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Scribing of Thin-film Solar Cells with Picosecond Laser Pulses

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Abstract

The thin-film CIGS technologies for photovoltaics are attractive due to their potential low cost and optimal performance. Efficiency of cells with a large area might be maintained if small segments are interconnected in series in order to reduce photocurrent in thin films and resistance losses, and laser scribing process is crucial for performance of the device. We present our results on scribing of CIGS thin-film solar cells with single and multiple parallel laser beams with the picosecond pulse duration. Solar-cell performance tests were performed before and after laser scribing together with Raman spectroscopy analysis. The quality of processing was evaluated with optical and scanning electron microscopes.

Keywords: Thin-film; CIGS; picosecond laser; solar cell scribing; Raman spectra; solar cell efficiency

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1. Introduction

Continued demand for renewable energy sources stimulates development of various solar cell technologies on flexible and rigid substrates. The thin-film PV technologies based on $CuIn_xGa_{(1-x)}Se_2$ (CIGS) become more attractive due to their potential in lowering the production cost and optimization of photoelectrical performance. Other properties such as flexibility, good power-weight ratio, resistance to radiation make CIGS solar cells ideal for space use, automotive industry and complex structure building integrated applications.

CIGS has been established as the most efficient thin-film technology in converting sunlight into electricity with the theoretical limit as high as 27% [1] and a record value of 20.3% achieved in the laboratory [2]. The manufacturing costs and cell efficiency are critical factors for the wider applicability in terms of economical point of view. Efficiency of thin-film solar cells with a large active area might be maintained if small segments are interconnected in series in order to reduce photocurrent in thin films and resistance losses, and laser scribing is crucial for performance of the device.

A comprehensive study of thin film scribing for photovoltaics including CIGS with different types of lasers has been conducted by Compaan et al. [3]. Long nanosecond pulses used were found to be favorable for damage-free exposure of molybdenum in the CIGS/Mo/glass structure but excessive melt formation was observed from the CIGS layer itself. The main limiting factor to nanosecond laser processing of the multilayer $CuInSe_2$ (CIS) structures is deposition of molybdenum on walls of channels scribed in the films, and the phase transition of semiconducting

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$CuInSe_2$ to a metallic state close to the ablation area due to the thermal effect [4]. Both effects create shunts in the photo-electric device and reduce its conversion efficiency. According to the results of theoretical modeling, processing without damage is possible with ultra-short-pulse lasers [4, 5]. High power industrial picosecond lasers are available on the market and due to their high process speeds with low thermal impacts on the materials could be promising tools for CIGS solar cell scribing.

2. Experimental

The picosecond laser (PL10100, 10 ps, 100 kHz, from EKSPLA) was used in the ablation and scribing experiments. Experimental setup included the laser, electro-optical shutter, a nonlinear crystal for wavelength conversion, a beam expander and galvanometer scanners (ScanLab) with 80 mm focusing objectives for both 1064 nm and 532 nm wavelengths. In extension of laser scribing experiments, a diffractive optical element was used for beam splitting to realize the parallel beam scribing setup (see Fig. 1.). The lenses L1 and L2 arranged in the 4F scheme were used to control the beam separation at focal plane.

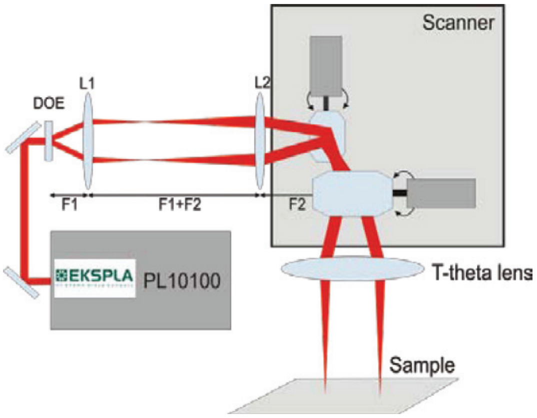

Figure. 1. Parallel beam scribing setup.

Our development was concentrated on the P3 process, scribing of the films, to expose the molybdenum back-contact by selective removal of both the top-contact and CIGS layers. Three types of complete flexible multilayer structure of the CIGS Solar cells were investigated: (i) with a thick top-contact made of ITO (1 µm), (ii) with a thick top-contact made of ZnO (350 nm), and (iii) without a top-contact. The absorber layer of $CuIn_xGa_{(1-x)}Se_2$ was 2 µm thick in all cases. A thin buffer layer of ZnO and CdS was between the top-contact and the absorber. The back-contact was made of molybdenum (1 µm) deposited on polyimide (PI) film with the thickness of 25 µm.

The quality of processing was controlled with an optical and scanning electron microscopes. Raman spectroscopy by using the confocal Raman spectrometer/microscope LabRam HR800 (Horiba Jobin Yvon) was applied to evaluate structural changes in the CIGS material after laser scribing near the ablated zone. Complete working solar cells of prefabrication stage were scribed with fundamental and second harmonics in the area between the front-contact grids, as shown in Figure 2, to evaluate alterations in solar cell performance after laser scribing. Red lines indicate separate laser scribes of 20 mm in length and the total scribe length was 360 mm. These solar cells were not final product and did not gain their optimal performance. The efficiency measurements were done at standard reference spectra AM 1.5 and 1000 W/m^2 total irradiance at Solarion AG, Germany. All samples were provided by Solarion AG, Germany.

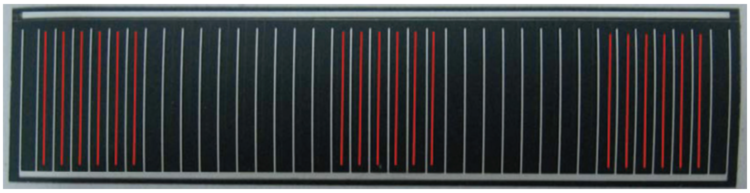

Figure. 2. Red lines indicate laser scribed trenches. The total length of the scribes was 360 mm.