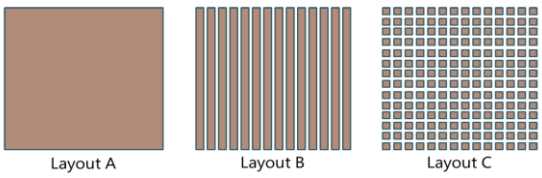

Fig. 1. Investigated layouts. A is a single device, B and C are arrays of devices connected in parallel.

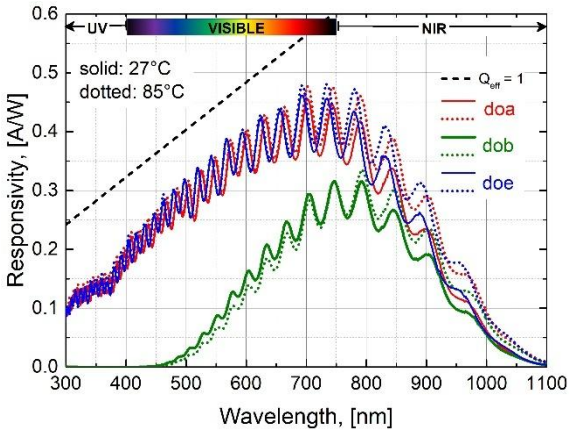

Fig. 2. Spectral response of the devices investigated.

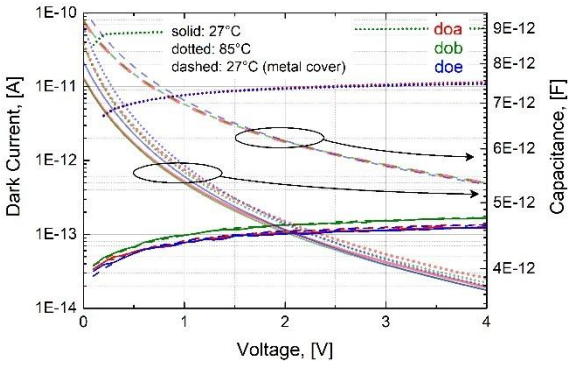

Fig. 3. Dark current and capacitance behavior of 250x250 µm² optical active area devices (Layout A).

For the matching investigations, 174 elements from 3 wafers for each diode pair, respective layout options (see Fig. 1), were tested on two temperatures (27°C and 85°C) for dark current, capacitance and photocurrent at two wavelengths (420 nm & 850 nm), altogether about 50k measurements. This was done using a Keithley S600 with a specialized optical probe card to enable the photocurrent test. The photodiodes were

biased at 0.9 V in reverse and the capacitance was measured at 100 kHz. All photodiodes had a 3.3 V reverse biased guard ring. Parasitic effects of the system and the layout (PAD, wiring) until the DUT (photodiode) have been subtracted using dummy layout elements.

Results and Discussion

Light insensitive (metal covered, here called "blind") photodiodes have a systematic offset of the capacitance caused by the metal plate used to shield the light, which can be compensated. The sigma is excellent. Sigma and mean are stated as percentage relative to the absolute value.

Tab. 1: doa dark current and capacitance matching.

Parameter /Layout		*open/open*		*blind/blind*		*open/blind*	
		sigma	mean	sigma	mean	sigma	mean
Dark Current @ 85°C	A	0.82	0.74	0.51	0.08	1.06	-1.10
	B	0.79	-0.01	0.63	-0.37	1.97	-4.79
	C	0.77	-0.02	0.47	0.11	1.27	-4.02
Capacitance @ 27°C	A	0.19	0.05	0.13	-0.03	0.38	29.27
	B	0.18	0.12	0.16	-0.01	0.20	-3.51
	C	0.19	0.06	0.16	-0.02	0.22	-9.52
Capacitance @ 85°C	A	0.47	0.02	0.40	-0.04	0.51	-28.48
	B	0.48	0.15	0.51	-0.08	0.48	-3.44
	C	0.64	0.09	0.64	-0.04	0.67	-9.47

Dark current measurements require a perfectly dark environment. The noise limit of the measurement equipment and the imperfect darkness require elevated temperatures for reliable results, therefore only the 85°C results are used. The offset (mean) is small, and the sigma below 2.5 % even for the combination of light sensitive (open) and dark reference (blind) showing the significant improvement achieved by [2].

Tab. 2: dob dark current and capacitance matching.

Parameter /Layout		*open/open*		*blind/blind*		*open/blind*	
		sigma	mean	sigma	mean	sigma	mean
Dark Current @ 85°C	A	1.91	-0.11	1.51	0.03	1.45	-0.59
	B	0.62	0.02	0.47	-0.05	1.45	-1.91
	C	0.69	0.37	0.44	0.24	1.29	-0.34
Capacitance @ 27°C	A	0.16	0.05	0.14	-0.03	0.40	-29.20
	B	0.18	0.06	0.17	-0.01	0.20	-3.59
	C	0.19	0.02	0.16	-0.03	0.22	-9.51

Such small sigma for the open to blind pair enables to expand the sensitivity range by 1.5 orders of magnitude. Alternatively, it maintains the sensitivity for up to 50 K higher temperature.

This is due to the usage of the blind device for dark current subtraction which cuts away the noise. It allows omitting cooling measures which are costly, bulky and consume energy. Additionally, the sensor devices can be made smaller because of the higher sensitivity, which saves chip area, improves yield, allows for smaller form factors and most importantly lowers the cost.

Tab. 3: doe dark current and capacitance matching.

Parameter /Layout		*open/open*		*blind/blind*		*open/blind*	
		sigma	mean	sigma	mean	sigma	mean
Dark Current @ 85°C	A	2.06	1.73	2.08	0.27	2.31	-0.88
	B	0.74	0.12	0.57	-0.23	1.91	-4.63
	C	0.70	0.01	0.59	-0.03	1.44	-4.07
Capacitance @ 27°C	A	0.17	-0.01	0.14	-0.03	0.35	-28.77
	B	0.15	0.07	0.18	-0.02	0.22	-3.88
	C	0.20	0.05	0.19	-0.01	0.24	-10.34

The capacitance matching values for 85°C have been left out for dob and doe, as they are redundant information.

Tab. 4: Photocurrent matching at 420 nm.

Parameter /Layout		*doa*		*dob*		*doe*	
		sigma	mean	sigma	mean	sigma	mean
Photocurrent @ 27°C	A	0.29	1.52	-	-	0.27	1.27
	B	0.30	2.24	-	-	0.21	1.13
	C	0.16	1.07	-	-	0.18	0.41
Photocurrent @ 85°C	A	0.23	-0.46	-	-	0.22	-0.66
	B	0.16	0.53	-	-	0.17	-0.56
	C	0.15	0.45	-	-	0.13	-0.76

The photocurrent needs light, thus only the combination open-open makes sense to look at. The photodiode *dob* is insensitive to short wavelength light (see Fig. 2). These values are left blank in table 4 by intention.

Overall, the photocurrent offset is small and the sigma superb with a value below 0.3 %, enabling high precision multi-channel sensors.

Tab. 5: Photocurrent matching at 850 nm.

Parameter /Layout		*doa*		*dob*		*doe*	
		sigma	mean	sigma	mean	sigma	mean
Photocurrent @ 27°C	A	0.20	0.25	0.23	0.40	0.24	1.23
	B	0.29	2.18	0.25	0.74	0.26	1.23
	C	0.21	0.18	0.26	1.07	0.23	0.07
Photocurrent @ 85°C	A	0.15	-1.43	0.21	-0.04	0.24	-0.47
	B	0.17	-0.61	0.24	0.78	0.22	-0.09
	C	0.19	0.03	0.20	0.48	0.20	-0.64

Conclusion and Summary

There is little improvement potential on the signal strength of a silicon photodetector. In contrast lowering the noise level has huge potential. Good matching photodetectors allow pushing the limits by ~1.5 orders of magnitude towards lower light levels or 50 K in temperature, which is a huge step with a lot of practical benefits.

References

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