

MOBILITY-LIFETIME PRODUCTS IN MICROCRYSTALLINE SILICON

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Experimental values for mobility-lifetime products in microcrystalline silicon are examined. The minority-carrier mobility lifetime product is put in relation with sub-gap absorption. Instabilities reported for the dark conductivity in microcrystalline silicon also affect the photoconductivity values. Comparison between samples is difficult because of the possible influence of thermal history on the photoconductivity or majority carrier mobility lifetime product. We also comment on the use of mobility-lifetime products to linking excess carrier properties to the Fermi energy in microcrystalline silicon.

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1. Introduction

Values for mobility-lifetime products in hydrogenated amorphous silicon (a-Si:H) and microcrystalline ($\mu\text{c-Si:H}$) are important parameters not only for reference to sample quality but also to reveal underlying physics of recombination and transport and to construct a relation to the density-of-states (DOS) in the band gap. The experimental techniques for their determination are steady-state photoconductivity (SSPC) for the majority-carrier $\mu\tau$ product $(\mu\tau)_{\text{maj}}$ and the steady-state photocarrier grating technique (SSPG) [1] for the minority-carrier $\mu\tau$ product $(\mu\tau)_{\text{min}}$.

In this paper we focus on three aspects related to the determination, interpretation and reliability of values for $\mu\tau$ in microcrystalline silicon: a) is there, and if, what is the relation between sub-gap absorption and minority carrier mobility-lifetime products, b) how do metastabilities or instabilities that have been reported for the dark conductivity σ_d [2-6] affect the photoconductivity or majority carrier mobility-lifetime product and c) how precise a parameter for $\mu\text{c-Si:H}$ is the value of b that represents the ratio of majority to minority carrier mobility-lifetime product and is used to relate excess carrier properties to thermal equilibrium properties [7-9].

2. Experimental

Microcrystalline silicon samples from hot-wire chemical vapour deposition (HWCVD) and plasma-enhanced chemical vapour deposition (PECVD) deposited at Ecole Polytechnique, Palaiseau, and Institut für Physikalische Elektronik, Stuttgart, were investigated with a range in values for crystalline volume fraction. Typical thicknesses ranged between 300 nm and 1500 nm. Coplanar Al electrodes were evaporated for current measurements. A red HeNe laser for illumination provided a typical photon flux between $5 \times 10^{16} \text{ cm}^{-2} \text{ s}^{-1}$ and $10^{17} \text{ cm}^{-2} \text{ s}^{-1}$. Further details

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concerning the conditions of the sample during the measurements like vacuum or air will be given with the presentation of the results. Additional results on the samples can be found in [3,10].

3. Results and discussion

3.1. Sub-gap absorption and minority-carrier mobility-lifetime product

Sub-gap absorption, as measured for example with the constant photocurrent (CPM) method, indicates the existence of states in the band gap, although the direct relation to an absolute value for the DOS is still under debate [11] depending on the so-called DC or AC mode of CPM. Nevertheless we take the value of the absorption coefficient α at sub-gap energies in $\mu\text{c-Si:H}$ from CPM as a rough measure of sub-gap density-of-states.

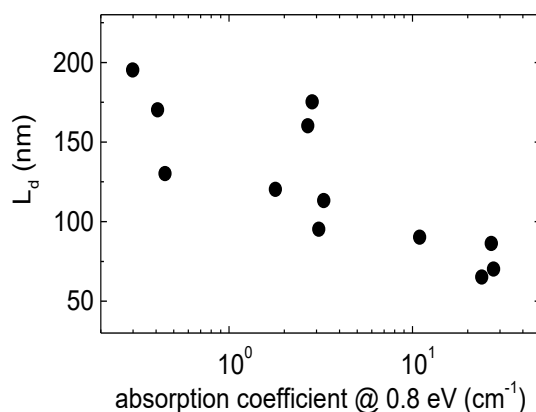


Fig. 1. Variation of the minority-carrier product with sub-gap absorption coefficient. The range in diffusion length for the values is from 200 nm to about 50 nm. These short diffusion length are difficult to measure and the given low values are upper limits because of the experimental procedure in SSPG.

Fig. 1 shows results from measurements in air for the variation of L_d , determined by SSPG, for a number of $\mu\text{c-Si:H}$ samples for which α was determined from AC-CPM measurements at 0.8 eV. The data indicate a moderate decrease of L_d with increasing $\alpha(0.8 \text{ eV})$. From measurements performed on many samples the diffusion length for minority carriers (or minority carrier $\mu\tau$ product) is a better indicator for sample quality than the majority carrier $\mu\tau$ product which has been shown to depend also on the Fermi level position [12]. Samples with sub-gap absorption at 0.8 eV lower than 10 cm^{-1} have diffusion lengths shorter than 100 nm. The highest values at 200 nm or above relate to sub-gap $\alpha(0.8 \text{ eV})$ of less than 1 cm^{-1} . In fact, results for additional samples were not shown in Fig. 1 because the standard CPM experiment could not provide data points for $\alpha(0.8 \text{ eV})$ as measurement of large enough photocurrents for the very low $\alpha(0.8 \text{ eV})$ values was not possible. The small influence of the large variation of $\alpha(0.8 \text{ eV})$ on L_d is likely to be related to the fact that the quasi-Fermi energy of holes does not reach into the DOS that is probed by CPM.

3.2. Instabilities in photoconductivity and majority-carrier mobility-lifetime product

Heat treatment in vacuum at elevated temperatures to remove adsorbates has been shown to result in changes in the dark conductivity [2-6]. Both increase and decrease in the room-temperature dark conductivity have been reported. It is also possible that the dark conductivity hardly changes upon heat treatment [13]. The value of the photoconductivity has been shown to depend on the dark conductivity in $\mu\text{c-Si:H}$ so that it is important to estimate the reliability of values for photoconductivity or majority carrier mobility-lifetime products in $\mu\text{c-Si:H}$.

We have investigated the changes in the photoconductivity upon heat treatment in vacuum for which Fig. 2 shows an example. It illustrates the change in the dark current and also the

corresponding change in photocurrent for a HWCVD $\mu\text{-Si:H}$ sample after heat treatment in vacuum at about 90 °C. The room-temperature value of the dark current increases by a factor of about 10 after heat treatment with an increase in the photocurrent of about a factor of 2.

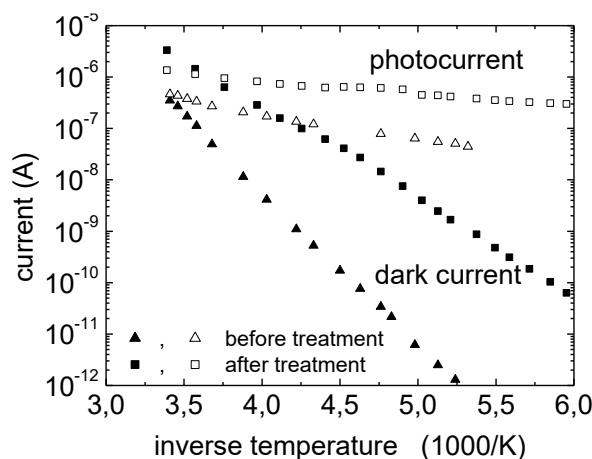


Fig. 2. Examples of the different behaviour of the photocurrent upon heat treatment. Open symbols show the photocurrent, close symbols the dark current. The dark current increases upon heat treatment and so does the photocurrent.

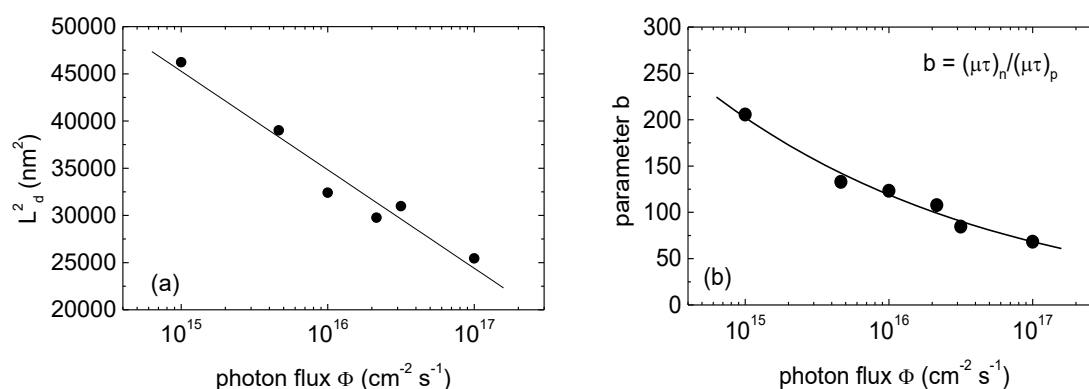


Fig. 3. Variation of minority-carrier diffusion length L_d with photon flux (a). The square of L_d is proportional to $(\mu\tau)_{\min}$. The parameter b changes between values of above 200 to below 90 (b).

We note that the observed changes are rather related to the influence of adsorbates on the band bending than on annealing of defects. Values must be taken with caution and, as suggested in [4] a well-defined experimental procedure should be agreed upon so that samples only with comparable thermal history are compared.

3.3. Relationship between excess carrier and thermal equilibrium carrier densities in $\mu\text{-Si:H}$

Fig. 3(a) shows the variation of the square of the diffusion length L_d which usually is proportional to the minority-carrier mobility lifetime product, with variation in the photon flux. The values for L_d vary between 215 nm and 160 nm. The value for b in Fig. 3(b), deduced from L_d and from SSPC, changes by a factor of 2 when Φ varies by two orders of magnitude. The variation of b

with photon flux is one problem that arises when relating b to the Fermi energy E_f in the sample as suggested [7,8]. The value of b should be unambiguously related to E_f and not be dependent of photon flux.

The usefulness of taking b as an indicator of E_f in $\mu\text{c-Si:H}$ is also limited because no one-to-one relation between b and the room-temperature σ_d can be found experimentally for the whole range of dark conductivities observed. Inspection of the data in [7,8] shows that b does vary with σ_d in the range between $10^{-5} \Omega^{-1} \text{ cm}^{-1}$ and a few times $10^{-4} \Omega^{-1} \text{ cm}^{-1}$. At lower σ_d values between $10^{-5} \Omega^{-1} \text{ cm}^{-1}$ and $10^{-7} \Omega^{-1} \text{ cm}^{-1}$, however, there is no one-to-one correlation in the b and σ_d data in [7,8]. As for a-Si:H [9], b appears to be only a very rough indicator for Fermi energy position.

4. Conclusions

We have raised three issues related to mobility-lifetime products in microcrystalline silicon. The presented observations will assist in putting together a more complete picture on transport and recombination in microcrystalline silicon.

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