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Harvesting indoor light to supply power to nomad embedded systems

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It is possible to design a system to supply power to low consumption systems (hundreds of µW to tens of mW) from industrial devices. To develop an autonomous system based on harvesting energy from mixed artificial and natural light, it is mandatory to know which solutions are available and suitable to the conditions of use of the system to be designed. In this paper a comparison of solar cells exposed to different indoor light sources is made. This allows to establish which technology is the most relevant to use in different light environments, in terms of power generation. In addition, the difference in behavior between the two most widely produced solar cells, crystallin and amorphous Si, is depicted. We conclude that for new efficient light sources as fluorescent tubes, CFLs and LEDs, amorphous silicon is the best solution to generate power. On the other hand, crystallin silicon is the most efficient under incandescent, halogen or sunlight exposition.

I. INTRODUCTION

Harvesting enough energy to compensate the mW power consumption of our modern wireless electronic devices is still challenging. Industrials have started to be more and more present on the market, proposing solutions to develop autonomous systems based on energy harvesting solutions. The aim of this paper is to introduce and describe some of these new industrial low-cost possibilities applied to a concrete example: a commercial e-ink wireless touch screen display in an indoor environment.

II. POWER CONSUMPTION CHARACTERIZATION

The first step of this study is to characterize the mean power consumption of our sample nomad device. Using an ultra-low cost bidirectional current/power monitor IC (less than USD \$2) from Texas Instrument (INA219), we have measured for several hours, every 6ms, the instantaneous power consumption of the device. The results are displayed in FIGURE 1. In average the measured device uses 35mWh every hour and becomes energetically autonomous by harvesting a mean power of 35mW in its environment.

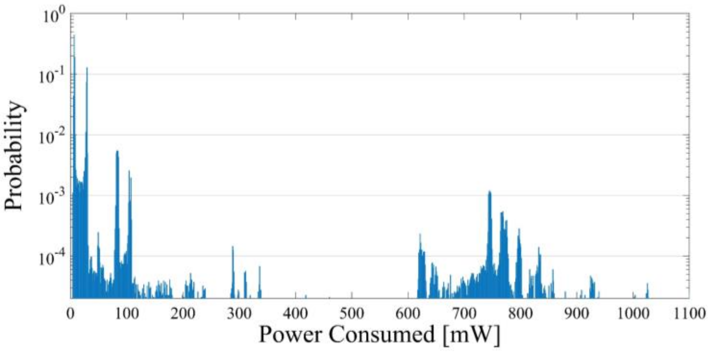

FIGURE 1: POWER CONSUMPTION OF A NOMADIC EMBEDDED DEVICE

III. INPUT POWER TO HARVEST

In an indoor environment like offices, several kinds of energy to harvest can be found: RF energy from WIFI or GSM; mechanical energy from sounds, building vibrations or even user touch, and finally light, from fully artificial to a mix of artificial and natural light during the day. Considering the very low amount of input power of RF and mechanical vibrations compared to the 35mW necessary to harvest, we will focus on light, the major source of power.

Traditionally, the indoor lighting industry gives the light specifications in lux and temperature units that relate more to the perceptions of the human eye than the actual standard units. In order to characterize the input power, we used a “BLACK-Comet-SR” spectrometer covering a range of 200-1100nm that gives the electromagnetic spectrum associated to each artificial and natural light in $W.m^{-2}.nm^{-1}$. We used different light with various spectrums, which can be found in indoor environment: A common halogen light bulb, a “warm” LED (2700K) and two compact fluorescent lights (CFL) of different “color” (2700K and 6500K) and daylight sources through anti-IR double glazing windows. In our example, a 500 lux of fluorescent light correspond to an incident power of $212\mu W/cm^2$ when integrating the whole spectrum. The measures were set at 500 lux, value in which meets most recommendations for indoor space lighting in Europe (EN 12464-1 standard).

IV. PV TRANSDUCERS

The transducers associated to light harvesting are the photovoltaic cells that include a lot of different technologies; monocrystalline Silicon, polycrystalline Silicon, amorphous Silicon, GaAs, thin films inorganic semiconductor cells with CIS, CIGS and CdTe, also organic cells (OPV), Dye cells and finally Perovskite cells. Each one of these technologies exhibits different External Quantum Efficiency (EQE). Based on these EQE differences, the power generated by a cell under a particular light source can be higher than with other cells [1]. The key to indoor energy harvesting is to optimize the match between the indoor input light spectrum and the EQE of the chosen PV technology used to harvest this input power.

For clarity, the cells studied for this abstract are only based on pc-Si and a-Si cells shown in TABLE 1. They will be considered as references for the other technologies that will be presented at the conference.

TABLE 1. CELLS STUDIED

Cell Array	**Cell Array Characteristics**			
	Technology	***Num. of cells***	***Dimensions***	***Cost***
Mars Rock Science SC-6733-9	a-Si	9	67 x 33mm	USD $2.1
Chinese Manufacturer SP-107*61	pc-Si	2 x 10	107 x 61mm	USD $1.75

V. EXPERIMENTAL SETUP

The setup, used to characterized photovoltaic devices for indoor light, already used for this purpose in the literature [2,3], consists in a standard current-voltage (I-V) measurement under different light sources. These measurements were performed in an enclosure surrounding the cell in order to limit exposure to the interfering lights as much as possible. The light source distance from the cell can be adjusted allowing to set the desired illuminance level. The used source meter is a commercial SMU Keithley 2450.

VI. RESULTS AND DISCUSSION

A significant difference of behavior between the pc-Si cell and a-Si emerges in the results shown in FIGURE 2. Under halogen exposure, the poly-crystallin silicon cell performs more than 7 times better than the amorphous one (123µW/cm² vs 16µW/cm² under 500 lux). However, under artificial lights the pc-Si cell performances fall dramatically down to half of what other cells can output. In contrast, amorphous cells show consistent power generation irrespective of the type of light source they are exposed to. As a matter of fact, it is noticeable that this type of cell can provide from 8µW/cm² under 200 lux of illumination to 19.8µW/cm² under 500 lux.

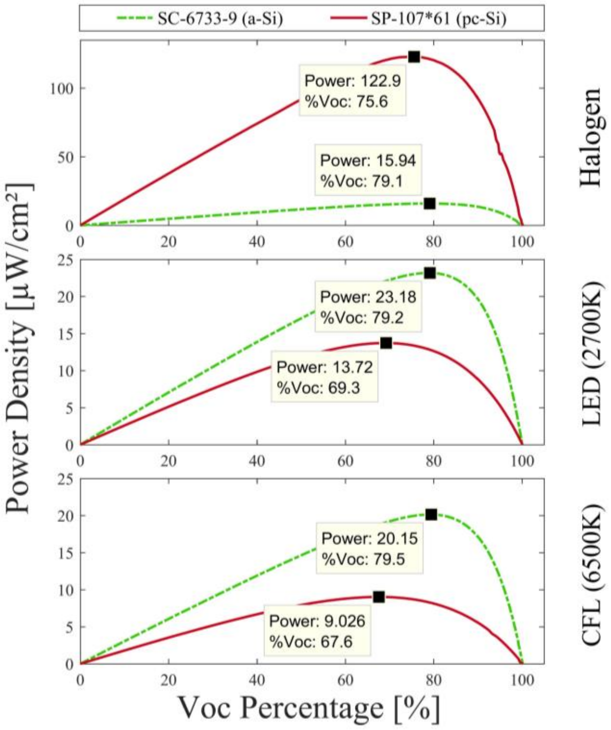

FIGURE 2: POWER PRODUCTION UNDER 500 LUX

Furthermore, amorphous silicon cells generate more power under most efficient light sources such as CFL, and even more power, with LED due to their band gap around 1.7eV. In contrast, poly-crystallin silicon's band gap of 1.1eV makes it the most efficient for harvesting energy from light of a wavelength above 1100nm.

VII. HARVESTED POWER

To complete this paper, testing and measuring the energy which can be harvested from a cell, managed by a Power Management IC (PMIC), has to be accomplished. This will conclude whether the setup used to characterize and estimate the recoverable power is capable of providing correct estimations or not. This part of the study will be presented at the conference.

VIII. CONCLUSION

We reported that the power density of solar cells in indoor environments can vary dramatically depending on its technology. Depending on the luminous indoor environment a device has to be powered from, the choice of the photovoltaic cell is decisive. Under light merely composed of efficient artificial illumination (i.e. LEDs, fluorescent lamp or tube), crystallin silicon is prescribed. However, with light coming from halogen or incandescent lights, it becomes interesting to use crystallin silicon.

In conclusion, a steady power generation level of 20µW/cm² is achievable with amorphous silicon. In our case a device consuming 35µW with a surface of 1750cm² of a-Si cells will be autonomous under 500 lux illuminance exposure. To go further a study of the behavior of the different cells under various mixt indoor light environment has to be done.

ACKNOWLEDGMENTS

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