CHARACTERIZATION OF SOLAR GRADE SILICON BY DEEP LEVEL TRANSIENT SPECTROSCOPY (DLTS)

(CHARAKTERISIERUNG VON SOLARSILIZIUM MITTELS DEEP LEVEL TRANSIENT SPECTROSCOPY (DLTS))

Klaus Wendl, Viktor Schlosser, Karlheinz Seeger Ludwig Boltzmann Institut für
Festkörperphysik A-I060 Wien, Kopernikusgasse 15

ÜBERSICHT: Entscheidend für eine breitere Anwendung photovoltai-scher Solargeneratoren auf Si-Basis ist eine Senkung der Herstellungskosten. Dies hat in letzter Zeit zur Entwicklung einer Vielzahl neuer Ausgangsmaterialien für die Solarzellenproduktion geführt. Hierbei muß zum Teil ein hoher Gehalt an Verunreinigungen in Kauf genommen werden, der zu einer Herabsetzung des Wirkungsgrades der Solarzellen führt. Ein besseres Verständnis dieser Störstellen ist für eine industrielle Anwendung unerläßlich.

Eine Möglichkeit zur Charakterisierung von Störstellen in Silizium stellt die Deep Level Transient Spectroscopy (DLTS) dar. Die Messung von Kapazitätstransienten an Dioden, Schottky-Kontakten oder MIS-Strukturen bei gepulster Vorspannung und veränderlicher Temperatur gibt Aufschluß über Aktivierungsenergie, Konzentration und Füllkinetik (Einfangsguerschnitt) von Haftstellen. Durch Veränderung der Vorspannung und der Pulshöhe gewinnt man auch Informationen über die räumliche Verteilung der Störstellen.

ABSTRACT: An important aspect for a broad application of photovoltaic solar energy conversion by silicon-based solarcells is a significant reduction of production costs. This explains increasing efforts to develope new materials and process-technologies. Some of these materials contain a large amount of impurities, involving a reduction of solar-cell efficiency. For an industrial application it is necessary to understand the behaviour of impurities and their influence on solar-cell parameters.

One possibility for the characterization of impurities in silicon is Deep Level Transient Spectroscopy (DLTS). The measurement of capacitance transients resulting from a diode, Schottky-barrier or MIS-structure under pulsed bias voltage and swept temperature can give information about the activation-energy, concentration and capture cross-section of a carrier-trap. Impurity depth-profiles can be obtained by varying bias voltage and pulse height.

DLTS (Deep Level Transient Spectroscopy) was introduced by D. V. Lang at Bell Laboratories in 1974, and is a method for observing carrier traps in semiconductors [1]. DLTS is a temperature biased measurement of capacitance-transients resulting from a diode, Schottky-barrier or MIS-structure under pulsed bias voltage. The injection pulse is used to fill the carrier traps in the depletion region caused by a constant reverse baseline voltage. In some cases also an optical excitation source is used [2]. By measuring the capacitance transients after reaching the steady-state bias conditions, the release of carriers from the traps can be monitored. The emission process depends on temperature, hence the transients also change their shape with temperature. The capacitance difference between two times t1 and t2 forms the so called DLTS-signal

$$\Delta C = C(t1) - C(t2) \qquad \text{(Fig. 1)} .$$

The DLTS-signal originating from one trap level will have a peak at a certain temperature for a chosen time constant

$$\tau = (t1-t2) / \log(t1/t2) .$$

The magnitude of the peak is related to the concentration of the trap level in the whole depletion region. In practice multiple trap levels and therefore multiple peaks are observed in a DLT-spectrum.

By changing ti and t2, another time constant τ can be set. This results in a shift of the peaks in the DLT-spectrum towards other temperatures. Now the activation-energy of the traps can be calculated from an Arrhenius-plot of $\log(\tau)$ versus 1/T, where T is the temperature where the peaks occur in the DLT-spectra

(Fig. 2).

One can obtain information on the filling processes (namely the capture cross-sections) by varying the length of the filling pulse and monitoring the peak heights in the DLT-spectra.

By varying the baseline voltage the depth of the depletion-region can be controlled and by reducing the pulse height only trap levels within a certain part of the space-charge region are allowed to fill. This yields in a separate depth profile for each impurity level [3].

The outpointed features show, that DLTS can be a powerful tool for the development of new materials and process-monitoring.

Additional benefits are:

- nondestructive measurement
- well known sample preparation
- low preparation effort
- only electrically active impurities are detected.

At our institute a fully computerized DLTS-system (Fig. 3) based on a HP 4280 sampling capacitance bridge and a closed-cycle refrigerator charged with He-gas has been developed. The actually used temperature range is 40-400 K. The microprocessor controlled capacitance bridge works at a frequency of 1 MHz and can process a large amount of data during a single temperature sweep. All measurement parameters are digitally set by the computer. Data from 5 different measurement points can be collected simultaneously with a scanner. Except for sample interchange there is no manual interaction with the system. Sweeping ranges for all parameters are set interactively from a computer terminal. DLTS-data as well as CV and IV data of the 5 samples are displayed on a graphics screen or the system plotter. The system allows continuous automatic operation and is therefore well suited for laboratory- and industrial applications.

Different approaches have been investigated to reduce costs of silicon production for solar cell applications. One approach is to avoid formation and purification of chlorosilanes by either upgrading metallurgical grade silicon coming from the arc furnace or-by purifying the starting materials, quartz and carbon, prior to the reduction of silicondioxide [4]. Although the quality of the resulting material is lower than the quality of electronic grade silicon, recently published results for solar cells prepared from UMG-Si show that conversion efficiencies as high as 85 per cent compared to solar cells from electronic grade silicon can be reached under standard test conditions [5]. Previous papers deal with the characterization of UMG-Si [6,7,8]. At present it is intended to obtain further information about that material by DLTS measurements.

References:

[1] D. V. Lang, J. Appl. Phys. 45 (1974) 3023

[2] H. Lefvre, M. Schultz, J. Appl. Phys. 12 (1977) 45

[3] A. Mittoneau et al., Inst. Phys. Conf. Ser. 33a (1977) 73

[4] H. A. Aulich, "Progress in Solargrade Silicon Production", paper presented at 17th IEEE PV Specialists Conf., May 1984,(Orlando, Florida)

[5] H. A. Aulich et al., "Progress on the Carbothermic Production of Solargrade Silicon using High-purity Starting Materials", paper presented at 17th IEEE PV Specialists Conf., May 1984,(Orlando, Florida)

[6] V. Schlosser, F. Kuchar, K. Seeger to be publ. in Proc. 5th PV Solar Energy Conf. (Athens), 1983, D. Reidel Publ. Comp., 1983

[7] V. Schlosser, K. Wendl, K. Seeger, 'Study of Diffused Solar Cells Based on Upgraded Metallurgical Grade Silicon", paper presented at 17th IEEE PV Specialists Conf., May 1984, (Orlando, Florida)

[8] V. Schlosser, IEEE Trans. on Electron. Dev. ED-31 (1984) 610

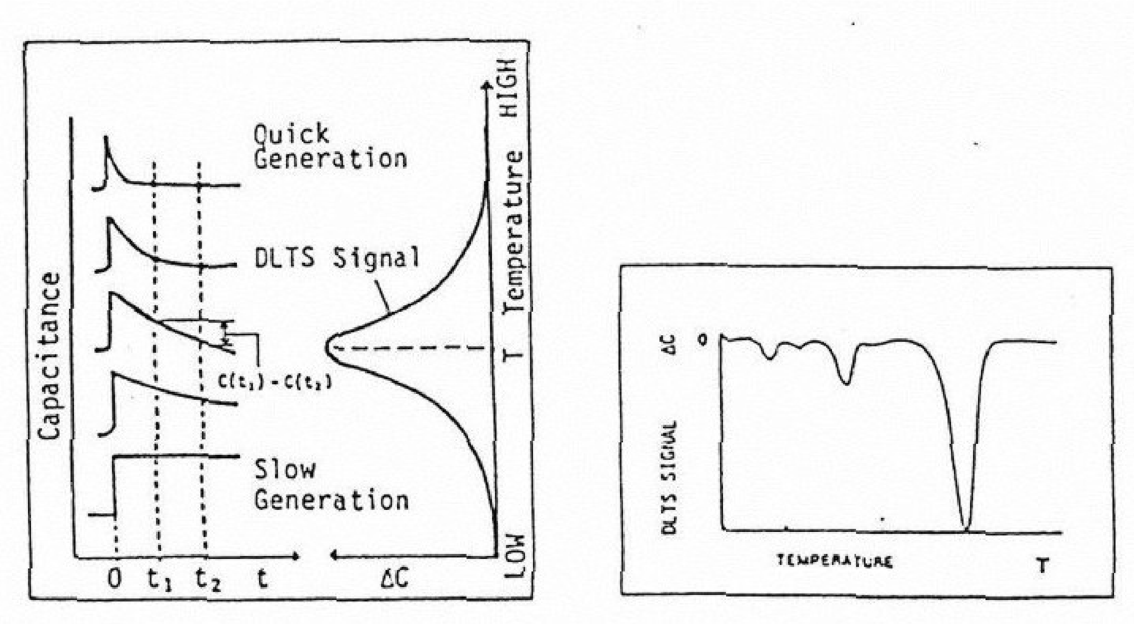

Fig. 1: Temperature dependent capacitance-transients. DLT-spectrum showing multiple trap levels.

Temperaturabhängige Kapazitätstransienten. DLT-Spektrum mit mehreren Störstellenniveaus.

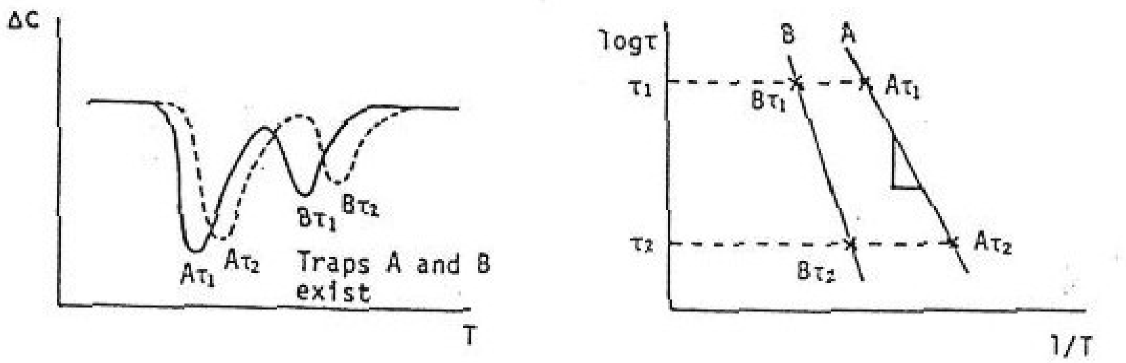

Fig. 2: DLT-spectra resulting from different time constants. Trap-energy is related to the slope of an Arrhenius-plot.DLT-Spektren für verschiedene Zeitkonstanten.

Aus der Steigung im Arrhenius-plot kann die Aktivierungsenergie der Störstellen bestimmt werden.

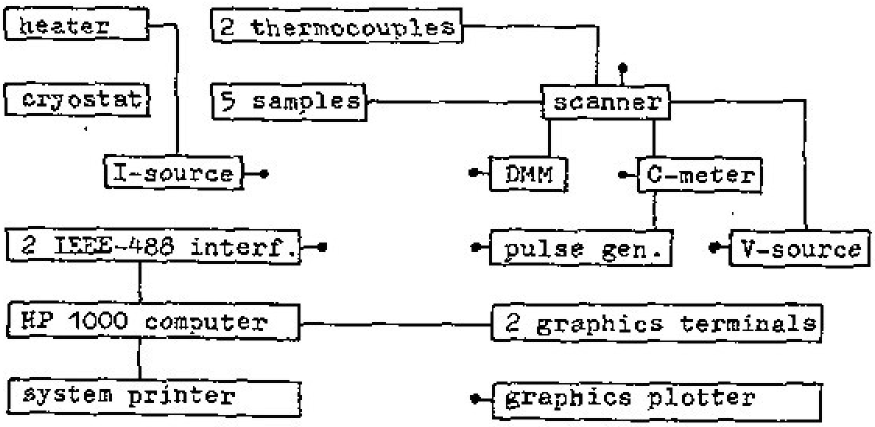

Fig. 3: Computer controlled DLTS-system.Computergesteuerte DLTS-Anlage