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Abstract

Systematic Experimental Evaluation of Submilliwatt PV Cells for Indoor Applications †

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Abstract: In the context of energy harvesting for tiny autonomous sensors placed indoors, this work carries out a systematic experimental evaluation of low-power, low-area photovoltaic (PV) cells. The evaluation involves several cell technologies and types of illumination and, for each technology–illumination pair, a sweep of different levels of illuminance and temperature expected indoors is performed. The information extracted from this work will enable a better selection of the cell technology for a given type of indoor illumination, and a better design of the ensuing maximum power point (MPP) tracker oriented to the cell technology–illumination pair.

Keywords: autonomous sensors; energy harvesting; indoor applications; PV cells

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1. Introduction

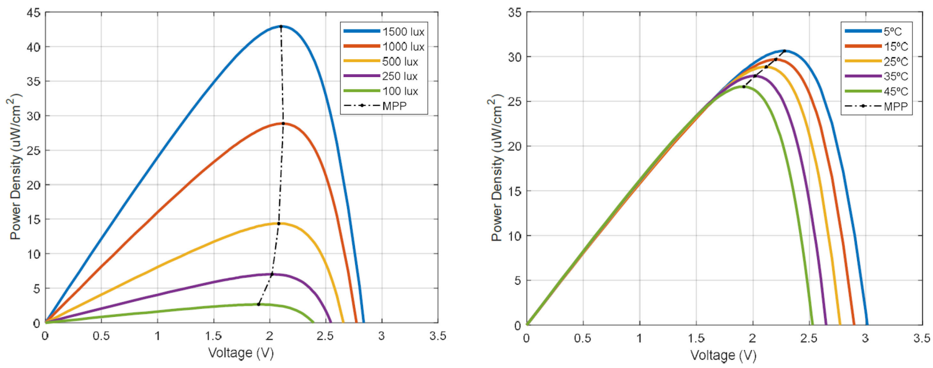
Billions of wireless sensors are expected to be installed over the coming decade through technological ecosystems such as the Internet of Things (IoT), collecting data, for example, from medical, manufacturing, and infrastructure applications. In addition, almost half of these wireless sensors are expected to be located inside buildings [1]. The energy required to power these wireless sensors can be provided by either primary batteries or energy harvesters, but the latter are a more sustainable option with less maintenance costs [2]. Although energy harvesters can extract the energy from different domains, the optical domain (via PV cells) provides the highest electrical power density. However, the optical power available indoors is much lower (around 1000 times lower) than outdoors and so is the electrical power density at the output of the PV cell. Furthermore, there are no international standards about the characterization of PV cells intended for indoors unlike what occurs for outdoors [3]. In such a context, this work proposes a systematic experimental evaluation of different PV cell technologies while subjected to different types of indoor illumination.

2. Materials and Methods

An experimental setup was developed to carry out the systematic evaluation of the PV cells while subjected to indoor illumination. Several technologies of PV cell, with an active area of around 10 cm^2, were considered: monocrystalline, polycrystalline and amorphous silicon, organic, dye-sensitized, and III-V type. Further, different manufacturers of the same technology were evaluated. Several types of indoor illumination were applied to the cells: warm and cold white LED, fluorescent, incandescent, and daylight. For each technology–illumination pair, a sweep of different levels of illuminance (from 100 to 1500 lux) and temperature (from 5 to 45 °C) expected indoors was carried out. The illuminance was controlled by a spectrally tunable light source, while the temperature was controlled by a thermoelectric cold/hot plate. The level of illuminance, irradiance, and spectrum was continuously monitored by a spectro-radiometer.

3. Experimental Results and Discussion

Among the different cell technology–illumination pairs under test, Figure 1 shows the experimental power density–voltage curves corresponding to the amorphous–cold LED pair; a previous exposure time of 6 weeks was considered for those cells to avoid the initial strong degradation (up to 20%) [4]. According to Figure 1a, the power density at the MPP increased linearly with the illuminance, whereas, from Figure 1b, it decreased with increasing the temperature. At reference conditions (i.e., 25 °C and 1000 lux, corresponding to an irradiance of 291 μW/cm^2 for that illumination), the power density at MPP was around 29 μW/cm^2 (overall power of 316 μW), which corresponded to an efficiency (i.e., power density over irradiance) of 10%. As for the amorphous–warm LED pair, the experimental results were very similar to those shown in Figure 1. The main difference was that the irradiance applied to achieve the same illuminance was 10% higher since the spectrum of the warm LED worse matches with the standard luminosity function. Consequently, the efficiency was lower (9% instead of 10% at 1000 lux, 25 °C). The results for the other technology–illumination pairs will be presented and compared in the extended version of this work.



(**a**) (**b**)

Figure 1. Experimental results for an amorphous PV cell (Panasonic AM1454, with an active area of around 11 cm^2) subjected to cold white LED at (**a**) different levels of illuminance with a constant temperature (25 °C), and (**b**) different temperatures with a constant illuminance (1000 lux).

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