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Theoretical analysis and experimental results on the modulated photocarrier grating technique

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We present a complete theoretical analysis of the modulated photocarrier grating method (MPG). Our calculations show that the response of the sample will be not only a photocurrent modulated with the frequency f of the illumination, but also a response in dc and with frequency $2f$. In order to put to test our calculations, we implement experimentally the MPG technique and we apply it to a hydrogenated amorphous silicon sample. We verify the existence of a response at frequency $2f$, and we measure the relative intensity of this signal – which compares well with the result of our theoretical calculation. We also show that under certain conditions the density of states (DOS) at the quasi-Fermi level for the majority carriers is related to the ratio of the MPG and modulated photoconductivity (MPC) signals. We present a simple formula that allows estimating the DOS as a function of energy by changing the temperature and the generation rate.

1 Introduction The modulated photocarrier grating (MPG) technique [1], proposed in 1993 as an improvement of the steady-state photocarrier grating (SSPG) technique [2], involves the generation of photocarriers by a temporally modulated interference pattern. By modulating the polarization of one of the interfering beams, the contrast of the light pattern is modulated without changing the average intensity. The measurement is performed in the frequency domain, recording the modulus and the phase shift of the resulting photocurrent. In this sense, the method is closely related to the modulated photocurrent (MPC) technique [3]. The theoretical analysis presented in the original publication [1] defined phenomenological parameters, like the small signal trap-controlled mobilities and the recombination lifetimes, working with the total carrier concentrations (mobile plus trapped). In that analysis, the density of states (DOS) does not appear in the equations that describe the MPG experiment. Nevertheless, the method has been used to test the ambipolarity condition and to measure accurately the diffusion length of hydrogenated amorphous silicon [1, 4] and GaAlAs [5] samples.

In this work, we present a theoretical analysis of the MPG method based on the general transport equations for mobile carriers and on the Simmons and Taylor [6] statistics for the recombination terms. We show that the response of the sample will be not only a photocurrent modulated with the frequency f of the illumination, but also a response in dc and with frequency $2f$. Since we can calculate the relative intensities of these photocurrents, we have a means to put to test our calculations. On the other hand, performing suitable approximations on the analytical solution of the MPG equations, we obtain a simple formula relating the DOS at the electron quasi-Fermi energy to material parameters and measurable quantities.

2 Theoretical analysis of the MPG We assume a thin photoconductive film with coplanar contacts, illuminated by two weakly absorbed light beams with intensities I_1 and I_2 ($I_1 \gg I_2$). Beam 2 impinges normally to the sample surface, while beam 1 forms an angle θ. When these two beams are coherent and have parallel polarization, an intensity grating $I(x) = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos(2\pi x/\Lambda)$ is created, where x is the coordinate between the contacts and Λ is the grating period [2]. A grating in the z direction (perpendicular to the sample surface) also develops, but the variation of the light intensity in this direction can be ignored for small θ [1]. If the polarization of beam 2 is rotated by 90°, no interference occurs and the illumination is uniform with intensity $I_1 + I_2$. If the plane of polarization of beam 2 is rotated with angular frequency ω, a temporally oscillating illumination grating results. In this case, the generation rate depends both on x and time (t), taking the form

$$\begin{aligned} G(x,t) &= G_0 + \Delta G(x,t) \\ &= G_0 + g\cos(kx)[1+\cos(\omega t)] \\ &= G_0 + \Re e\left[\sum_{\Omega=-\omega,0,\omega} g_\Omega\, \mathrm{e}^{\mathrm{i}(kx+\Omega t)}\right], \end{aligned}$$

where $G_0 = G_1 + G_2$, $g = \sqrt{G_1 G_2}$, $k = 2\pi/\Lambda$, $\Re e$ means the real part of the complex number, and g_Ω takes the values $g_0 = g$, $g_\omega = g_{-\omega} = g/2$. This spatially and temporally modulated generation rate in turn creates free electron and hole distributions, $n(x,t)$ and $p(x,t)$, with the same period and angular frequency. However, since electrons and holes have different mobilities and lifetimes, the carrier distributions will not be in-phase with the generation rate. The different amplitudes and phases of the electron and hole distributions will generate an internal electric field, $\xi_{\mathrm{int}}(x,t)$, that will add to the externally applied electric field ξ_{ext}. The internal electric field is related to the local charge densities via Poisson's equation

$$\frac{\mathrm{d}\xi_{\mathrm{int}}(x,t)}{\mathrm{d}x} = \frac{q}{\varepsilon\varepsilon_0}\left\{\begin{array}{l} p(x,t) + \int_{E_\mathrm{v}}^{E_\mathrm{c}} [1-f(E,x,t)]N^{\mathrm{DON}}(E)\,\mathrm{d}E \\ -n(x,t) - \int_{E_\mathrm{v}}^{E_\mathrm{c}} f(E,x,t)N^{\mathrm{ACC}}(E)\,\mathrm{d}E \end{array}\right\}, \tag{1}$$

where q is the elementary electric charge, ε is the dielectric constant of the sample, ε_0 is the dielectric permittivity of vacuum, E_v is the energy at the top of the valence band, E_c is the energy at the bottom of the conduction band, $f(E,x,t)$ is the occupation function, $N^{\mathrm{DON}}(E)$ is the density of donor states (neutral when occupied and positively charged when empty), and $N^{\mathrm{ACC}}(E)$ is the density of acceptor states (neutral when empty and negatively charged when occupied). Though we have solved analytically the equations describing the MPG experiment for DOS distributions including different types of defects (monovalent and/or amphoteric), for clarity we will concentrate here on the case of monovalent states, either donors or acceptors.

Both the externally applied electric field and the internally developed space charge field will contribute to the current density, which is given by [1]

$$j(t) = \frac{1}{\Lambda}\int_0^\Lambda [q\mu_\mathrm{n} n(x,t) + q\mu_\mathrm{p} p(x,t)] [\xi_{\mathrm{ext}} + \xi_{\mathrm{int}}(x,t)]\,\mathrm{d}x = j_0 + \Delta j(t). \tag{2}$$

The carrier concentrations $n(x,t)$ and $p(x,t)$ are obtained by solving the continuity equations for electrons and holes

$$\begin{aligned} \frac{\partial n(x,t)}{\partial t} &= G(x,t) - R_\mathrm{n}(x,t) + \mu_\mathrm{n}\frac{\partial}{\partial x}[n(x,t)\,\xi(x,t)] + D_\mathrm{n}\frac{\partial^2 n(x,t)}{\partial x^2}, \\ \frac{\partial p(x,t)}{\partial t} &= G(x,t) - R_\mathrm{p}(x,t) - \mu_\mathrm{p}\frac{\partial}{\partial x}[p(x,t)\,\xi(x,t)] + D_\mathrm{p}\frac{\partial^2 p(x,t)}{\partial x^2}, \end{aligned} \tag{3}$$

where μ is the extended-states mobility, and D is the diffusion coefficient. Subscripts (n or p) refer to electrons and holes, respectively. The recombination rates $R(x,t)$ are given by

$$\begin{aligned} R_\mathrm{n}(x,t) &= \int_{E_\mathrm{v}}^{E_\mathrm{c}} \{c_\mathrm{n} n(x,t)[1-f(E,x,t)] - e_\mathrm{n}(E)f(E,x,t)\}N(E)\,\mathrm{d}E, \\ R_\mathrm{p}(x,t) &= \int_{E_\mathrm{v}}^{E_\mathrm{c}} \{c_\mathrm{p} p(x,t)f(E,x,t) - e_\mathrm{p}(E) [1-f(E,x,t)]\}N(E)\,\mathrm{d}E \end{aligned} \tag{4}$$

where c is the capture coefficient, $e(E)$ is the emission coefficient, and $N(E)$ is the DOS.

In the low-modulation condition established when $I_1 >> I_2$, it is expected that the relevant physical parameters vary sinusoidally as $G(x,t)$ does. In general, however, there will be variable phase shifts, and any quantity (for example, the electron concentration) can be expressed as $n(x,t) = n_0 + \Re e\left[\sum_{\Omega=-\omega,0,\omega} n_\Omega\, \mathrm{e}^{\mathrm{i}(kx+\Omega t)}\right]$, where n_0 is the value under uniform illumination G_0, and n_Ω is a complex magnitude originated from the modulated term of the generation rate $\Delta G(x,t)$. Introducing these expressions for $n(x,t)$, $p(x,t)$, and $\xi(x,t)$ into the differential equations (1), (3), and (4) linearizes them, giving rise to the following three systems of linear complex equations (for $\Omega = -\omega,\ 0,\ \omega$)

$$\left\{\begin{array}{l} \left[\frac{1}{\tau_{\mathrm{nn},\Omega}} + k^2 D_\mathrm{n} + \frac{(1+Q_\Omega^-)}{\tau_{\mathrm{dn}}} + i(\Omega - k\mu_\mathrm{n}\xi_{\mathrm{ext}})\right] \times n_\Omega \\ + \left[\frac{1}{\tau_{\mathrm{pn},\Omega}} - \frac{(1+Q_\Omega^+)}{\tau_{\mathrm{dn}}}\right] \times p_\Omega = g_\Omega \\ \left[\frac{1}{\tau_{\mathrm{np},\Omega}} - \frac{(1+Q_\Omega^-)}{\tau_{\mathrm{dp}}}\right] \times n_\Omega \\ + \left[\frac{1}{\tau_{\mathrm{pp},\Omega}} + k^2 D_\mathrm{p} + \frac{(1+Q_\Omega^+)}{\tau_{\mathrm{dp}}} + i(\Omega + k\mu_\mathrm{p}\xi_{\mathrm{ext}})\right] \times p_\Omega = g_\Omega \end{array}\right. \tag{5}$$

The coefficients are given by

$$\frac{1}{\tau_{\mathrm{nn},\Omega}} = c_{\mathrm{n}} \int \left[1 - \frac{(c_{\mathrm{n}} n_0 + e_{\mathrm{n}})\tau}{1 + \mathrm{i}\Omega\tau}\right](1 - f_0)\, N \mathrm{d}E,$$

$$\frac{1}{\tau_{\mathrm{np},\Omega}} = c_{\mathrm{n}} \int \frac{(c_{\mathrm{p}} p_0 + e_{\mathrm{p}})\tau}{1 + \mathrm{i}\Omega\tau}(1 - f_0)\, N \mathrm{d}E,$$

$$\frac{1}{\tau_{\mathrm{pp},\Omega}} = c_{\mathrm{p}} \int \left[1 - \frac{(c_{\mathrm{p}} p_0 + e_{\mathrm{p}})\tau}{1 + \mathrm{i}\Omega\tau}\right] f_0\, N \mathrm{d}E,$$

$$\frac{1}{\tau_{\mathrm{pn},\Omega}} = c_{\mathrm{p}} \int \frac{(c_{\mathrm{n}} n_0 + e_{\mathrm{n}})\tau}{1 + \mathrm{i}\Omega\tau} f_0\, N \mathrm{d}E,$$

$Q_{\Omega}^{-} = c_{\mathrm{n}} \int \frac{\tau(1-f_0)}{1+\mathrm{i}\Omega\tau} N \mathrm{d}E$, $Q_{\Omega}^{+} = c_{\mathrm{p}} \int \frac{\tau f_0}{1+\mathrm{i}\Omega\tau} N \mathrm{d}E$, $\tau_{\mathrm{dn}} = \varepsilon\varepsilon_0/(q\mu_{\mathrm{n}} n_0)$ is the electron contribution to the dielectric relaxation time, and $\tau_{\mathrm{dp}} = \varepsilon\varepsilon_0/(q\mu_{\mathrm{p}} p_0)$ is the holes contribution to the dielectric relaxation time (τ_{d}). The integrals are evaluated between E_{v} and E_{c} (the energy dependence is omitted for the sake of clarity), and we call $\tau^{-1} = c_{\mathrm{n}} n_0 + c_{\mathrm{p}} p_0 + e_{\mathrm{n}} + e_{\mathrm{p}}$.

From the solution of Eqs. (5), analytical expressions for n_{Ω} and p_{Ω} can be obtained. Inserting them into Eq. (2), it is found that $\Delta j(t)$ has contributions in dc and at angular frequencies ω and 2ω

$$\Delta j^{\mathrm{dc}} = \Re e\left(\frac{\mathrm{i}q^2}{2k\varepsilon\varepsilon_0}\sum_{\Omega}\left\{\begin{array}{l} \mu_{\mathrm{n}}\left[n_{\Omega}p_{\Omega}^{*}(1+Q_{\Omega}^{+})^{*} - n_{\Omega}n_{\Omega}^{*}(1+Q_{\Omega}^{-})^{*}\right] \\ -\mu_{\mathrm{p}}\left[p_{\Omega}n_{\Omega}^{*}(1+Q_{\Omega}^{-})^{*} - p_{\Omega}p_{\Omega}^{*}(1+Q_{\Omega}^{+})^{*}\right] \end{array}\right\}\right), \tag{6}$$

$$\Delta j^{\omega} = \Re e\left(\frac{\mathrm{i}q^2 \mathrm{e}^{\mathrm{i}\omega t}}{2k\varepsilon\varepsilon_0}\left\{\begin{array}{l} \mu_{\mathrm{n}}\left[\begin{array}{l} n_{\omega}p_0^{*}(1+Q_0^{+})^{*} - n_{-\omega}^{*}p_0(1+Q_0^{+}) \\ +n_0 p_{-\omega}^{*}(1+Q_{-\omega}^{+})^{*} - n_0^{*}p_{\omega}(1+Q_{\omega}^{+}) \\ +n_{\omega}n_0^{*}(Q_{\omega}^{-} - Q_0^{-*}) + n_0 n_{-\omega}^{*}(Q_0^{-} - Q_{-\omega}^{-}{}^{*}) \end{array}\right] \\ -\mu_{\mathrm{p}}\left[\begin{array}{l} p_{\omega}n_0^{*}(1+Q_0^{-})^{*} - p_{-\omega}^{*}n_0(1+Q_0^{-}) \\ +p_0 n_{-\omega}^{*}(1+Q_{-\omega}^{-})^{*} - p_0^{*}n_{\omega}(1+Q_{\omega}^{-}) \\ +p_{\omega}p_0^{*}(Q_{\omega}^{+} - Q_0^{+*}) + p_0 p_{-\omega}^{*}(Q_0^{+} - Q_{-\omega}^{+}{}^{*}) \end{array}\right] \end{array}\right\}\right), \tag{7}$$

$$\Delta j^{2\omega} = \Re e\left(\frac{\mathrm{i}q^2 \mathrm{e}^{\mathrm{i}2\omega t}}{2k\varepsilon\varepsilon_0}\left\{\begin{array}{l} \mu_{\mathrm{n}}\left[\begin{array}{l} n_{\omega}p_{-\omega}^{*}(1+Q_{-\omega}^{+})^{*} - n_{-\omega}^{*}p_{\omega}(1+Q_{\omega}^{+}) \\ +n_{\omega}n_{-\omega}^{*}(Q_{\omega}^{-} - Q_{-\omega}^{-}{}^{*}) \end{array}\right] \\ -\mu_{\mathrm{p}}\left[\begin{array}{l} p_{\omega}n_{-\omega}^{*}(1+Q_{-\omega}^{-})^{*} - p_{-\omega}^{*}n_{\omega}(1+Q_{\omega}^{-}) \\ +p_{\omega}p_{-\omega}^{*}(Q_{\omega}^{+} - Q_{-\omega}^{+}{}^{*}) \end{array}\right] \end{array}\right\}\right), \tag{8}$$

where the superscript * means the complex conjugate. These current densities originate from the internal electric field that develops due to the modulated electron and hole distributions.

3 Experiments and simulations To test the results of our calculations, we implemented the MPG experiment with a configuration identical to the one described by Hattori et al. in Fig. 1 of Ref. [1], except that the electro-optic modulator was sinusoidally modulated. We measured a 1 µm thick hydrogenated amorphous silicon sample, prepared by PECVD from pure silane at a substrate temperature of 200 °C. We used a He–Ne laser with intensities $I_1 = 90\,\mathrm{mW/cm^2}$ and $I_2 = I_1/100$, providing a generation rate of $G_1 \cong 8 \times 10^{20}\,\mathrm{cm^3/s}$. The grating period was fixed at 1.13 µm, and the external electric field was $\xi_{\mathrm{ext}} = 100\,\mathrm{V/cm}$. The measurement was performed at room temperature and under ambient conditions. Figure 1 (symbols) presents the ac photocurrent measured as a function of the modulation frequency, where the components at frequencies f and $2f$ are shown. Therefore, the existence of a response in the second harmonic – as predicted by the calculations – is confirmed.

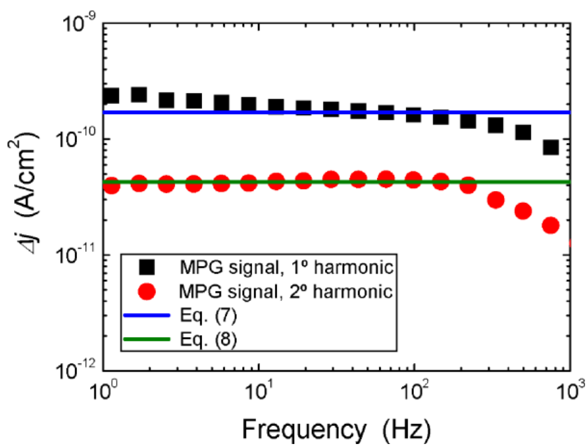

Figure 1 (online color at: www.pss-a.com) Measured (symbols) and calculated (lines) components of the modulated photocurrent in the first and second harmonic.

The existence of a dc component (Eq. (6)) could not be confirmed, because Δj^{dc} is much lower than j_0 and therefore difficult to measure.

We have also performed a numerical simulation of the experiment, starting from a typical DOS for hydrogenated amorphous silicon. We have taken standard values for the material parameters ($\mu_{\mathrm{n}} = 10\,\mathrm{cm^2/V/s}$, $\mu_{\mathrm{p}} = 1\,\mathrm{cm^2/V/s}$,

$c_n = c_p = 10^{-8}\,cm^3/s$), and we reproduced the experimental conditions (temperature, generation rates, grating period, external electric field). Then we solved the set of Eqs. (5) to get n_Ω and p_Ω, inserting them into Eqs. (6)–(8) to calculate the different components of Δj. The results of the calculations are also presented in Fig. 1 (lines), where we can see that Eqs. (7) and (8) agree with the measurements. The drop in the measured values at high frequencies is due to the limited bandwidth of the amplifier that we used. Therefore, we are confident that our theoretical description of the experiment is adequate. The calculations show that an internal electric field as high as 180 V/cm can develop at certain points inside the sample, even when $\xi_{ext} = 100$ V/cm, due to the influence of the trapped charge.

4 Simplified expressions If we concentrate on the first harmonicΔj^ω, after some calculations it can be written

$$\Delta j^\omega = -\frac{q^2}{2k\varepsilon\varepsilon_0}\left[(\mu_n A_n + \mu_p A_p)\cos(\omega t) - (\mu_n B_n + \mu_p B_p)\sin(\omega t)\right], \quad (9)$$

where we call

$$A_n = (1 + I_1^p)C_1 - (1 + I_2^p)C_2 + \omega\, I_3^p 3 - \omega\, I_3^n\, C_4 - \omega^2\, I_4^n\, C_5,$$
$$A_p = -(1 + I_1^n)C_2 + (1 + I_2^n)C_1 - \omega\, I_3^n C_6 + \omega\, I_3^p\, C_7 + \omega^2\, I_4^p\, C_8,$$
$$B_n = -(1 + I_1^p)C_6 + (1 + I_2^p)C_3 + \omega\, I_3^p C_2 - \omega\, I_3^n\, C_5 + \omega^2\, I_4^n\, C_4,$$
$$B_p = (1 + I_1^n)C_3 - (1 + I_2^n)C_6 - \omega\, I_3^n C_1 + \omega\, I_3^p\, C_8 - \omega^2\, I_4^p\, C_7,$$

with

$$I_1^n = c_n\int(1-f_0)\tau N\mathrm{d}E, \quad I_2^n = c_n\int\frac{(1-f_0)\tau}{1+\omega^2\tau^2}N\mathrm{d}E,$$
$$I_3^n = c_n\int\frac{(1-f_0)\tau^2}{1+\omega^2\tau^2}N\mathrm{d}E, \quad I_4^n = c_n\int\frac{(1-f_0)\tau^3}{1+\omega^2\tau^2}N\mathrm{d}E,$$

$$I_1^p = c_p\int f_0\tau N\mathrm{d}E, \quad I_2^p = c_p\int\frac{f_0\tau}{1+\omega^2\tau^2}N\mathrm{d}E,$$
$$I_3^p = c_p\int\frac{f_0\tau^2}{1+\omega^2\tau^2}N\mathrm{d}E, \quad I_4^p = c_p\int\frac{f_0\tau^3}{1+\omega^2\tau^2}N\mathrm{d}E,$$

$$C_1 = p_{re}^0(n_{im}^\omega + n_{im}^{-\omega}) - p_{im}^0(n_{re}^\omega + n_{re}^{-\omega}),$$
$$C_2 = n_{re}^0(p_{im}^\omega + p_{im}^{-\omega}) - n_{im}^0(p_{re}^\omega + p_{re}^{-\omega}),$$
$$C_3 = n_{re}^0(p_{re}^\omega - p_{re}^{-\omega}) + n_{im}^0(p_{im}^\omega - p_{im}^{-\omega}),$$
$$C_4 = n_{re}^0(n_{re}^\omega - n_{re}^{-\omega}) + n_{im}^0(n_{im}^\omega - n_{im}^{-\omega}),$$
$$C_5 = n_{re}^0(n_{im}^\omega + n_{im}^{-\omega}) - n_{im}^0(n_{re}^\omega + n_{re}^{-\omega}),$$
$$C_6 = p_{re}^0(n_{re}^\omega - n_{re}^{-\omega}) + p_{im}^0(n_{im}^\omega - n_{im}^{-\omega}),$$
$$C_7 = p_{re}^0(p_{re}^\omega - p_{re}^{-\omega}) + p_{im}^0(p_{im}^\omega - p_{im}^{-\omega}),$$
$$C_8 = p_{re}^0(p_{im}^\omega + p_{im}^{-\omega}) - p_{im}^0(p_{re}^\omega + p_{re}^{-\omega}).$$

Simplified expressions for the coefficients can be found for some particular conditions. We will concentrate here on the case of low electric field ($\xi_{ext} < 200$ V/cm), high angular frequency ($\omega\tau_d \gg 1$) and high grating period ($\Lambda > 10\,\mu$m), with the additional assumption that electrons are the majority carriers and are more mobile than holes. In that case, after lengthy calculations we find

$$\left|\Delta j_{MPG}^\omega\right| \cong \frac{g}{2G_0}\frac{|\Delta j_{MPC}|}{[1 + c_n\,\tau_n\,k_B T\,N(E_{tn})]}, \quad (10)$$

where $\left|\Delta j_{MPG}^\omega\right|$ is the modulus of the MPG signal at angular frequency ω, $|\Delta j_{MPC}|$ is the modulus of the MPC signal obtained under the same experimental conditions, τ_n is the electron recombination lifetime, k_B is Boltzmann's constant, T is the absolute temperature, and E_{tn} is the quasi-Fermi level for trapped electrons. Therefore, we have

$$N(E_{tn}) \cong \frac{q\mu_n G_0}{c_n k_B T\sigma_0}\left[\frac{\sqrt{G_1 G_2}}{2G_0}\frac{|\Delta j_{MPC}|}{\left|\Delta j_{MPG}^\omega\right|} - 1\right]. \quad (11)$$

This equation expresses the DOS at the quasi-Fermi energy as a function of material parameters (c_n and μ_n) and experimental magnitudes that can be easily measured (temperature, generation rate, photoconductivity, and the modules of the MPC and MPG signals). The quasi-Fermi energy E_{tn} can be evaluated from the steady-state photoconductivity σ_0, and it can be varied either from a temperature scan or a generation rate scan. That gives the basis for a DOS spectroscopy in the upper half of the band gap. The experimental setup is essentially the same for the MPG and MPC experiments, since this last experiment only requires introducing a polarizer to prevent the beams from interfering. The advantage of Eq. (11) with respect to MPC alone [7] is that only the modules are needed, instead of the modulus and the phase shift. This eliminates the complication of calibrating for additional phase shifts introduced by the equipment used to measure the ac photocurrents.

From the numerical simulations presented above we have calculated the MPC and MPG curves for a low electric field ($\xi_{ext} = 100$ V/cm), a high angular frequency ($\omega\tau_d \gg 1$), and a high grating period ($\Lambda = 20\,\mu$m). Then we applied Eq. (11) to reconstruct the DOS, changing E_{tn} from a variation of T and G_0. Figure 2 shows the reconstruction of the initially

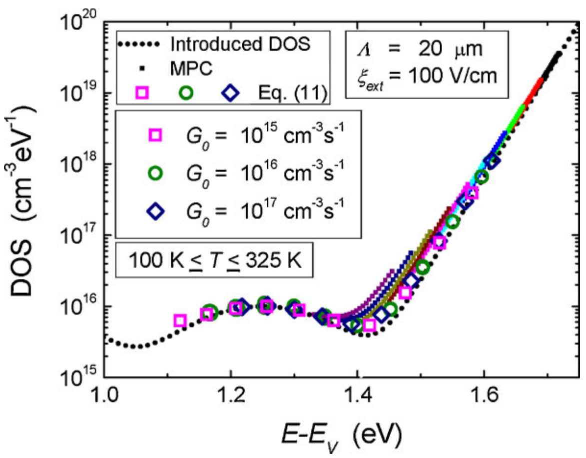

Figure 2 (online color at: www.pss-a.com) DOS used in our calculations (lines) and reconstruction by means of Eq. (11) and the usual MPC formula [7].

introduced DOS. As it can be seen, the DOS can be reconstructed with quite good accuracy. For comparison, the results of high-frequency MPC (Eq. (29) of Ref. [7]) are also presented. Similar results have been obtained from several simulations for different DOS. Therefore, the method proves to be a valuable means to estimate the DOS in the upper half of the gap of photoconductors.

5 Conclusion We have provided a theoretical description of the MPG experiment. We have obtained a general expression for the photocurrent under modulated grating conditions, showing that the response of the sample involves signals in dc, in the first harmonic and in the second harmonic. We have shown that under certain conditions the DOS at the quasi-Fermi level for the majority carriers is related to the ratio of the MPG and MPC signals. This makes possible to estimate the DOS as a function of energy by changing the temperature and the generation rate. We have performed simulations starting from a DOS typical for a-Si:H, and we have shown that the method is able to reproduce the introduced DOS.

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