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Study of the Linearity of Low-Area Photovoltaic Cells for Indoor Autonomous Sensors

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Summary:

In the field of energy harvesting for autonomous sensors located indoors, this work analyses the linearity of low-area photovoltaic (PV) cells of different technology while subjected to different levels of illuminance coming from either artificial or natural sources. For indoor artificial lighting (to be precise, cold LED), the PV technologies under test show a linear response, except for the monocrystalline technology. However, for indoor natural light, only PV cells belonging to the III-V technology show a linear response. Monocrystalline PV cells show an increasing quadratic response, whereas amorphous and organic PV cells have a decreasing quadratic response. Accordingly, the most appropriate technology to leverage the indoor energy coming from the natural light is the monocrystalline.

Keywords: Autonomous sensor, energy harvesting, photovoltaic cells, indoor applications, maximum power point.

Introduction

Billions of wireless sensors are expected to be installed in the coming decade [1] using technological ecosystems such as the *internet of things*. In addition, almost half of these sensors will be installed indoors [1], which is the scenario of interest here. For example, most of the sensor nodes related to the *Industry 4.0* will be located indoors. However, the installation and interconnection of this massive number of sensor nodes motivates several technological challenges. One of these challenges is the power supply [2] of the sensor nodes, which is the focus of this work.

The most appropriate power-supply solution is the use of an energy harvester, which powers the sensor node by collecting energy from the environment. In comparison with primary batteries, an energy harvester is a more sustainable solution with less maintenance costs, especially for hard-to-reach locations [2]. Among the different energy harvesting domains, here we focus on the optical since it provides the highest electrical power density [3]. Optical energy harvesters rely on photovoltaic (PV) cells, which are commercially available in different dimensions and technologies. For tiny autonomous sensor nodes, PV cells are expected to have a low area (e.g., around 10 cm^2 or even lower) so as not to increase the dimensions of the node. As for the technology, monocrystalline and polycrystalline technologies are mainly recommended for outdoor applications, in which the optical energy comes from the sun. However, other technologies with a spectral sensitivity more adapted to the visible light (such as amorphous and organic technologies) are, in principle, suggested for indoor applications. The use of PV cells for outdoor applications has been extensively evaluated in the literature in the last decades. Nevertheless, its use for indoor applications is relatively new and the design of the complete system is more challenging since the energy available is much lower.

In the previous context, this work aims to study the linearity of different PV cell technologies while subjected to different levels of artificial and natural light available indoors, with the final aim to extract guidelines for the selection of the most appropriate technology.

Materials and Method

The study of linearity has been carried out for the commercial low-area PV cells of different technology (monocrystalline silicon, amorphous silicon, organic, and III-V type) summarized in Tab. 1. Two testing scenarios were considered: 1) scenario #1 under artificial lighting from 100 to 1000 lux of cold LED, and 2) scenario #2 under natural (sun) light from 1000 to 10000 lux; such levels of illuminance (both artificial and natural) are typically found indoors. The cold LED was reproduced by a spectrally tunable light source (Asensetek Light Cube) [4], whereas the sun light was emulated by a AAA

Tab. 1: Features of the commercial PV cells selected in this study

Ref.	Technology	Manufacturer	Model	Active area (cm^2)	Substrate
MonoC	Monocrystalline	AnySolar	IXOLAR KX0B141K06TF	8.77	Non-flexible
Am1	Amorphous	Panasonic	AM-1454	10.94	Non-flexible
Org1	Organic	Epishine	LEH3_50x20_6_10	10.00	Flexible
III-V	III-V type	Lightricity	EXL2-1V50	2.15	Non-flexible

solar simulator (Scientech SciSun-150). The temperature of the cells was kept at 25ºC using a thermoelectric cold/hot plate (Teca AHP-301CPV). The applied level of illuminance was monitored by a spectroradiometer (Avantes AvaSpec-ULS2048CL-EVO). For each testing condition, the current-voltage characteristic of each PV cell was measured through a source and measure unit (Agilent B2901A) and, then, the maximum power point (MPP) was extracted [4]. For a fair comparison between the four PV cells, the power related to MPP was divided by the corresponding PV-cell area (see Tab. 1) to have the power density at MPP.

Experimental results and discussion

Figs. 1 and 2 show the experimental power density at MPP versus the illuminance for scenarios #1 and #2, respectively. In both figures, the power density is normalized to the value obtained at the minimum illuminance (100 lux in Fig. 1 and 1000 lux in Fig. 2).

From Fig. 1, three technologies (Am1, Org1, III-V) show a linear response with respect to the illuminance. However, the MonoC cell shows an increasing quadratic response. Note that an increase of 10 of the input illuminance generates an increase of 28 in the output power.

As for Fig. 2, only the III-V technology shows a linear response versus the illuminance. Similar to Fig. 1, the MonoC cell shows an increasing quadratic response, but the Am1 and Org1 cells have a decreasing quadratic response. Here, an increase of 10 of the input illuminance brings about an increase of 15 in the output power for the MonoC cell, but only 6 and 5 for the Org1 and Am1 cells, respectively.

Such a quadratic behavior leads to a high efficiency at 10000 lux in the MonoC cell (17 %), but a low value in the Am1 and Org 1 cells (3% and 5%, respectively). The efficiency at 10000 lux of the III-V cell is 22%, but with a significant cost limitation. Therefore, amorphous and organic technologies are not recommended to leverage the peaks of optical power coming from the sun in rooms with outside windows. In such conditions, the most appropriate PV cell technology seems to be the monocrystalline.

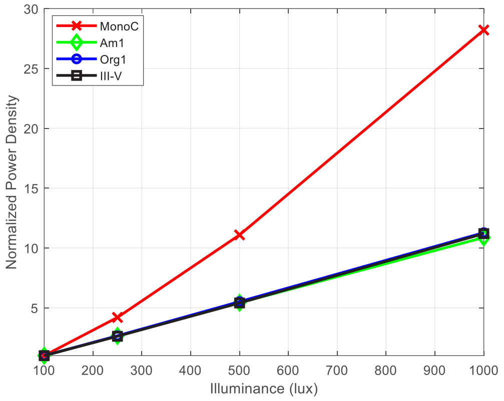

Fig. 1. Normalized power density versus illuminance of cold LED at 25ºC for different PV technologies.

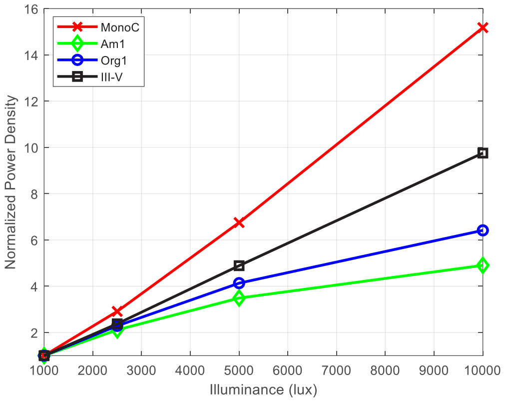

Fig. 2. Normalized power density versus illuminance of solar light at 25ºC for different PV technologies.

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