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# Far UV responsivity of commercial silicon photodetectors

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**Abstract**

Responsivity measurements have been performed on commercial silicon photodetectors in the UV range 200–400 nm. The microstrip and pixel detectors have been reverse biased in fully depleted condition (more than 25 V reverse bias) and in partially depleted condition (5 V reverse bias). We have also performed measurements in back illumination geometry, of particular interest in most industrial applications. Promising results obtained with commercial photodetectors in the UV range in terms of photocurrent stability and sensitivity open a variety of applications. © 2001 Published by Elsevier Science B.V.

*Keywords:* UV; Silicon; Photodetectors; Responsivity; Back-side illumination

## 1. Introduction

Silicon photodetectors are used since 1960. In particular microstrip silicon detectors produced with the planar technology have become a common tool for high energy physics for the detection of particles because silicon has very low value of the energy needed to get an electron-hole pair (about 1/10 that is required to ionize a gas molecule in a gaseous detector) and to the silicon energy loss (390 eV/μm). The number of applications of silicon detectors is continually growing also in other fields of science like astronomy, medicine and material testing. The success of silicon photodetectors is mainly due to precise position measurements, high readout speed, direct availability of signals in electronic form, possibility of integrating detector and readout electronics on a common substrate [1]. More recently, with the fast development of biotechnology, the importance to realise a photodetector that works in the UV range with high responsivity and economy has become clear.

## 2. Tests on commercial Si photodetectors

We have investigated the properties of different types of commercial silicon photodetectors: pixel and microstrip devices with different bulk and surface composition from two different vendors, Sintef and CSEM. They are described in Table 1.

The measured total dark current in the microstrip active area is approximately 40–80 pA/mm$^2$ at the depletion voltage. Pixel detectors usually have lower values of dark current.

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Table 1

| Vendor | Type | Area size (mm × mm) | Total thickness (μm) | Front $SiO_2$ thickness (μm) | Back $SiO_2$ thickness (μm) | Front Al thickness (μm) | Back Al thickness (μm) | Depletion voltage (V) |
|---|---|---|---|---|---|---|---|---|
| Sintef | Microstrip | 21 × 23 | 300 | 0.8 | 0 | 1.5 | 0.8 | 60 |
| Sintef | Microstrip | 15 × 17 | 300 | 0.8 | 0 | 1.5 | 0.8 | 60 |
| Sintef | Pixel | 5 × 1 | 300 | 0.8 | 0 | 1.5 | 0.8 | 60 |
| Sintef | Pixel | 6 × 6 | 300 | 0.8 | 0 | 1.5 | 0.8 | 60 |
| Sintef | Pixel | 3 × 3 | 300 | 0.8 | 0 | 1.5 | 0.8 | 60 |
| CSEM | Microstrip | 19 × 19 | 300 | 0.8 | 0.8 | 1.0 | 1.2 | 25 |
| CSEM | Microstrip | 7 × 20 | 300 | 0.8 | 0.8 | 1.0 | 1.2 | 25 |
| CSEM | Microstrip | 13 × 13 | 300 | 0.8 | 0.8 | 1.0 | 1.2 | 25 |

We have used a deuterium lamp as UV source in the wavelength range 200–400 nm with a monochromator for specific wavelength with a 2 nm bandwidth. An optic fibres bundle was used for light transmission from the source to the photodetector. Data have been collected by automatic acquisition of the photodetector current in reverse biased condition with a Keithley 2400.

In the UV range of interest, the absorption length in silicon is approximately 50–800 Å. The majority of photons are absorbed within the detector contact-window. The electron-hole pair created by photon absorption is close to the surface and it is quickly transferred to metal contacts giving a high readout speed even at few volts reverse bias. In Fig. 1 the detector photocurrent and the UV lamp spectrum distribution is shown. This gives an idea of the device's efficiency in the 200–400 nm UV range. It is shown in the plot of the ratio as "Responsivity" in Fig. 2. It depends strongly on the wavelength.

Recombination lifetime of the carriers in bulk and front contact region of detector and high recombination velocity may cause a decrease in responsivity. Studies [2] have demonstrated that, for wavelength shorter than 350 nm, the probability to create more than one electron-hole pair increases at low $\lambda$ due to the impact ionisation effect. This effect is visible in Fig. 2, though slightly, due to the fact that under 350 nm the responsivity falls down very quickly. However, the value of responsivity at 350 nm wavelength is approximately 0.15 A/W, in perfect agreement with the value predicted by G. Thungström et al. [3].

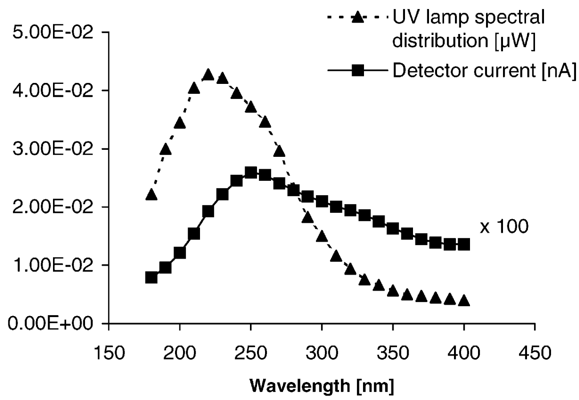


Fig. 1. UV lamp spectrum and related detector photocurrent for a CSEM microstrip detector.

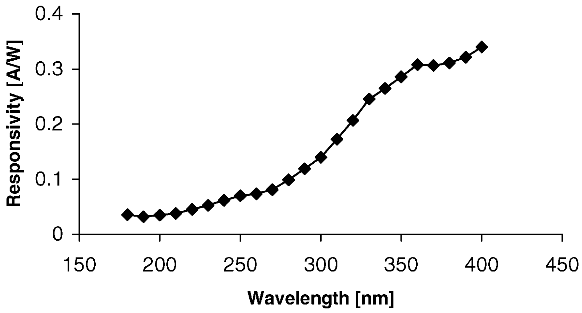


Fig. 2. Responsivity (A/W) of a CSEM microstrip silicon detector.

It has been observed [4] that filling of defects can give rise to ppc (persistent photocurrent) or time dependent photocurrent, depending on the history of illumination.

## 3. Silicon detectors stability

For silicon, dark current and photocurrent value stability have been studied obtaining very good results. Fig. 3 shows the time dependent data collection of dark current when a 25 V reverse bias is applied ($t = 0$) to the CSEM photodetector. After $t = 300$ s, the dark current raises the constant value of $\sim 37$ nA and the current during the illumination is $\sim 43$ nA. In order to evaluate the response, we have calculated the current difference between the dark current and the illumination current. The difference was around 6 nA and it was constant in time. This allows to use the detectors in experiments that need long illumination and repetitive shots, high stability and reliability. Our measurements on similar CVD diamonds [4] and GaAs detectors didn't give the same results in term of reproducibility and stability.

## 4. Undepleted and back-illumination working conditions

### *4.1. Undepleted condition*

Data have been collected in under-depleted conditions of photodetectors. The goal is to investigate the possibility of using detectors at bias level typical for readout electronic integrated circuits. This solution may be of interest to reduce the design complexity of electronics and the dissipated power. In Fig. 4 the difference between illumination and dark current are shown for various detectors. The differences between the two working conditions are not crucial as one could expect: the current gap at 65 V, at which all the detectors deplete, is approximately the same as at 5 V reverse bias.

### *4.2. Back-side illumination*

We have also performed measurements in back-side illumination condition on microstrip detectors that are not completely metalized on the back with aluminum, such as the CSEM devices. In many applications [5], it is desirable to illuminate the photodetectors from the back side, i.e. the unpatterned side, to allow the electrical and mechanical interface with the readout electronics. Back illuminated photocurrent data collection is needed to study the detector properties at these conditions. The best case should be when no aluminum pattern is on the back of detector: our devices did not have a uniform optical window rather a strip pattern. Furthermore dead areas exist in the device perimeter due to the metalization used for device contacts.

In Fig. 5 current intensity data are reported, both front and back illumination conditions, as function of wavelength: when the device is front

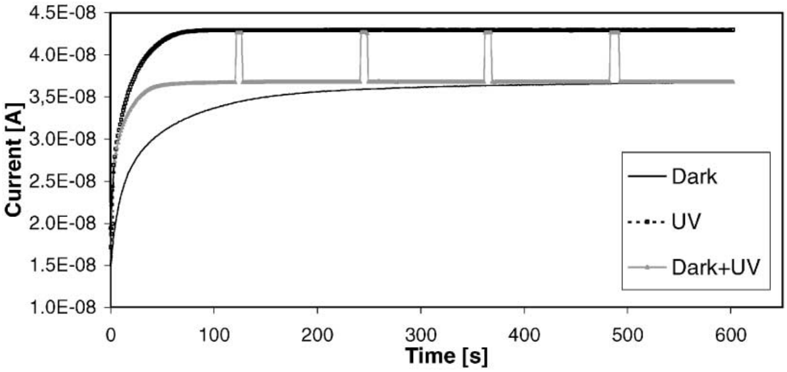


Fig. 3. Time dependent curves of dark current and current produced by photons absorption on CSEM microstrip detector (25 V reverse bias and 260 nm photon wavelength).

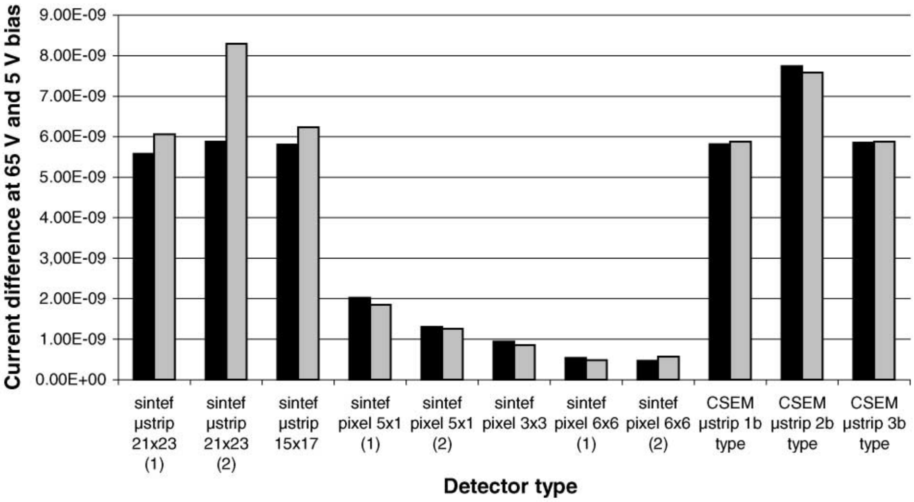


Fig. 4. Difference between dark and illumination current in depleted (black bars) and undepleted (grey bars) condition for different silicon detectors. Incident UV light is at 260 nm wavelength.

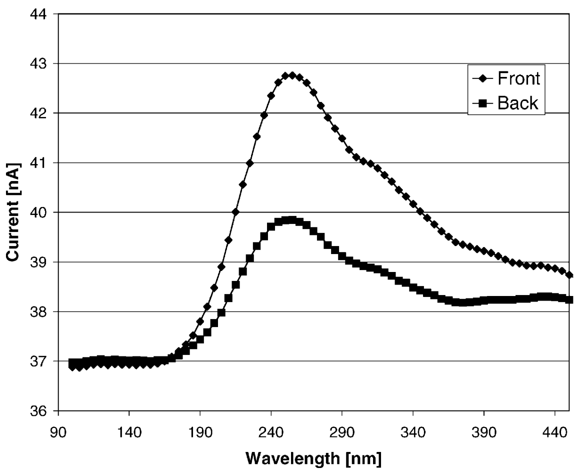


Fig. 5. Wavelength dependent current intensity for front-side and back-side illumination of CSEM microstrip detector.

illuminated, the photocurrent is almost twice the current in back-illumination referred to the same dark current. The current difference in back-side still allows to obtain good signals and responsivity.

## 5. Conclusions

Responsivity measurements on commercial silicon photodetectors are in accordance with the theoretical predictions. Stability and efficiency of silicon devices are higher than other similar devices in CVD diamond or GaAs. Furthermore, high performance in back-illumination geometry has been obtained in microstrip detectors and current signals with sharp time edge, have been collected also at low reverse bias.

## References

[1] G. Lutz, Semiconductor Radiation Detectors, Springer, Berlin, 1999.
[2] S. Kolodinski, J.H. Werner, T. Wittchen, H.J. Queisser, Quantum efficiencies exceeding unity due to impact ionization in silicon solar cells, Appl. Phys. Lett. 63 (1993) 2405.
[3] G. Thungström, E. Dubaric, B.G. Svensson, Processing of silicon UV-photodetectors, Proceedings of the First International Workshop on radiation imaging detectors, 2000, Nucl. Instr. and Meth. A 460 (2001) 165.
[4] L. Barberini, S. Cadeddu, M. Caria, F. Murgia, Nucl. Instr. and Meth. A 442 (2000) 400.
[5] S.E. Holland, N.W. Wang, W.W. Moses, IEEE Trans. Nucl. Sci. 44 (3) (1997) 443.