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ScienceDirect

Energy Procedia 124 (2017) 47–52

Energy Procedia

www.elsevier.com/locate/procedia

7th International Conference on Silicon Photovoltaics, SiliconPV 2017

Temperature dependent photoluminescence imaging calibrated by photoconductance measurements

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Abstract

In this paper we present a novel method for measuring temperature dependent lifetime images with high spatial resolution using photoconductance calibrated photoluminescence (PL) imaging. In order to achieve this, PL images are recorded at various temperatures by implementing a temperature stage into a commercial, steady state PL imaging setup. Carrier lifetime images are then calculated from the detected PL intensity, based on quasi-steady state photoconductance calibration measurements performed at the same temperatures that are used for the PL images. By analysing the carrier lifetime data as a function of injection level and temperature, this method allows for in-depth, spatially resolved defect characterization of Si wafers. Such temperature dependent lifetime data are also useful as input for device simulations of the temperature coefficient of solar cell efficiency. The uses of the method are illustrated with different examples based on commercial high performance multicrystalline Si wafers.

Peer review by the scientific conference committee of SiliconPV 2017 under responsibility of PSE AG.

Keywords: Carrier lifetime, temperature, photoluminescence, imaging, photoconductance

1. Introduction

Minority carrier lifetime measurements based on PL imaging has been a popular characterization method in Si solar cell research and engineering since it was introduced in 2006 [1]. In the latest years, there has been an increasing interest for using the method for temperature and injection dependent lifetime spectroscopy with spatial

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Peer review by the scientific conference committee of SiliconPV 2017 under responsibility of PSE AG.
10.1016/j.egypro.2017.09.338

resolution. Such measurements have normally been performed by so-called harmonically modulated PL measurements [2–4], where the carrier lifetime is calculated from the detected PL signal in a purely optical manner. This however requires expensive and often custom-built measurement setups with time resolved excitation and detection of the PL signal. Most PL imaging setups available in solar cell research laboratories today are based on steady state excitation and detection, and the PL intensity is therefore calibrated using an external QSSPC measurement [5,6]. However, the calibration constant is strongly temperature dependent, caused by a complex combination of the luminescence properties of the sample and the sensitivity of the camera at different wavelengths [7]. These effects can be taken into account theoretically [8], but the added complexity introduces several uncertainties in the quantification of the carrier lifetime from the measured luminescence signal. We therefore suggest a way to perform these measurements with individual QSSPC calibration measurements at each temperature. The advantage of this approach is that temperature dependent lifetime images can be obtained using relatively uncomplicated measurement setups with steady state detection systems (in contrast to the method used in Ref. [2]), and with few assumptions and possible sources for error (in contrast to the approach presented in Ref. [8]).

2. Experimental setup

Minority carrier lifetime curves were measured as a function of the excess carrier density at a range of temperatures using a Sinton WCT-120 TS lifetime tester. In this setup, the inductive coil used for photoconductance measurement is built into a temperature controlled sample stage, allowing for lifetime measurement in the temperature range from 25 to 200 °C [9]. Subsequently, uncalibrated PL intensity images were recorded as a function of temperature by building the WCT-120 TS heating stage into a LIS-R1 setup from BT imaging with an excitation wavelength of 808 nm. By using the same heating stage and temperature controller for both series of measurements, the error in the absolute wafer temperature for each pair of QSSPC and PL measurements was minimized. A constant photon flux of 1×10^{17} $cm^{-2}s^{-1}$ was used for the measurements presented below. The carrier lifetime images were finally calculated automatically based on similar algorithms used for room temperature measurements [10]. To ensure stable conditions and reduce the operator time needed each temperature series was measured automatically at set temperature intervals during cooling. The maximum temperature was set at a sufficiently low value in order to avoid permanent annealing effects, such as lifetime regeneration after light induced degradation (LID) related to boron-oxygen defects or iron-boron pairs. Such annealing effects were ruled out in each case by performing a reference QSSPC measurement at room temperature before and after each temperature scan.

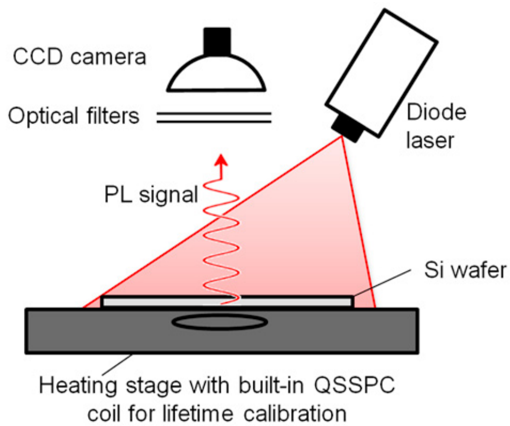

Fig. 1. Schematic illustration of the measurement setup. The wafer is placed on a heating stage during the PL imaging measurement, and the PL images are calibrated in post processing based on QSSPC measurements performed at each temperature.