Annealing of TCO Thin Films on Temperature-Sensitive Solar Cells with Short and Ultrashort UV Laser Pulses

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Transparent conductive oxide (TCO) thin films are used as front side electrodes in various innovative, high-efficiency solar cell concepts, due to their high conductivity and transparency over a large wavelength range. Many of these solar cell types, such as a-Si/c-Si heterojunction solar cells, have a limited thermal budget [1]. Since the TCO layers are deposited at low temperatures and optimal post deposition thermal annealing cannot be conducted without degrading the solar cell, compromising the cell efficiency [2].

In this work, we address this challenge, by demonstrating short and ultrashort pulse UV laser processes, achieving modification depths below 40 nm in TCO thin films. Two TCO films of 100 nm thickness were investigated: An amorphous hydrogenated indium oxide (a-IOH) and a polycrystalline tin doped indium oxide (p-ITO), which are deposited on temperature-sensitive silicon solar cells. The annealing impact and depth selectivity of four different UV laser systems was examined; three ns-lasers (λ = 248 nm, 308 nm, 343 nm with t_p = 25 ns, 25 ns, 15 ns, respectively) and a picosecond laser (λ = 355 nm, t_p = 10 ps). For both TCOs, all ns-laser processes show a similar trend of R_{sheet} reduction with increasing pulse fluence and repetitions as shown in Fig 1 a). However, after ps-laser processing, this effect is only seen for the p-ITO, but not for the a-IOH thin film. The exemplary SEM images in Fig 1 b) show crystallization of the a-IOH film with a modification depth of less than 40 nm after ns-laser annealing (λ = 308 nm, 100 pulses, pulse fluence of 120 mJ/cm^2). In contrast, the polycrystalline structure of the p-ITO thin film remains unchanged. These results suggest the existence of different annealing mechanisms, depending on the as-deposited TCO properties. Therefore, the laser material interaction is further investigated, to determine optimal parameters for TCO annealing. The charge carrier lifetime, determined by photoluminescence measurements of the temperature sensitive solar cell after TCO annealing shows no degradation, confirming the surface near thermal impact on the cell structure. In summary, our work demonstrates the feasibility of using short and ultrashort UV laser pulses as fast and efficient processes to selectively anneal the front side TCO film on temperature sensitive solar cells.

a)

b)

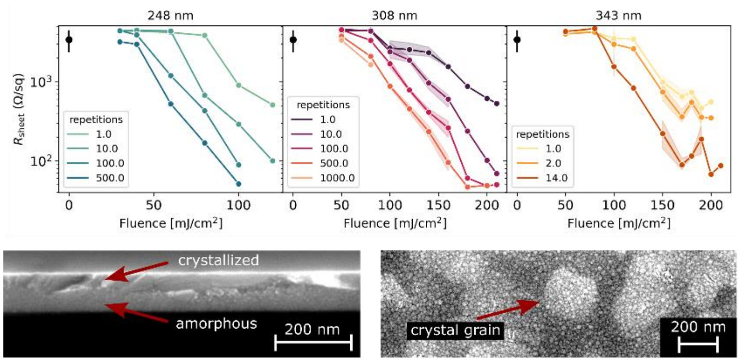

Fig 1: a) R_{sheet} measurements of the p-ITO thin film for the three ns-laser processes. A continuous R_{sheet} reduction with increasing fluence and pulse repetitions is measured. b) SEM cross section and top view of the a-IOH thin film after laser annealing at 308 nm with 100 pulses.

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References: [1] D. Wang, M. Wright, N. K. Elumalai, and A. Uddin, Sol. Energy Mater. Sol. Cells, 2016; [2] C. Messmer, L. Tutsch, S. Pingel, J. Schön, A. Fell, et al., Prog. Photovoltaics, 2022