Photopyroelectric versus photoacoustic characterization of photovoltaic cells

I. F. Faria, C. C. Ghizoni, L. C. M. Miranda, and H. Vargas

Citation: *J. Appl. Phys.* **59**, 3294 (1986); doi: 10.1063/1.336878

View online: <http://dx.doi.org/10.1063/1.336878>

View Table of Contents: <http://jap.aip.org/resource/1/JAPIAU/v59/i9>

Published by the [American Institute of Physics](#).

Additional information on J. Appl. Phys.

Journal Homepage: <http://jap.aip.org/>

Journal Information: http://jap.aip.org/about/about_the_journal

Top downloads: http://jap.aip.org/features/most_downloaded

Information for Authors: <http://jap.aip.org/authors>

ADVERTISEMENT

The advertisement banner features a green and yellow background with abstract wavy lines. On the left, the text 'AIPAdvances' is displayed in a stylized font, with 'AIP' in blue and 'Advances' in green, followed by a series of orange dots. On the right, a circular seal contains the text 'Now Indexed in Thomson Reuters Databases'. Below this, a blue bar contains the text 'Explore AIP's open access journal:' followed by a list of three bullet points.

AIPAdvances

Now Indexed in
Thomson Reuters
Databases

Explore AIP's open access journal:

- Rapid publication
- Article-level metrics
- Post-publication rating and commenting

Photopyroelectric versus photoacoustic characterization of photovoltaic cells

I. F. Faria, Jr., C. C. Ghizoni, and L. C. M. Miranda

Instituto de Estudos Avançados, Centro Técnico Aeroespacial, 12200 S. J. Campos, SP, Brazil

H. Vargas

Instituto de Física, Universidade Estadual de Campinas, 13100-Campinas, SP, Brazil

(Received 4 November 1985; accepted for publication 2 January 1986)

The photothermal pyroelectric technique is applied to the characterization of photovoltaic cells and a comparison with the photoacoustic detection is presented. The difference between the photoacoustic and the pyroelectric data is interpreted in terms of a simple model for a junction-type solar cell.

In the last few years a great deal of effort has been devoted to the development of the so-called photothermal spectroscopies (PTS). The basic principle underlying these spectroscopic techniques is the detection of the heat produced in a sample, due to nonradiative deexcitation processes, resulting from the absorption of modulated light. The different techniques employed in the photothermal spectroscopy are named according to the mechanism used for detecting the thermal wave. Since the pioneering photoacoustic (PA)¹ and piezoelectric² detection techniques, several mechanisms have been proposed for the PTS. These include the photodisplacement spectroscopy,^{3,4} the beam deflection spectroscopy,^{5,6} the photothermal radiometry,^{7,8} and the newly developed photopyroelectric spectroscopy⁹⁻¹¹ (PPS). The common feature of all these techniques is that their signals are proportional to the light into heat conversion efficiency and therefore complementary to the other photoinduced energy conversion processes. This aspect of the thermal wave signal has been explored by several authors for investigating photoinduced energy conversion processes. These investigations range from the study of photosynthetic processes in leaves^{12,13} to the monitoring of photovoltaic conversion efficiency of solar cells,^{14,15} and the study of nonradiative recombination processes in semiconductors.¹⁶ Except for a few works^{17,18} using the photothermal radiometry, most of these works on photoinduced conversion efficiency have been carried out using photoacoustics.

In this paper we report on the use of the recently developed PPS⁹⁻¹¹ to the characterization of photovoltaic cells. This technique consists of using a thin pyroelectric film (e.g., polyvinylidene difluoride, PVF₂) in intimate contact with the (nonilluminated) back surface of a solar cell. Following the absorption of modulated light, the nonradiative deexcitation processes within the cell cause its temperature to fluctuate and through heat diffusion to the surrounding pyroelectric film, the cell-pyroelectric film interface temperature fluctuates. As a result of this temperature fluctuation a pyroelectric signal is produced which is proportional to the temperature change in the film. The generated signal in the PVF₂ film due to the internal heat generation in a resistively loaded solar cell is written as $S(R_L) = S(OC)(1 - \gamma)$, where $S(OC)$ is the open-circuit signal which depends on the internal loss mechanisms and γ is the photovol-

taic conversion efficiency to an external load R_L . Figure 1 shows the results for γ for a p - n solar cell illuminated at 18 Hz by a 5.2-mW He-Ne laser, using both the PP and the PA techniques. The PA data was obtained using a conventional gas-microphone PA chamber with the back contact of the Si cell flushed against the back wall of the PA chamber. Both curves in Fig. 1 show a clear maximum around the optimal load resistance R_L^* . The PA-determined optimal load resistance, $R_L^*(PA) = 350 \Omega$, agrees quite well with that determined from electrical measurements, whereas the PP-determined optimal load resistance, $R_L^*(PP) = 400 \Omega$, is slightly higher. Two other significant differences between the PA

FIG. 1. Photopyroelectric γ_{PP} (solid) and photoacoustic γ_{PA} (dashed) conversion efficiencies as a function of the load resistance R_L , for a 500- μ m-thick p - n solar cell, at 18 Hz under ~ 5.2 mW He-Ne laser illumination. At 350 Ω the PA-determined conversion efficiency is $\sim 12\%$, whereas the PP-determined optimal conversion efficiency is $\sim 5\%$ at 400 Ω .

FIG. 2. Excess PP signal, normalized relative to the OC signal, $\Delta S/S(OC)$ as a function of the load resistance.

and PP conversion efficiencies were observed. First, the value of γ at the optimal load resistance obtained from the PA measurement is about 12%, whereas the corresponding PP optimal conversion efficiency is 5%. Second, the PP-determined γ becomes negative for $R_L \lesssim 200 \Omega$. This latter feature suggests that the pyroelectric measurement is sensitive to some additional heat sources resulting from the illumination. The difference between the PP and PA normalized signals, $\Delta S/S(OC) = \gamma_{PAS} - \gamma_{PP}$, as a function of the load resistance is shown in Fig. 2. This figure shows that the excess PP signal is a monotonically decreasing function of the load resistance. In contrast, as recently suggested by Cahen and Halle,¹⁵ the PA measurement seems to be sensitive only to the heat generated close to the surface. This is confirmed by our PA results at high modulation frequencies for which our sample is no longer thermally thin. Our PA results at 200 Hz, for which the thermal diffusion length μ_{th} is $360 \mu m$ ($< l = 500 \mu m$), yielded the same optimal conversion efficiency and load resistance as that at 18 Hz.

To explain the observed differences between the PA and PP conversion efficiencies we resort to the simple model for a p - n junction-type solar cell shown in Fig. 3. The radiation absorbed within one carrier diffusion length from the junction generates a current I_{SC} and a voltage V_J . This current splits into two components—one, I_L , which flows through the diode to the load, and another one, I_J , which is injected across the junction. The additional heating which seems to

be detected by the PP measurements may be attributed to two main sources. One is the heating in the cell and contacts caused by the current I_L . This contribution corresponds to the current dissipation at the internal resistance R_s of Fig. 3 given by $Q_s = R_s I_L^2$. The second heat source may be the nonradiative surface recombination at the back surface of the cell. Assuming the carrier relaxation time in a Si solar cell to be typically about 10^{-4} s, the electron (hole) diffusion length would be of the order of 600 (350) μm , so that the carriers generated at the top portion of the cell would eventually diffuse deeper into the base of the cell. To check for these two possibilities we have measured the PP signal at 200 Hz. At this frequency the sample is thermally thick so that the PP signal dependence on R_L would eventually single out the dominant heating mechanism. In Fig. 4(a) we show the dependence of the normalized PP signal, $S(R_L)/S(OC)$, as a function of R_L . Here, we note that the PP signal is a monotonically decreasing function of R_L exhibiting no minimum. This is evidence that at this modulation frequency no photovoltaic effect is being detected by pyroelectric film. In Fig. 4(b) we show the dependence of I_L^2 on the load resistance as obtained from the electrical measurements. The remarkable similarity between Figs. 4(a) and 4(b) suggests that the dominant additional heating detected by the PVF_2 film is due to the dissipation of I_L through R_s , as suggested above, with the surface recombination being apparently negligible. This additional heating sensed by the PP technique is also responsible for the difference observed in the PA- and PP-determined values of the optimum conversion efficiencies. The electrical measurements yielded an optimum conversion efficiency of 10.7% at the optimum load resistance as the PA measured one ($\approx 350 \Omega$). This value is quite close to the PA-determined optimum conversion efficiency of 12% (with an error of $\pm 15\%$), and differs by a factor of roughly 2 from the PP-determined value of 5%. The Joule heating is mainly generated in the base region (the widest of the three regions) of the solar cell and could, in principle, also contribute to the PA signal. The PA measurements, both at low and high modulation frequencies, show, however, that this additional heating is strongly damped so that the PA signal senses only the front surface contribution. One possible explanation for this is that there is a preferential flow, towards the back silvered contact, for the heat generated in the base region. The thermal conductance to the silvered back contact is roughly three times ($k_{Ag}/k_{Si} \approx 2.8$) larger than that of Si, so that the

FIG. 3. Equivalent circuit of a p - n solar cell. R_L is the load resistance, R_s is the internal series resistance of the diode including the contact resistance, R_J is the junction resistance, I_{SC} is the short-circuit current, I_J is the current injected across the junction, and I_L is the load current. The internal resistance R_s was found to be equal to 6.5Ω as determined from the dark-current characteristics of the junction.

FIG. 4. (a) PP signal for the solar cell, as a function of the load resistance at 200 Hz under ~ 5.2 -mW He-Ne laser illumination. (b) Dependence of the square of the load resistance I_L (mA) as a function of R_L , as obtained from the electrical measurements.

back contact may be viewed as a heat sink. Since in the PP technique this heat sink is in intimate thermal contact with the pyroelectric film, it is, therefore, not surprising that the PP signal senses the Joule heat. In contrast, in the PA case, this heat, reaching the back contact, is dissipated through the PA cell walls so that only the front surface contribution is detected.

¹A. Rosencwaig and A. Gersho, *J. Appl. Phys.* **47**, 64 (1976).

²A. Hordvik and H. Schlossberg, *Appl. Opt.* **16**, 101 (1977).

³S. Ameri, E. A. Ash, V. Nenman, and C. R. Petts, *Electron. Lett.* **17**, 337 (1981).

⁴L. C. M. Miranda, *Appl. Opt.* **22**, 2882 (1983).

⁵D. Fournier, A. C. Boccara, and J. Badoz, *Appl. Phys. Lett.* **32**, 640 (1978).

⁶J. C. Murphy and L. C. Aamodt, *Appl. Phys. Lett.* **38**, 196 (1981).

⁷P. E. Nordal and S. O. Kanstad, *Phys. Scr.* **20**, 659 (1979).

⁸R. Santos and L. C. M. Miranda, *J. Appl. Phys.* **52**, 4194 (1981).

⁹H. Coufal, *Appl. Phys. Lett.* **44**, 59 (1984).

¹⁰A. Mandelis, *Chem. Phys. Lett.* **108**, 388 (1984).

¹¹A. Mandelis and N. Zwer, *J. Appl. Phys.* **57**, 4421 (1985).

¹²D. Cahen, S. Malkin, and E. I. Lerner, *FEBS Lett.* **91**, 339 (1978).

¹³C. A. S. Lima, J. C. V. Mattos, A. F. S. Penna, J. F. W. von Bülow, L. C. M. Miranda, and C. C. Ghizoni, *J. Photoacoust.* **1**, 61 (1982).

¹⁴D. Cahen, *Appl. Phys. Lett.* **38**, 810 (1978).

¹⁵D. Cahen and S. D. Halle, *Appl. Phys. Lett.* **46**, 446 (1985).

¹⁶C. C. Ghizoni and L. C. M. Miranda, in *IEEE Ultrasonics Symposium Proceedings* (IEEE, New York, 1982), Vol. 2, p. 601.

¹⁷G. Bults, P. E. Nordal, and S. O. Kanstad, *Biochim. Biophys. Acta* **682**, 234 (1982).

¹⁸S. O. Kanstad, D. Cahen, and S. Malkin, *Biochim. Biophys. Acta* **722**, 182 (1983).

Correspondence between coherently strained multilayers and a single coherently strained layer on lattice mismatched substrate

R. People

AT&T Bell Laboratories, Murray Hill, New Jersey 07974

(Received 11 November 1985; accepted for publication 23 January 1986)

The equilibrium in-plane lattice parameter for lattice mismatched multilayers, as first derived by Matthews and Blakeslee [*J. Cryst. Growth* **32**, 265 (1976)], has been used to obtain an expression for the misfit between the multilayers as a whole and a lattice mismatched substrate. The resulting expression immediately suggests a correspondence between the multilayers as a whole and a single coherently strained layer of equal thickness but having a misfit equal to the misfit between the constituent layers spatially averaged over a single repeat distance. The present results are obtained without reference to the energy density of a misfit dislocation. In particular, the present correspondence allows one to predict the critical thickness of coherently strained multilayers if single-layer critical thicknesses are known.

Coherently strained multilayers consist of thin alternating layers of materials which are lattice mismatched in bulk form but which elastically strain to uniformly match up the lattice constants of the materials in the planes parallel to the heterointerfaces. An unstrained set of mismatched layers and the corresponding set of strained layers are shown schematically in Fig. 1. The resulting value of the in-plane lattice

constant ($a^{\parallel}$) is intermediate between the unstrained lattice constants of the multilayer constituents. Matthews and Blakeslee¹ have obtained an expression for $a^{\parallel}$ by minimizing the total elastic strain energy of a single pair of layers. If it is assumed that $a_A < a_B$, then

$$a^{\parallel} = a_A \left(1 + f / \left(1 + \frac{G_A h_A}{G_B h_B} \right) \right), \quad (1)$$