LED-Based Photoluminescence Inspection of Crystalline Silicon As-Cut Wafers

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Martin Regehly[1], Roman Kemmler[1]

[1] greateyes GmbH, Rudower Chaussee 29, 12489 Berlin, Germany, email: info@greateyes.de

ABSTRACT

Photoluminescence (PL) imaging has become an indispensable tool for quality control and optimisation along the whole process chain of solar cell manufacturing. It delivers spatially resolved information about important material properties and is therefore widely used within production as well as research and development.

We are reporting about a novel LED-based PL inspection system capable of imaging as-cut silicon wafers for quantitative analysis. Previously such characterisation has only been reported for PL systems employing powerful near-infrared emitting lasers. In contrast to laser-based systems, LEDs are offering unique advantages like higher flexibility, scalability, and safety, all at reduced cost. Besides as-cut imaging, the proposed system enables characterisation of preprocessed wafers and finished cells below 1sec as well. This opens the possibility for in-line integrations. The compact system furthermore features electroluminescence (EL) and dark lock-in thermography (DLIT) measurement capability making it a versatile, cost-effective tool.

MOTIVATION

The PL emission of as-cut wafers is decreased by multiple orders compared to finished solar cells. As-cut imaging systems are traditionally employing lasers because of high illumination intensities and narrow spectral bandwidths. This results in sufficient PL intensity at the detector side and high contrast ratio between PL signal and reflected laser light contributing to the signal. On the other side, high acquisition costs for laser-based systems are an obstacle for wide usage and they also provide limited flexibility in terms of excitation wavelength and larger substrates. LEDs as excitation source enable flexible arrangements in stacks or arrays to illuminate larger areas. Safety restrictions are less critical and a variety of emission wavelengths are available at reduced cost.

The use of LEDs for PL measurements remains difficult because of their long tail emission extending into the PL emission wavelength region as well as lower intensities. For these reasons no LED-based PL system with as-cut imaging capability has been commercially available up to the presence. Our work aimed to develop such system with multiple functionalities.

APPROACH

The system (*Figure 1*) is a combined EL, PL, and DLIT off-line inspection tool. It consists of two software-controlled power supplies, one for the LED-based PL excitation source and the other capable of four-quadrant operation (+/-20V, +/-10A) for EL, biased PL and DLIT measurements. The LED light source has a centre emission at 650nm and operates at significant shorter wavelengths compared to laser sources. For EL and PL imaging a scientific deep-depletion CCD camera with thermoelectric cooling, 16bit ADC, and 1 megapixel (GE 1024 1024 DD NIR) is utilised. It delivers a quantum efficiency of 25% at 1000nm. A set of filters blocks the reflected LED excitation light from the camera detector. A Windows based software package controls the complete system, allowing to switch between different characterisation techniques.

Central innovation is an improved filter concept to suppress the long emission tail of the LEDs and therefore enhance the contrast ratio between PL signal and reflected LED light.

Figure 1: Inspection System with integrated EL, PL and DLIT capability.

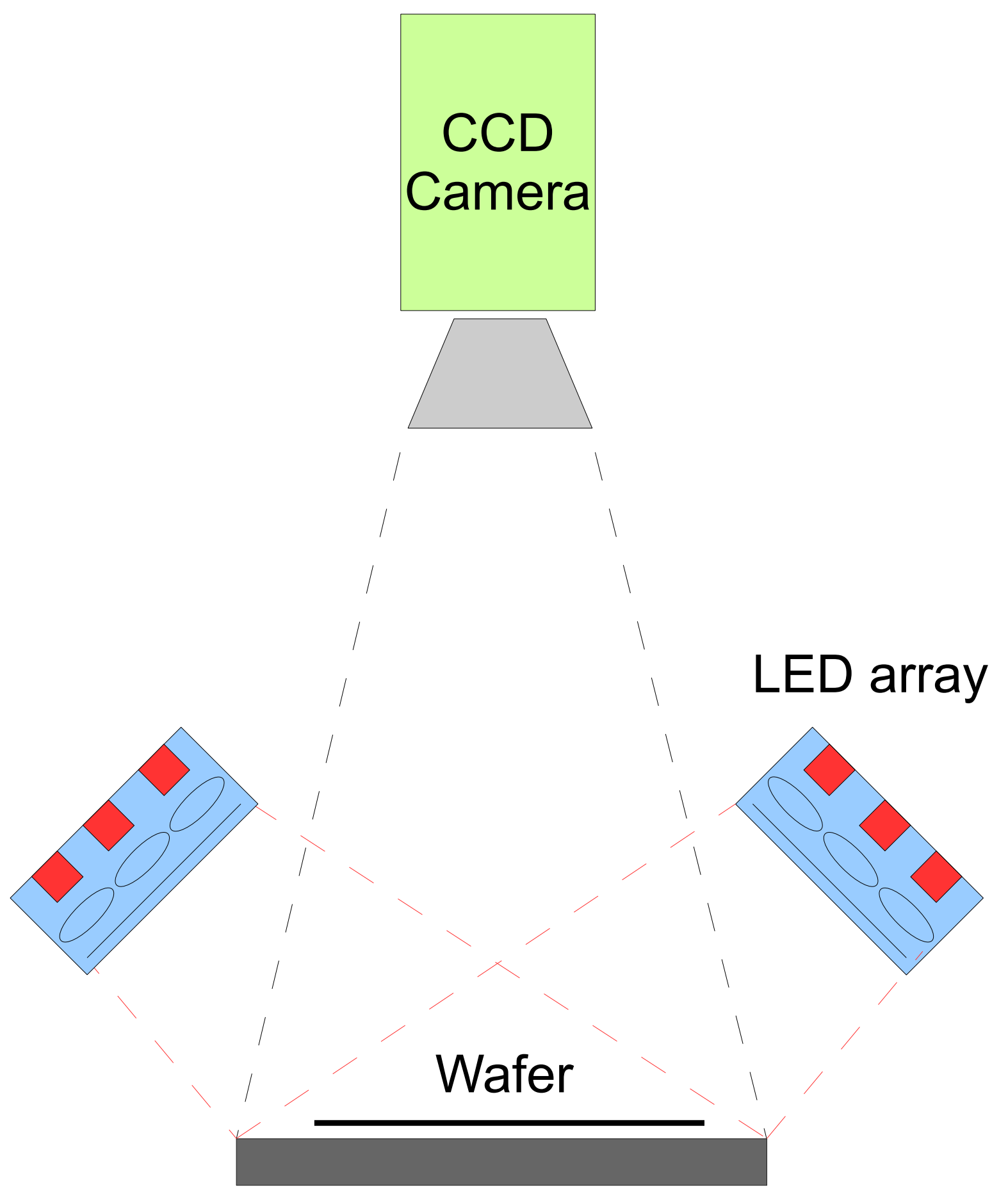

Figure 2: Schematic drawing of the PL system

RESULTS

All PL images where taken from 6 inch multicrystalline as-cut wafers and feature a spatial resolution of 155µm/pixel. Exposure time was set to 120sec. The CCD was cooled to -40°C in order to reduce dark current. Shorter acquisition times of 60sec were possible but led to images of less contrast.

Figure 3, *4*, and *5* display grain boundaries and recombination active dislocation areas. *Figure 5* shows a typical impurity pattern at the edges. The signal-to-noise ratio of the images and the low content of reflected LED light contribution enables further quantitative analysis of the data.

We aimed to demonstrate the feasibility of an as-cut characterisation through a LED-based system and focused on image quality instead of measurement speed.

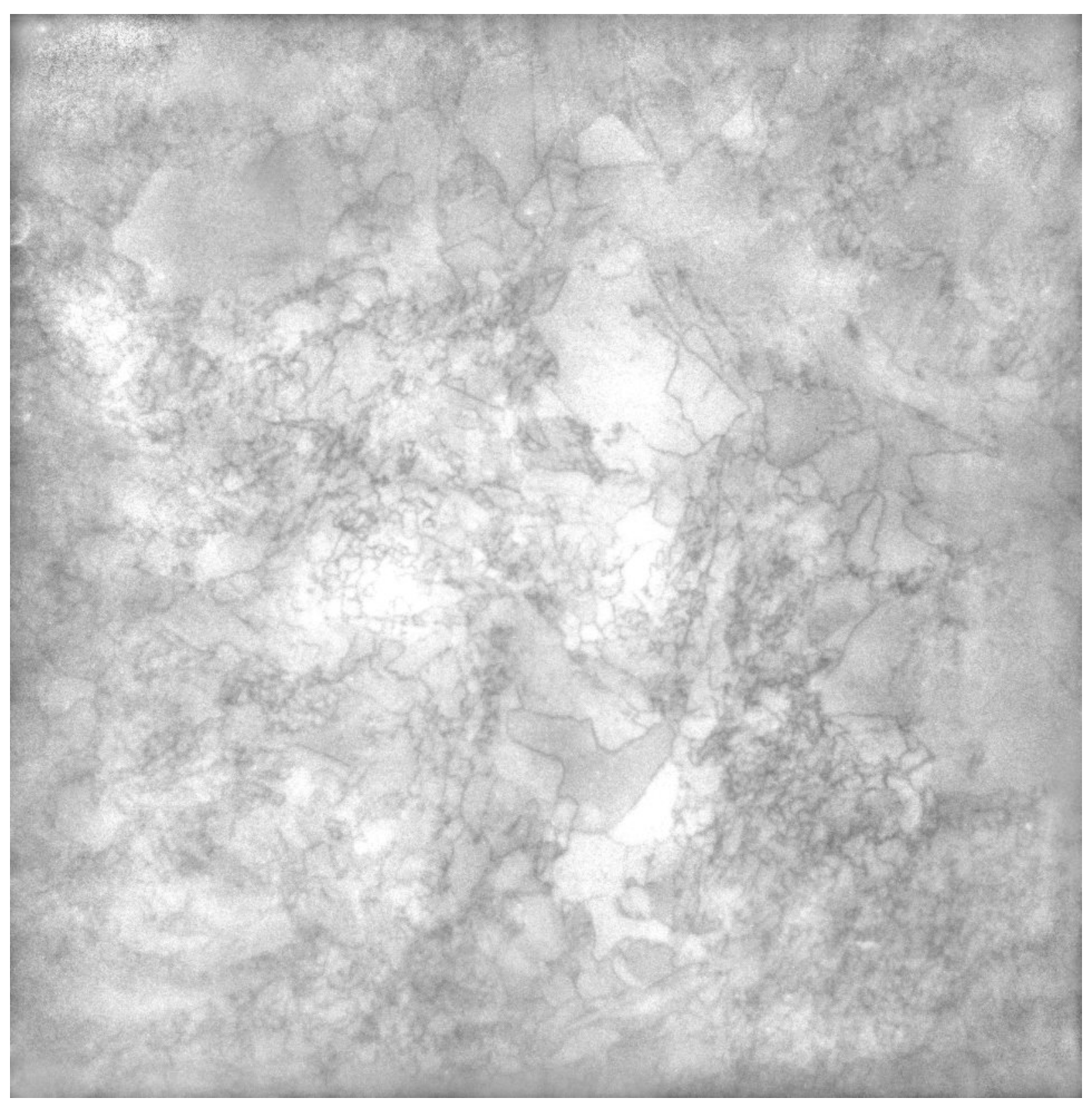

Figure 3: PL image of a multi as-cut wafer. LED excitation source

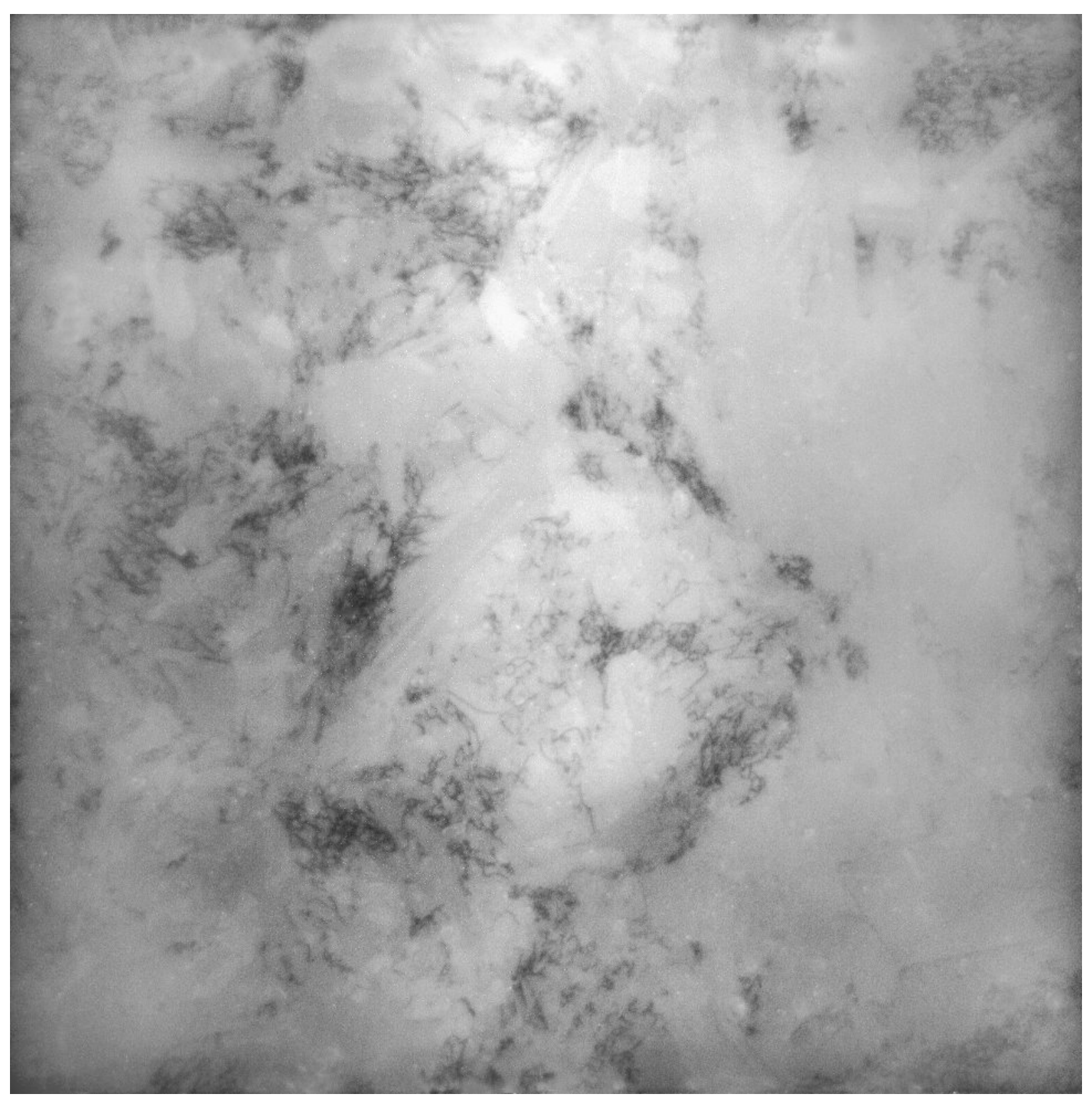

Figure 4: PL image of a multi as-cut wafer. LED excitation source

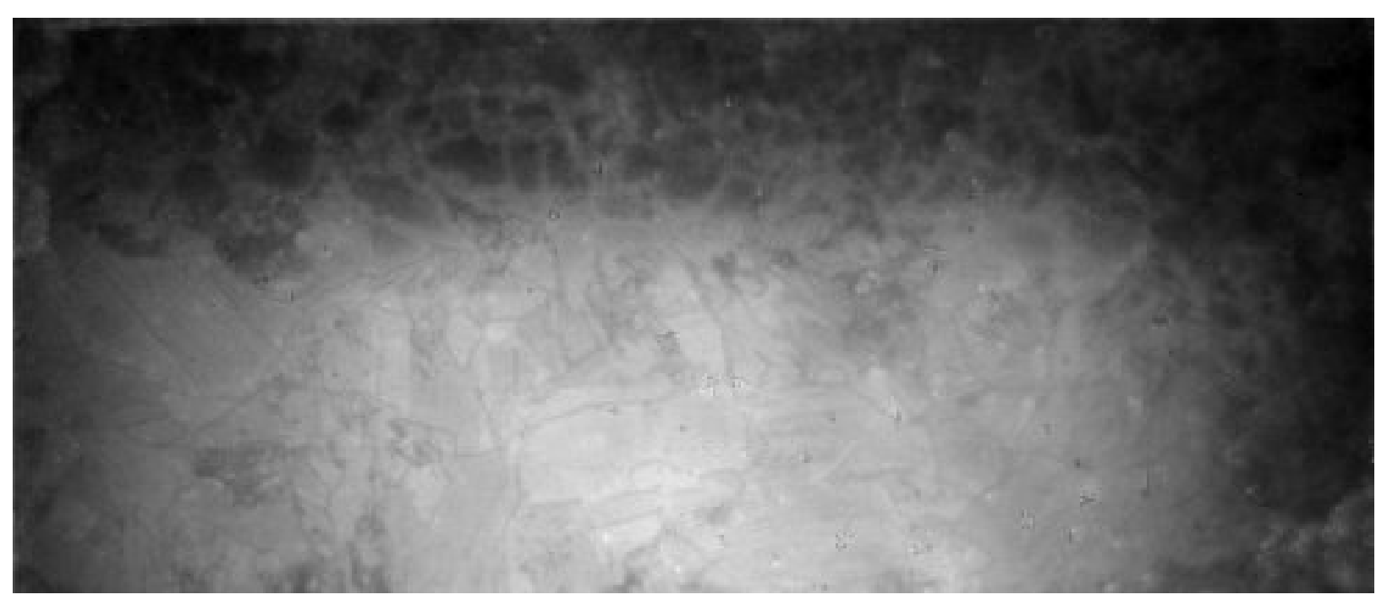

Figure 5: PL image of a multi as-cut wafer. LED excitation source

OUTLOOK

For further reduction of measurement time, higher illumination intensities at the sample surface must be realized. A straight forward approach is to integrate a higher number of LEDs on the same footprint. This requires design changes towards smaller LED lenses and a more efficient heat removal. Next generation high power LEDs will support this route. Special care has to be taken with respect to wafer cleanness because dust particles on the wafer surface generate strong luminescence signals under 650nm excitation.

SUMMARY

PL inspection of as-cut wafers with a LED-based system is a novel and cost-attractive method compared to classical laser-based systems. With this work we are demonstrating that LED-based PL systems are capable of measuring as-cut wafers in a front side illumination measurement scheme.

Besides as-cut imaging, the integrated EL, PL, and DLIT inspection system is a compact and cost-effective tool for characterisation of processed wafers and finished silicon-based cells. New thin-film substrates and organic photovoltaic devices can also be studied using this innovative instrument.