Perovskite Powered Internet of Things

Suzanne Thomas
College of Engineering
Swansea University
Swansea, SA1 8EN, UK
S.K.Thomas@Swansea.ac.uk

Matt Carnie
College of Engineering
Swansea University
Swansea, SA1 8EN, UK
m.j.carnie@swansea.ac.uk

Adam Pockett
College of Engineering
Swansea University
Swansea, SA1 8EN, UK
Adam.Pockett@Swansea.ac.uk

Micheal Spence
College of Engineering
Swansea University
Swansea, SA1 8EN, UK
988717@Swansea.ac.uk

Yogesh Kumar Meena
Computational Foundry
Swansea University
Swansea, SA1 8EN, UK
y.k.meena@swansea.ac.uk

Krishna Seunarine
Computational Foundry
Swansea University
Swansea, SA1 8EN, UK
Krishna.Seunarine@Swansea.ac.uk

CHI'20,, April 25–30, 2020, Honolulu, HI, USA
ACM 978-1-4503-6819-3/20/04.
https://doi.org/10.1145/3334480.XXXXXXX

Abstract
With the rapid rise in connectivity in the home, office, and public spaces through the internet of things (IoT), there is a need for an increase in off grid and self-sustainable power solutions for the growing energy requirements of interconnected devices. Here we present an off-grid option for powering a simple IoT device in the home/office. We demonstrate a simple and cost-effective way to power an IoT device using perovskite solar cells (PSCs), a relatively new photovoltaic technology, that demonstrates high efficiency at ambient conditions, to charge a battery in a IoT device. We propose a new measurement protocol for PSCs under ambient light by measuring the maximum power output in a realistic indoor scenario. Utilisation of a maximum power point tracking software has allowed for the effective calculation of energy yield for a given solar cell technology under a given lighting condition, culminating in the testing of an array of cells in a prototype IoT device. Using our protocol we show that standard testing protocols overestimate the maximum power output of the PSC devices.

Author Keywords
Photovoltaics; Internet of Things; Perovksites; Energy Harvesting.

Introduction

The internet of things (IoT), whether in the home, office or public space environment is growing rapidly [5]. The introduction of a large quantity of new IoT nodes has resulted in the desire to introduce off grid power solutions and self-sustainable IoT devices, to mitigate the additional power draw of these devices. Each node may only require a very small amount of energy, but the combined weight of their power requirements may cause a large power draw from the grid [10]. The eventual integration of these off-grid power sources into IoT devices will not only reduce the cost of running, but ultimately decrease the power draw from the grid that these devices have.

There are many sustainable energy harvesting methods such as wind, hydroelectric and solar power however, only one of these can be discretely integrated into an IoT device. Photovoltaic (PV) devices are a prime candidate for self-powered IoT devices as they can be discretely integrated into the device design [11]. However, the high cost of commercial devices such as Gallium Arsenide (GaAs) based PV and the poor performance of commercial Silicon based PV in low light conditions result in an increased cost and size to devices designed to be cheap and discreet. Therefore, a cost effective and easily producible cell which performs well in low light conditions is desirable.

The recent emergence of organic-hybrid perovskite materials has recently gained a lot of interest in the scientific community for high efficiency and ease of manufacture. They are direct band gap semiconductors and absorb strongly in the visible spectrum. PSCs have been demonstrated to exhibit a high voltage response at high light intensity (1 sun at AM 1.5G spectrum) which implies a minimal intrinsic loss, implying that PSCs will perform well in low light conditions [9]. Indeed, the dependence of PSCs on light intensity was demonstrated in 2016 in the report by Raifuku et al [7].

There have been multiple studies outlining the efficiency and behaviour of PSCs in low light testing conditions [1, 8, 2, 4, 3]. However almost all these studies focus on a stable light intensity of 100, 200, 400, or 1000 Lux. From these experiments it is possible to estimate behaviour of the PSCs, and extract parameters such as maximum power point (P_{mpp}), short circuit current (I_{sc}), and open circuit voltage (V_{oc}). However, the lighting conditions in office and home settings where one might place an IoT device are not always stable. It is therefore prudent to develop a more realistic testing scenario in order to accurately deduce the behaviour of the cells in indoor conditions, as well as form an estimate for total cell area required to power an IoT device.

Maximum Power Point Tracking

To form a realistic representation of the energy harvesting capabilities of each photovoltaic device in a given set of realistic light level scenarios and compare this to standard testing procedures there are three main data sets that must be acquired. The realistic scenarios, the behaviour of each cell under each scenario, and standard IV curve testing both under standard AM 1.5G solar simulation, as well as low light conditions using the LED testing array of the maximum power point tracking (MPPT) system.

For the realistic test conditions, an Onset MX 2202 pendant data logger was employed, an example of which can be found in figure 1. These data loggers are inexpensive, durable, and discreet, allowing for test scenarios to be acquired in public and office spaces with little intrusion. The data logger records both lux and temperature data, however for the purpose of this experiment only the lux data was required. Three distinct settings were utilised: an office scenario with no natural light, an office scenario with

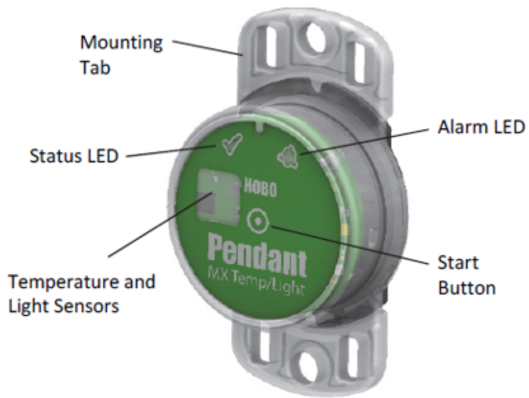

Figure 1: The Onset MX2202 HOBO Pendant MX Temperature, Water Temperature and Light Intensity Data Logger

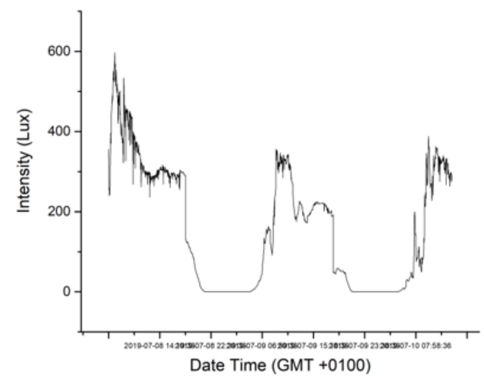

Figure 2: An example data set acquired using the data logger from an office scenario with some incident natural light

some natural incident light, and an external covered walkway. Each of these scenarios was chosen due to the daily variance in light intensity in order to provide insight into PV behaviours. The lux level for each scenario can be found in figure 2.

Five cell architectures were explored during this experiment. Two commercially available modules: Gallium Arsenide (GaAs) and amorphous silicon (a-Si); and three in house produced cells: inverted (PIN) structure PSCs, NIP structure PSCs, and carbon stack PSCs (specifics of which can be found in the fabrication section). Each of these cells was subjected to the MPPT scenarios in the same ambient conditions.

In order to test each cell in the realistic scenarios the lux data was uploaded to a candlelight ageing setup which allows for MPPT. MPPT obtains the sustained power output of the cell under simulated ageing conditions. The system employed for these experiments utilises a modified perturb and observe (P&O) algorithm. A standard P&O algorithm maximises the power output by constantly perturbing the operating voltage and recording the effect on the power output, the algorithm is modified by the inclusion of an arbitrarily defined power inversion threshold to mitigate high hysteresis of PSCs and eliminate non-optimal power tracking [6]. An example MPPT data set for an inverted PSC can be found in figure 3 wherein the average power output from the cell is calculated to be 0.0095 mW/cm^2.

$$P_{mpp} = FF \times V_{oc} \times I_{sc} \tag{1}$$

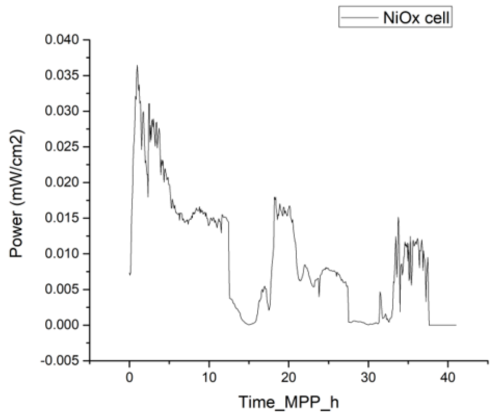

Figure 3: An example data set acquired from the candlelight ageing MPPT using the scenario from an office with partial incident natural light for an inverted (PIN) structure PSC.

IV curve comparison

To form a comparison between the MPP data acquired through realistic testing scenarios and standard maximum power calculations, IV curves for each cell are acquired under: AM 1.5 G solar simulation conditions, 200 lux low light LED, and 1000 lux LED. From each IV curve a maximum power point can be calculated using the equation

Where FF is the fill factor, a parameter which characterizes the non-linear electrical behaviour of the solar cell, V_{oc} is the open circuit voltage, and I_{sc} is the short circuit current.

The IV and power curve at 200 lux for an inverted PSC can be found in figure 4. From this FF, V_{oc} and I_{sc} were calculated along with the voltage and current at the maximum power point (V_{mpp} and I_{mpp} respectively). Finally, the P_{mpp} was calculated. The values for each of these parameters can be found in table 1.

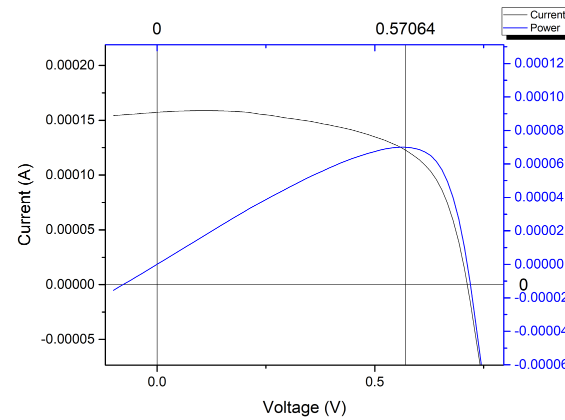

Figure 4: An example data set acquired from the candlelight ageing MPPT using the scenario from an office scenario with some incident natural light for an inverted (PIN) structure PSC.

Parameter name	Value
V_{oc}	0.71 V
V_{mpp}	0.57 V
I_{sc}	0.157 mA
I_{mpp}	0.122 mA
FF	62%
P_{mpp}	0.0705 mW/cm^2

Table 1: Table of key parameters extracted from low light IV curves for an inverted PIN structure PSC.

Prototype IoT device

An IoT device with tuneable energy output was designed consisting of a pressure and temperature sensor, screen display, a rechargeable Li-ion battery, an energy harvester (STEVAL-ISV021V1), and an array of PSCs. The purpose of the PSCs is to produce enough power during the day to recharge the Li-ion battery. Overnight, when the lights in the office are switched off, the IoT device will run solely on the battery. A picture of the set-up can be found in figure 5.

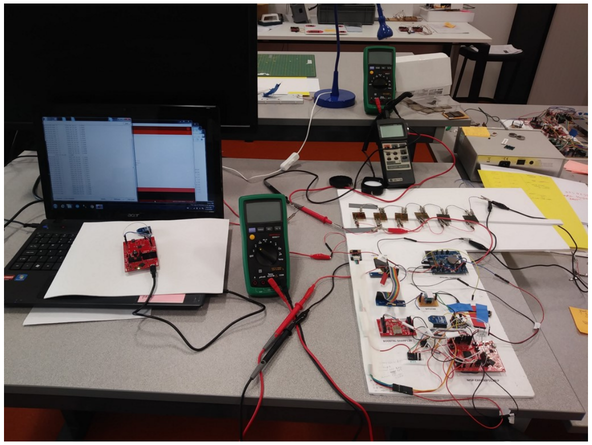

Figure 5: A picture illustrating the set-up of the PSC powered IoT device.

Conclusions

We present a method for obtaining realistic power output data for perovskite solar cells, in order to calculate an average maximum power output. This allows for a more precise calculation of active area of solar cell required for specific power requirements. This method was compared with standard low-light IV curve measurements. The average power output of an inverted structure PSC was 0.0095 mW/cm^2, significantly lower than the P$_{mpp}$ calculated from standard low-light IV testing of 0.0705 mW/cm^2. This implies that using a standard testing procedure severely overestimates the power output of the test PSC, which will lead to inaccurate estimations of cell area required to power an IoT device.

REFERENCES

[1] Chien-Yu Chen, Jung-Hao Chang, Kai-Ming Chiang, Hong-Lin Lin, Sheng-Yi Hsiao, and Hao-Wu Lin. 2015. Perovskite Photovoltaics for Dim-Light Applications. *Advanced Functional Materials* 25, 45 (2015), 7064 – 7070. DOI: http://dx.doi.org/10.1002/adfm.201503448

[2] Sean Sung-Yen Juang, Pei-Ying Lin, Yu-Chiung Lin, Yu-Sheng Chen, Po-Shen Shen, Yu-Ling Guo, Yu-Chun Wu, and Peter Chen. 2019. Energy Harvesting Under Dim-Light Condition With Dye-Sensitized and Perovskite Solar Cells. *Frontiers in Chemistry* 7 (2019), 209. DOI: http://dx.doi.org/10.3389/fchem.2019.00209

[3] Soyeon Kim, Muhammad Jahandar, Jae Hoon Jeong, and Dong Chan Lim. 2019. Recent Progress in Solar Cell Technology for Low-Light Indoor Applications. *Current Alternative Energy* 3, 1 (2019), 3–17. DOI: http://dx.doi.org/10.2174/1570180816666190112141857

[4] Harrison Ka Hin Lee, Jérémy Barbé, Simone M. P. Meroni, Tian Du, Chieh-Ting Lin, Adam Pockett, Joel Troughton, Sagar M. Jain, Francesca De Rossi, Jennifer Baker, Matthew J. Carnie, Martyn A. McLachlan, Trystan M. Watson, James R. Durrant, and Wing C. Tsoi. 2019. Outstanding Indoor Performance of Perovskite Photovoltaic Cells - Effect of Device Architectures and Interlayers. *Solar RRL* 3, 1 (2019), 1800207. DOI: http://dx.doi.org/10.1002/solr.201800207

[5] Knud Lasse Lueth. 2020. "IoT 2019 in Review: The 10 Most Relevant IoT Develoments of the Year". Online article. (7 January 2020). https://iot-analytics.com/iot-2019-in-review/

[6] Norman Pellet, Fabrizio Giordano, M. Ibrahim Dar, Giuliano Gregori, Shaik Mohammed Zakeeruddin, Joachim Maier, and Michael Grätzel. 2017. Hill climbing hysteresis of perovskite-based solar cells: a maximum power point tracking investigation. *Progress in Photovoltaics: Research and Applications* 25, 11 (2017), 942–950. DOI: http://dx.doi.org/10.1002/pip.2894

[7] Itaru Raifuku, Yasuaki Ishikawa, Seigo Ito, and Yukiharu Uraoka. 2016. Characteristics of Perovskite Solar Cells under Low-Illuminance Conditions. *The Journal of Physical Chemistry C* 120, 34 (2016), 18986 – 18990. DOI: http://dx.doi.org/10.1021/acs.jpcc.6b05298

[8] Francesca De Rossi, Tadeo Pontecorvo, and Thomas M. Brown. 2015. Characterization of photovoltaic devices for indoor light harvesting and customization of flexible dye solar cells to deliver superior efficiency under artificial lighting. *Applied Energy* 156 (2015), 413 – 422. DOI: http://dx.doi.org/https://doi.org/10.1016/j.apenergy.2015.07.031

[9] Nasim Sahraei, Erin E. Looney, Sterling M. Watson, Ian Marius Peters, and Tonio Buonassisi. 2018. Low trap-state density and long carrier diffusion in organolead trihalide perovskite single crystals. *Applied Energy* 224 (2018), 322 – 329. DOI: http://dx.doi.org/https://doi.org/10.1016/j.apenergy.2018.04.091

[10] Charlie Sammonds. 2019. "The Internet of Things Will Depend on Sustainable Energy". Online article. (24 July 2019). https://medium.com/primalbase/the-internet-of-things-will-depend-on-sustainable\-energy-65b10815a925

[11] Dong Shi, Valerio Adinolfi, Riccardo Comin, Mingjian Yuan, Erkki Alarousu, Andrei Buin, Yin Chen, Sjoerd Hoogland, Alexander Rothenberger, Khabiboulakh Katsiev, Yaroslav Losovyj, Xin Zhang, Peter A. Dowben, Omar F. Mohammed, Edward H. Sargent, and Osman M. Bakr. 2015. Adaptive power consumption improves the reliability of solar-powered devices for internet of things. *Science* 347, 6221 (2015), 519 – 522. DOI: http://dx.doi.org/10.1126/science.aaa2725