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

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## I. INTRODUCTION

The study of semiconductor diode elements, pioneered by McWorther [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 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, we assess that 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).

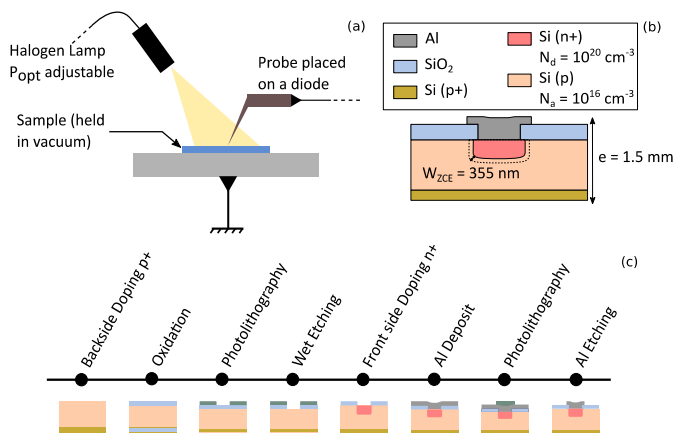


Fig 1 - (a) Schematic of the probe station. (b) Diode structure, cross-sectional view. (c) Process flow for diode production. The diode area is  $0.2592 \text{ mm}^2$

To better comprehend the origin of noise under illumination, two devices has been studied: an Advanced Photonix CdS photoresistor (NSL 19M51), with a dark resistance of  $20 \text{ M}\Omega$ , and a p-n Si diode, whose cross-sectional view and process flow are respectively described in Fig 1 (b) and (c).

## III. RESULTS

### A. Static Measurements

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

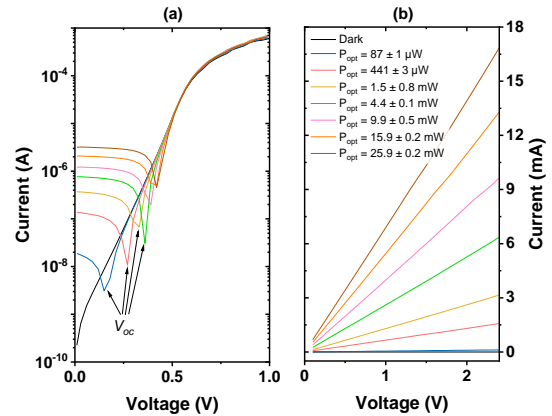


Fig 2 - I-V curves for different optical powers  $P_{\text{opt}}$ , (a) for the diode and (b) for the photoresistor

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.

### 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 such as to highlight their influence on noise spectra behavior, which differs between the two devices. For the diode, at low voltage ( $0.16 \text{ V}$ ), the PSDs are influenced by  $P_{\text{opt}}$ , while they are independent with the optical power at higher voltages ( $0.54 \text{ V}$ ). 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.).

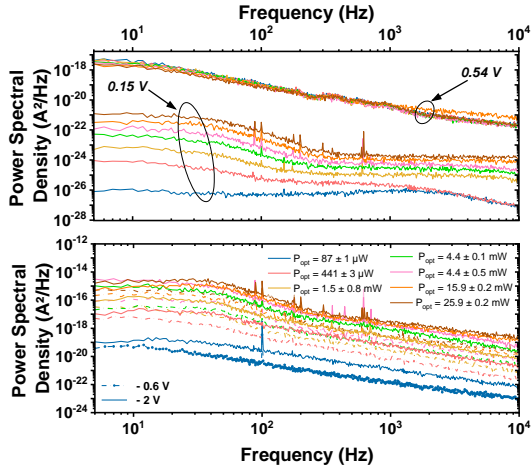


Fig 3 - Power Spectral Density vs. frequency for two voltages and for several optical powers: (a) diode and (b) photoresistor

For the diode (Fig 3 (a)), noise spectra are Lorentzian like at low voltage, whose amplitude increases with  $P_{opt}$ . However, at high voltage, we obtain a  $1/f$  noise spectra, 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 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 as a function of the applied voltage at two frequencies: at 20 Hz (before the cut-off) and at 300 Hz (after the cut-off).

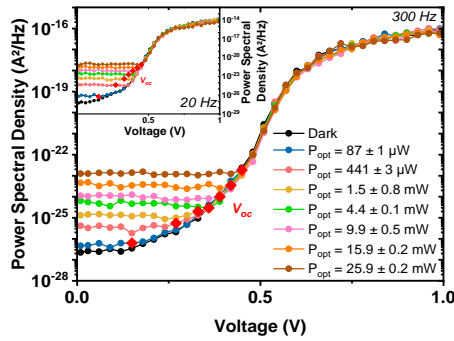


Fig 4 - Power Spectral Density of the diode vs. Voltage for different optical powers at 300 Hz and at 20 Hz (inset)

Before a value close or equal to  $V_{oc}$  (measured from the IV of fig 2 (a)), the PSDs are constant with  $V$  (and  $I$ , 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.

The presence of a common light source noise is further illustrated in Fig. 5, which shows the PSDs of both devices, at different voltages but same  $P_{opt}$ , arbitrary normalized for the diode's PSD (times  $15 \cdot 10^6$  for 4.4 mW and  $2 \cdot 10^6$  for 25.9 mW). For frequencies below 200 Hz, the PSD trends of both devices

are very similar only under illumination, despite their significant difference in operation and dark noise behaviour, hence further suggesting 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.

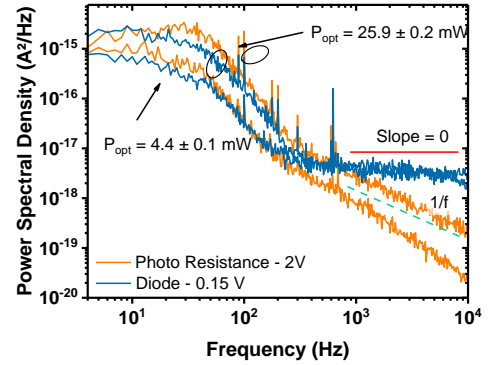


Fig 5 – Power Spectral Density vs. frequency for two  $P_{opt}$  at a voltage set: the diode's curves have been normalized with an arbitrary constant

#### 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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