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# Experimental Evidence of Light Source Contribution in the Noise of Optoelectronic Devices Under Illumination

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**Abstract**— Low frequency noise measurements is used tool to characterize and analyse defects in photovoltaic cells, under both darkness and illumination condition. Several studies have attempted to identify the noise fluctuations under light, none of them have raised the question of the physical origin of the noise, as fluctuations can be induced by light stimulated defects or by the light source itself. This issue is investigated in this study through static current and noise measurements for a photoresistor and a np diode. The comparison of the results demonstrates that, depending on the voltage range, the noise measured can be identified as caused either by the light source or by the same mechanism than the device under darkness.

**Keywords**— Low Frequency Noise, Characterization, Photodiode, Photoresistor, Dark Noise, Illumination Noise

## I. INTRODUCTION

The study of semiconductor diode elements, pioneered by McWhorter [1], Kleinpenning [2] or Vandamme [3], has demonstrated the key importance of low frequency noise (LFN) measurements, and particularly  $1/f$  noise, to identify and analyse parasitic effects and identify sources responsible for performance degradation of photodiodes and photovoltaic (PV) cells. Initially devoted to measurements in dark condition, later studies have included illumination, aiming to enhance traps noise with light. These studies have investigated several types of photovoltaic cells, such as perovskites [4,5], organic [6], Si heterojunction [7], single junction Si cells or LEDs [8] and have, in some cases, shown modified noise spectra in the presence of light. Despite these experimental demonstrations, the origin of the additional noise under illumination has not been fully clarified yet, as it could either arise from the device under test (DUT) or from the light source itself, an effect that has not yet been evaluated. The aim of this work is hence to examine if the light source noise is present in the current power spectral density (PSD) of the DUT when the latter is illuminated.

## II. METHODS

The LFN measurements have been carried out using a probe station set in a Faraday cage, isolated from external vibrations and electrical interferences, connected to a regulated power supply and an additional light source. To

perform LFN measurements, the probe station is linked to the noise acquisition system NOISYS7, developed by SYNERGIE CONCEPT. The light source used to illuminate the devices is a Schott Megalight 100 halogen lamp, featuring a fibre output. A scheme of the setup is shown in Fig. 1 (a).

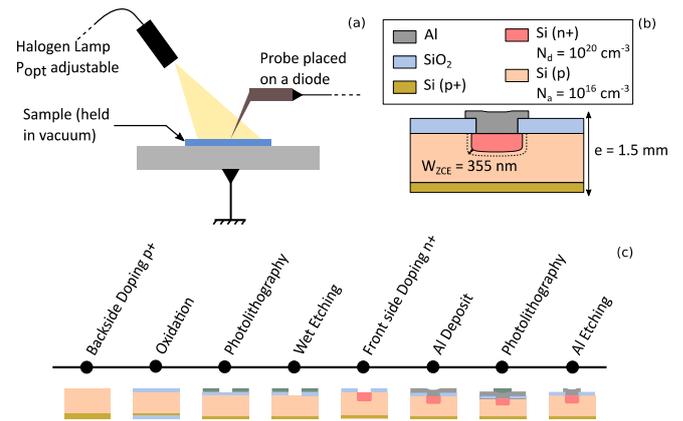


Fig 1. (a) Schematic of the probe station. (b) Diode structure, cross-sectional view. (c) Process flow for diode production. The diode area is  $0.2592 \text{ mm}^2$ .

To better comprehend the origin of noise under illumination, two devices has been studied. The first one is an Advanced Photonix CdS photoresistor (NSL 19M51), with a dark resistance of  $20 \text{ M}\Omega$ . This device is seen as a reference here, due to its resistive nature evolving with the light response. The other device is a p-n Si diode, whose cross-sectional view is illustrated in Fig 1 (b).

Samples have a thickness of  $1500 \mu\text{m}$  and depletion zone width of  $355 \text{ nm}$ , due to the device's architecture and doping of layers n and p. More precisely, the diode studied is the largest of the cell, with an area of  $0.2592 \mu\text{m}^2$ . The process flow is described in Fig 1 (c): Si wafer featuring thick oxide opening are doped by ion implantation, followed by deposition are carried out by vacuum evaporation. The rear face of the cells has also been p+ doped to ensure a better contact with the probe station.

### III. RESULTS

#### A. Static Measurements

Static measurements for both devices under various illumination conditions are shown in fig. 2. These measurements demonstrate the operation of both devices and the difference when exposed to light: while the resistance is decreasing with optical power ( $P_{opt}$ ) for the photoresistor, the diode presents a negative photonic current, which is constant in voltage and increasing in absolute value with  $P_{opt}$ , leading to a shift of the open circuit voltage ( $V_{oc}$ ). In dark condition, the diode follows the double diode model [9] while a value of 20.9 M $\Omega$  is obtained for the photoresistor.

The significant difference of the mechanisms governing the photo-induced variation of conduction in the diode and the photoresistor will be used to discriminate between a potential LFN contribution by the light source and by the devices.

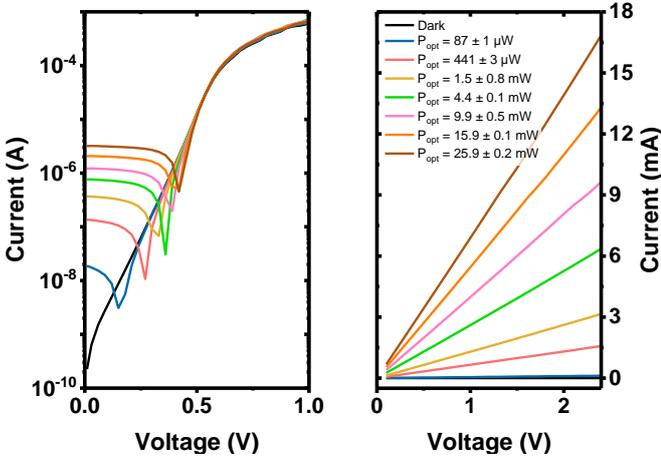


Fig. 2. I-V curves for different optical powers  $P_{opt}$ , (a) for the diode and (b) for the photoresistor.

#### B. Noise Measurements

The measured current PSDs are plotted on fig. 3 for both the photoresistor and the photodiode, as a function of the frequency, for various optical power levels and two bias voltages. Those two voltages have been chosen to highlight their influence on noise spectra behavior, which differs between the two devices. For the diode, at low voltage (0.15 V), the PSDs are influenced by  $P_{opt}$ , while they are independent with the optical power at higher voltages (0.54 V). This behaviour is not however observed on the photoresistor, whose PSDs are steadily modified by  $P_{opt}$  and slightly less by the applied voltage ( $\sim V^2$  variation, as expected from fig 2.).

For the diode (Fig 3 (a)), noise spectra are Lorentzian like at low voltage, whose amplitude increases with  $P_{opt}$ . However, at high voltage, a  $1/f$  noise spectra is obtained, regardless of  $P_{opt}$ . The same Lorentzian like PSD are obtained for the photoresistor (Fig 3(b)), whose amplitude also increases with  $P_{opt}$ . The main difference between these two Lorentzian like PSD for both devices relies on the spectra shape after the cut off frequency: for the diode, flat spectra are obtained and can be identified as white or shot noise whereas a  $1/f$  noise spectra is observed for the photoresistor.

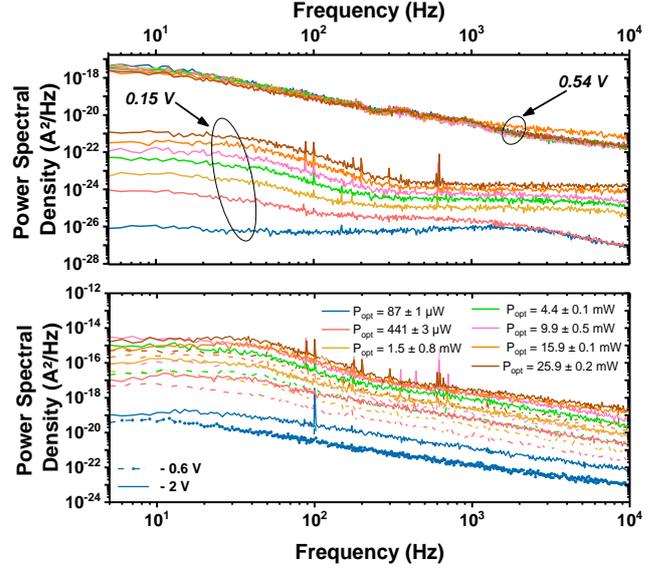


Fig. 3. Power Spectral Density vs. frequency for two voltages and for several optical powers: (a) diode and (b) photoresistor.

The variations of the spectra with voltage reflect the operation of the devices, but the common Lorentzian like curve indicates the potential presence of a noise component induced by the light source and not by the device. To confirm that assumption, the PSD of the diode is plotted on Fig 4 and 5 as a function of the applied voltage at two frequencies: at 20 Hz (before the cut-off, on Fig 4) and at 300 Hz (after the cut-off, on Fig 5).

Before a value close or equal to  $V_{oc}$  (measured from the IV of fig 2 (a)), the PSDs are constant with the voltage (and the current, not shown here), but they increase with  $P_{opt}$ . After  $V_{oc}$ , all curves overlap with the dark one, regardless of  $P_{opt}$ . Fig 4 hence validates that two regimes of noise can be observed on the diode. Before a value close or equal to  $V_{oc}$ , the noise is dominated by the light source, which explains the common Lorentzian like PSD for low frequencies, for both photoresistors and diode. Above  $V_{oc}$ , the noise is fully independent of the light source, and follows the dark characteristic.

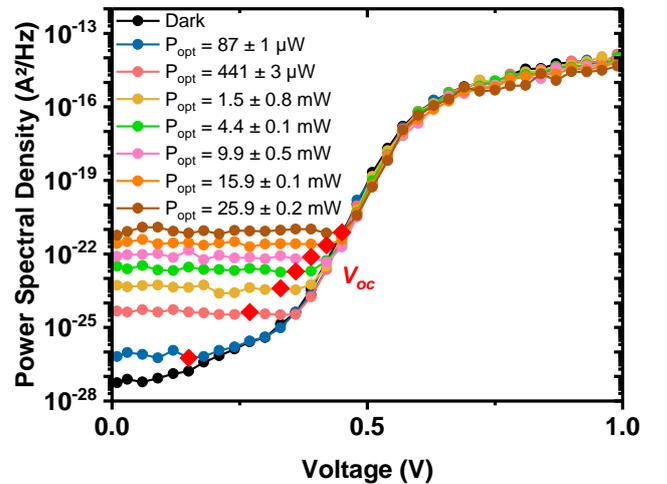


Fig. 4. Power Spectral Density of the diode vs. Voltage for different optical powers at 20 Hz.

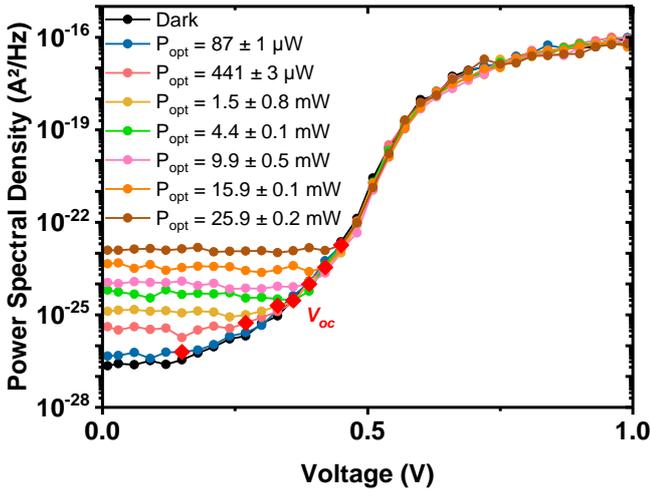


Fig. 5. Power Spectral Density of the diode vs. Voltage for different optical powers at 300 Hz.

The transition voltage between the two regimes of noise seems linked to the open-circuit voltage  $V_{oc}$ , as it can be seen in fig 6, which illustrates the evolution of  $V_{oc}$  and of the transition voltage  $V_{cut}$  with the optical power applied on the cell  $P_{opt}$ . This graph shows that these voltages are close to each other (or at least have a slight difference) for all optical powers.

To confirm the presence of both regimes and analyse the noise variation with the current, the PSD of the diode is plotted on Fig 7 as a function of the measured current for different optical powers. Moreover, these PSD have the same behavior than the ones obtained in Fig 4: the two regimes of noise appear again, even though they are less noticeable. These regimes are found here confirm the voltage one: the PSD are either constant with the current or have a variation in approximately  $I^2$ . It confirms once again the fact that the transition between the two regimes is related to  $V_{oc}$ , as currents for voltages below this value are negative.

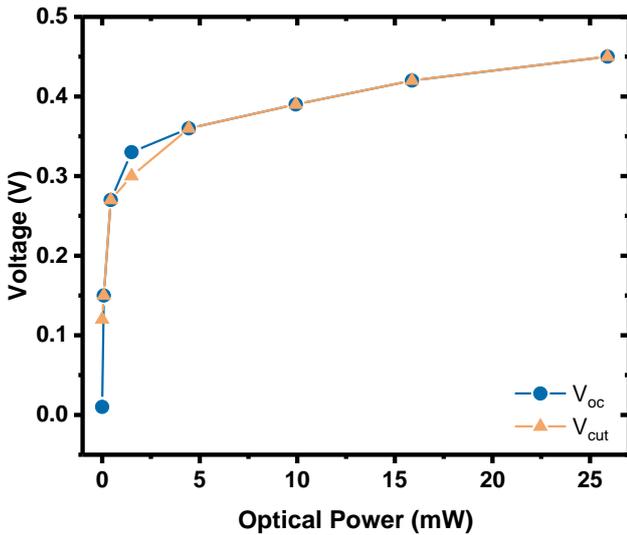


Fig. 6. Open circuit voltage and transition voltage between the two regimes of noise at 300 Hz.

This observation of two regimes of noise in the NP diode demonstrates that two types of noise fluctuations are involved in the device, one of which is predominant under  $V_{oc}$  and the other one at higher voltages. Then, to confirm

that the light source is responsible of the noise fluctuations for voltages under  $V_{oc}$ , the study must focus on noise spectra obtained in this voltage condition.

The presence of this common light source noise is further illustrated in Fig. 8, which shows the PSDs of both devices, at different voltages and under  $V_{oc}$  for the diode, for three illumination condition  $P_{opt}$  and normalized by the square of the measured current. This kind of normalization is legitimate here as it enables to reconcile data separated from several orders of magnitude of current (as it can be seen in Fig 3).

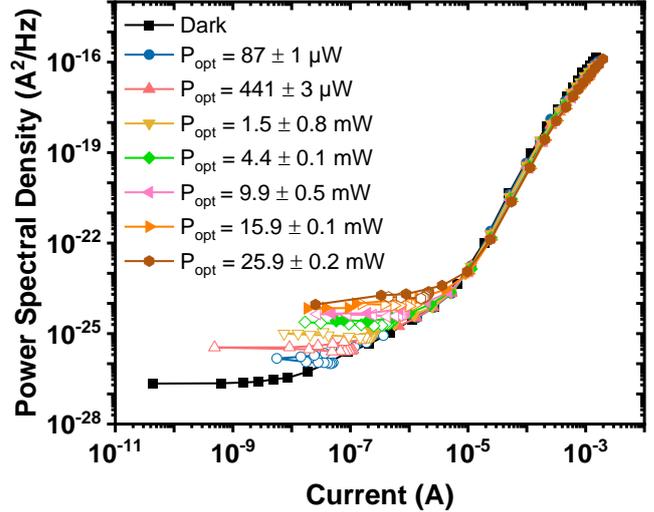


Fig. 7. Power Spectral Density vs Current for different optical power at 300 Hz: empty and entire dots represent respectively negative and positive currents.

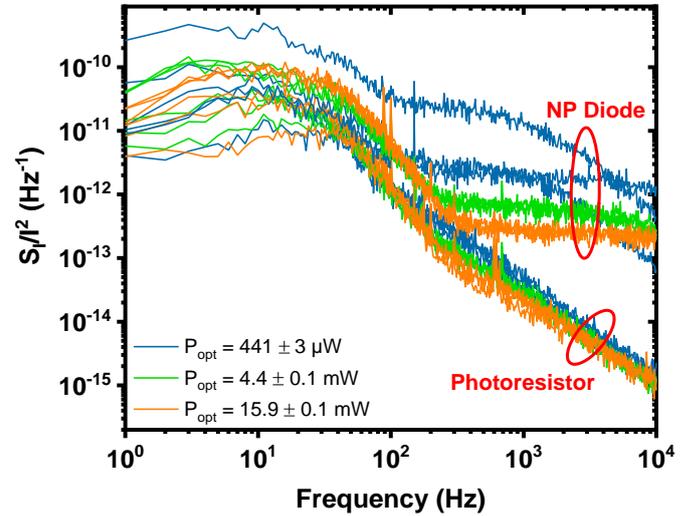


Fig. 8. Power Spectral Density, of the photoresistor and the diode, normalized by the square of the Current vs. Frequency for three optical powers at three different voltages (diode: 0.06V, 0.15V and 0.24V; photoresistor: 0.6V, 1.2V and 2.4V).

For frequencies below 100 Hz, the PSD of both devices for the same optical power are almost overlapping, despite their significant difference in operation and dark noise behaviour. Only one order of magnitude separates the data, which is part of the measurement uncertainty. Hence, this superposition further suggests that the noise in this range is produced by the light source. After this frequency, the PSDs

differ between the two devices, tending each toward their dark behaviour at high frequencies, i.e. white or shot noise for the diode and  $1/f$  noise for the photoresistor. In the case of the diode, the flat section above 300 Hz under illumination has been found to match the noise level above 300 Hz in dark condition, for a bias corresponding the value of  $V_{oc}$  obtained under the same illumination condition.

#### IV. CONCLUSION

This work has shown that the measurement of noise under illumination of photo-sensitive semiconductor devices could contain both the noise of the DUT and the noise of the light source. This is particularly critical as most of the noise measurement carried on PV under illumination in the literature has been performed at low voltages or even short circuit condition, which, according to our results, may be dominated by the light source.

An outcome of this work implies also that the measurement of the light source noise (like LEDs) could be performed either conventionally from their terminals (as previously done in [8]), but also from the fluctuation of their emitted light, if measured by a photodiode in the regime where the optical power fluctuation is dominant.

#### ACKNOWLEDGMENT

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