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On the meaning(fullness) of the intensity unit 'suns' in light induced degradation experiments

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Abstract

In many studies on light induced degradation (LID) phenomena, light intensity is specified in the unit 'suns'. However, the actual meaning of this expression is rather undefined at least if a light source with its spectrum deviating from sun's spectrum is used, e.g., a halogen incandescent lamp featuring a distinctly red shifted black body spectrum. Within this contribution it is shown that the different spectrum can imply different photon fluxes depending on the interpretation of the unit 'sun'. Furthermore, it is shown that also the quantitative determination of intensity can yield different photon fluxes if the sensitivity of the detector is not taken into account. Finally, it is shown that also the optical properties of sample and setup yield different absorbable photon fluxes or generation. All three effects should be taken into account when describing and comparing LID studies.

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1. Introduction

In recent years studies on light-induced degradation (LID) phenomena have gained attention for the development of highly efficient solar cells which are not only more sensitive to bulk and surface defects being present right after fabrication, but also to defects developing afterwards. LID in the bulk occurs virtually on any material, be it LeTID in mc-Si [1], FeB-LID (mainly mc-Si) [2], Cu-LID [3], BO-LID (mainly Cz-Si) [4] or even FZ-Si [5] often used as reference material. Surface passivation like SiN_x:H [6] is also known to react to illumination.

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In many investigations, the light intensity is given in the unit ‘suns’ or ‘suns equivalent’ which seems to be a rather undefined description. In this paper, the meaning of the expression ‘suns’ is discussed with respect to spectral properties, quantitative determination and optical properties of sample and experimental setup.

2. Spectral properties

The expression ‘suns’ or ‘1 sun’ most probably originates from standard test conditions (STC) defined in IEC 60904 [7] and especially the ASTM G173 spectrum known as the reference spectrum AM 1.5g. $P_{G173}(\lambda)$ describes the sun’s spectrally resolved power density spectrum after passage of earth’s atmosphere. Sun appears roughly as a black body radiator of ~5700 K and the total power density p_{G173} is standardized to 100 mW/cm^2 by

$$p_x = \int_0^\infty \Phi_x(\lambda) \cdot \frac{hc}{\lambda}\, d\lambda \quad (1)$$

For a PV device, the photon flux $\Phi_{G173}(\lambda) = P_{G173} / (hc/\lambda)$ (with hc/λ being the photon energy) is a more suitable entity yielding a usable (absorbable) photon flux ϕ in the electron-hole generation range of 280-1200 nm of $\phi_{G173} \approx 2.9\times10^{17}$ /cm^{2}s according to the definition

$$\phi_x = \int_{280nm}^{1200nm} \Phi_x(\lambda)\, d\lambda \quad (2)$$

However, virtually no lab-style LID investigation utilizes the sun directly or a sun simulator (with a costly high pressure metal vapor plasma discharge lamp). Very often halogen incandescent lamps are used, fewer investigations use alternative light sources such as LEDs or lasers.

Halogen incandescent lamps are fairly good black body radiators with temperature of ~2950 K. The according spectrum (approx. a black body spectrum) $\Phi_{BB3k}(\lambda)$ is distinctly red shifted as compared to $\Phi_{G173}(\lambda)$ (see Fig. 1 left) with maximum photon flux around 1250 nm. The usable photon flux ϕ_{BB3k} is now a question of definition. Some authors refer to a comparable total power density of p_{BB3k} = 100 mW/cm^2 ($\phi_{BB3k} \approx 1.7\times10^{17}$ /cm^{2}s;–40%), some to a comparable photon flux $\phi_{BB3k} \approx 2.9\times10^{17}$ /cm^{2}s ($p_{BB3k} \approx 166$ mW/cm^2; +66%), some to a ‘current equivalent’ (discussed later on). Assuming every author describes properly his experimental setup, a noticeable deviation of –40% in usable photon flux ϕ or +66% in power density p at ‘1 sun’ occurs.

The (virtually) monochromatic spectra of LEDs and lasers are by far not comparable with a broad blackbody spectrum. Nevertheless, the same issue arises regarding definition. The values of power density p and photon flux ϕ for selected wavelength are shown in tables 2 to 4 in the appendix. The general advantage of LEDs and lasers is that virtually every photon contributes to generation of excess charge carriers. The ratio of photon flux ϕ to power density p scales linear with wavelength: $\phi/p \sim \lambda$. Hence the longer the emitted wavelength, the more efficient the conversion of power density to photon flux as can be seen from Table 2.