Ellipsometric analysis of KrF laser textured silicon surfaces

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Introduction

Laser ablation at low fluence levels by multiple laser pulses is a clean and non-contact method to produce surface textures on solid materials. It is a promising process to produce black silicon surfaces which may enhance efficiency of solar cells. Surface modification of silicon can be achieved by irradiating it with nanosecond [1] or femtosecond length [2] laser pulses.
The ablation processes are significantly different in the two cases. The first changes due to the first laser pulses, called incubation period, define how the process will proceed. These changes are invisible for e.g. microscopic techniques, therefore our aim was to follow the incubation processes by spectroscopic ellipsometry.

Experimental

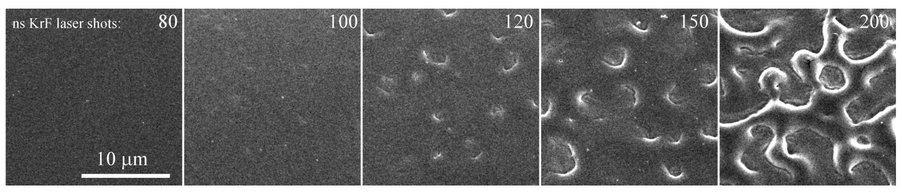
In this study textured silicon was obtained in air atmosphere by multipulse ablation using **30 ns** and **480 fs** pulse length KrF excimer and dye-KrF excimer hybrid [3] lasers, respectively (wavelength 248 nm). Intensities were chosen to be slightly below the single shot ablation threshold. Irradiated areas were investigated using scanning electron microscopy (Hitachi S4700) and spectroscopic ellipsometry (GES5E rotating polarizer ellipsometer). The ellipsometric evaluations were performed with SEA software (Semilab Inc.). Based on photometric measurements sample depolarization was also detected. It was ensured that all spots are investigated at the same position relative to the laser spot.

Results

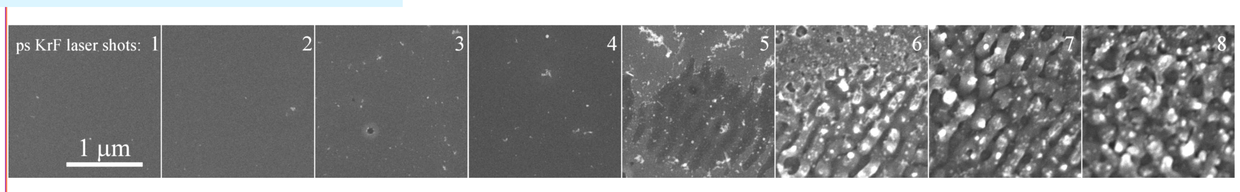
ns laser texturing

fs laser texturing

Scanning electron microscopy



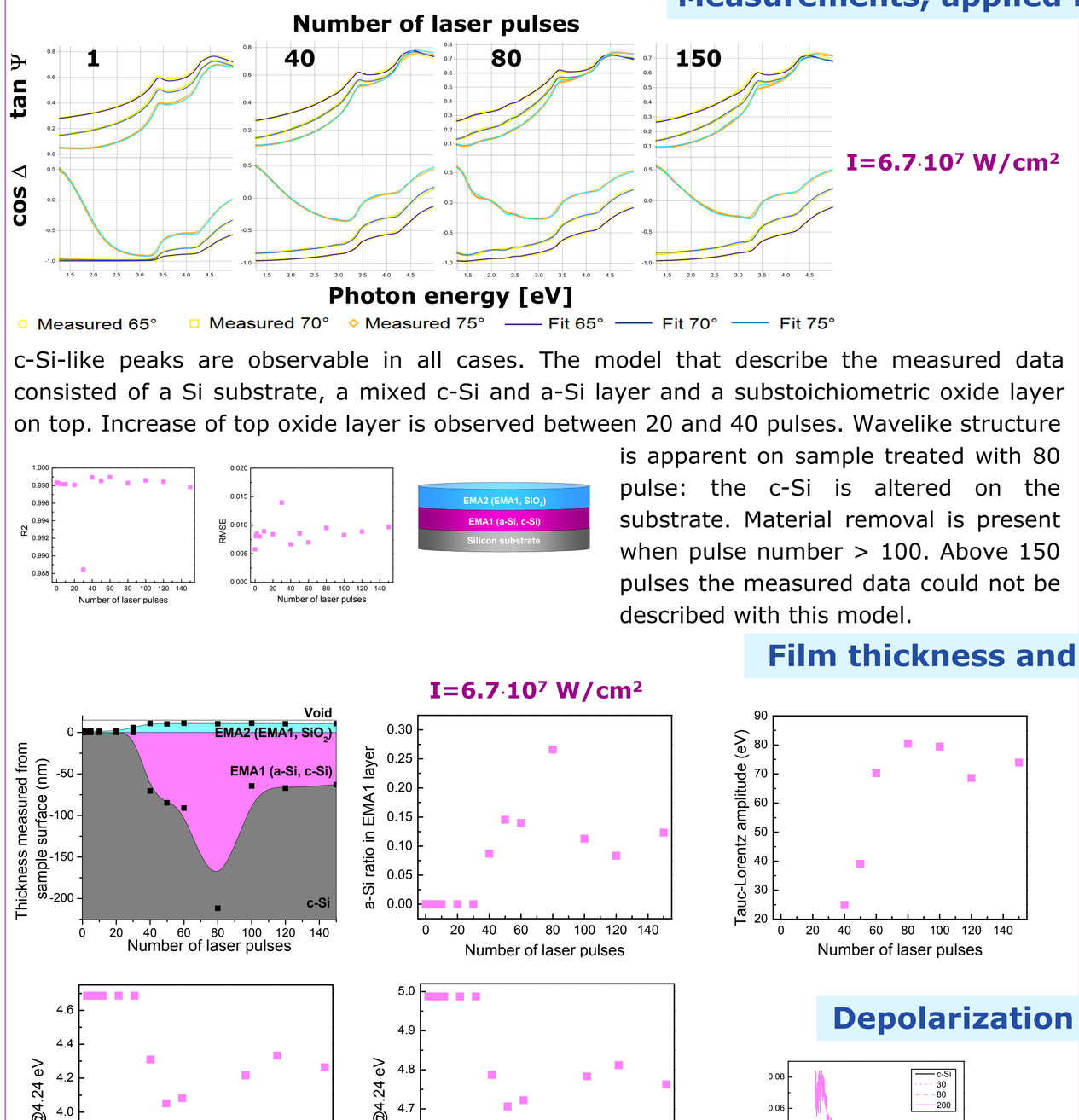
I=6.7·10⁷ W/cm²



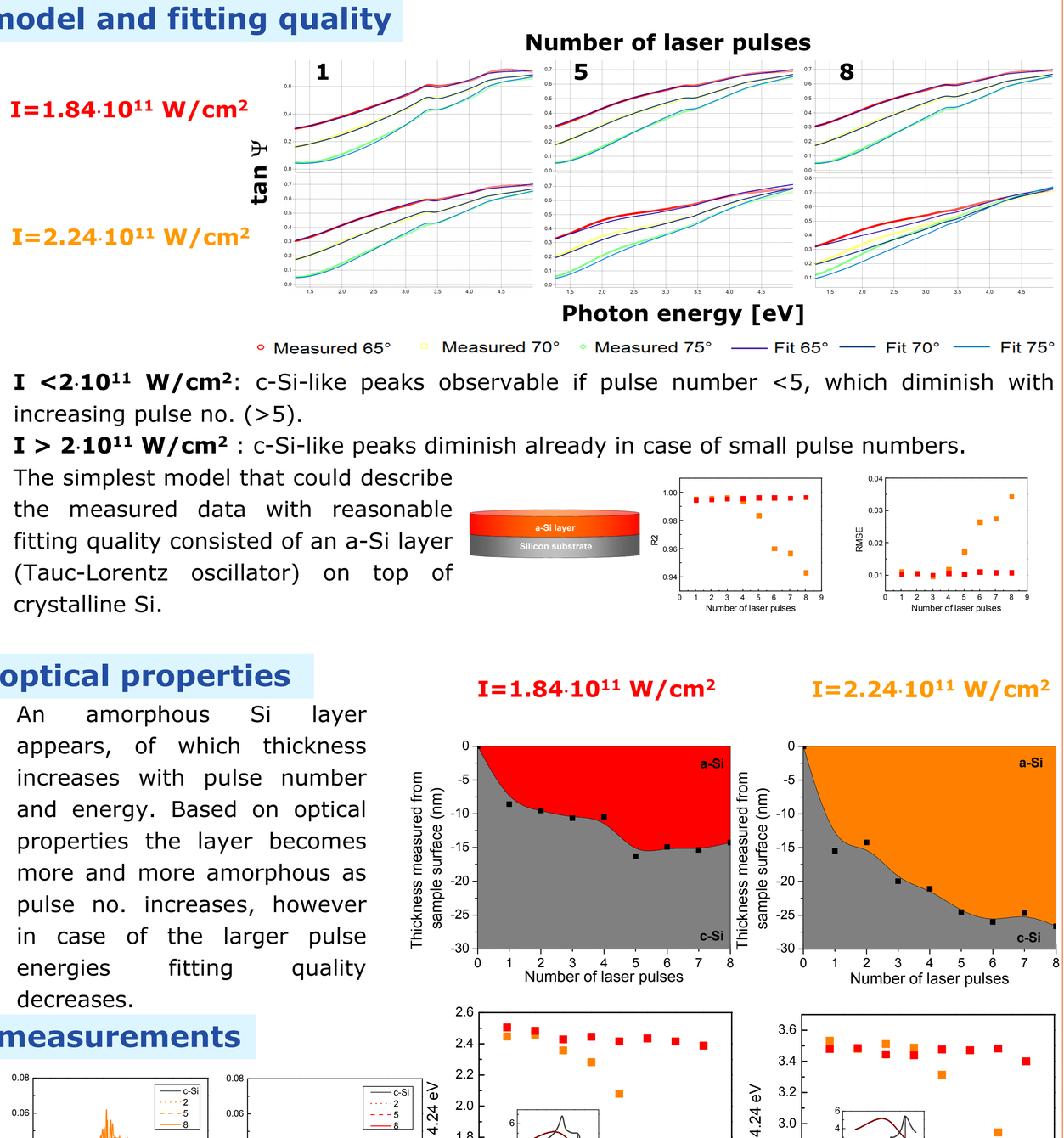
I=2.24·10¹¹ W/cm²

Spectroscopic ellipsometry

Measurements, applied model and fitting quality



c-Si-like peaks are observable in all cases. The model that describe the measured data consisted of a Si substrate, a mixed c-Si and a-Si layer and a substoichiometric oxide layer on top. Increase of top oxide layer is observed between 20 and 40 pulses. Wavelike structure is apparent on sample treated with 80 pulse: the c-Si is altered on the substrate. Material removal is present when pulse number > 100. Above 150 pulses the measured data could not be described with this model.



I <2·10¹¹ W/cm²: c-Si-like peaks observable if pulse number <5, which diminish with increasing pulse no. (>5).

I > 2·10¹¹ W/cm² : c-Si-like peaks diminish already in case of small pulse numbers.

The simplest model that could describe the measured data with reasonable fitting quality consisted of an a-Si layer (Tauc-Lorentz oscillator) on top of crystalline Si.

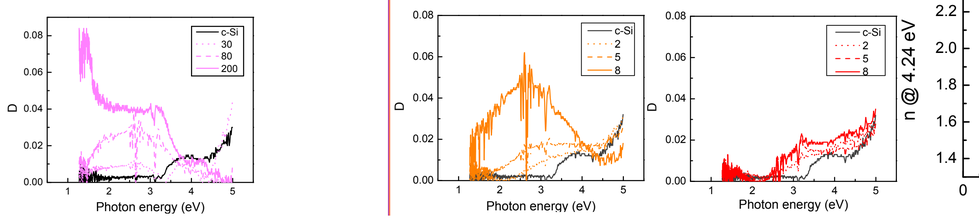
Film thickness and optical properties

I=6.7·10⁷ W/cm²

An amorphous Si layer appears, of which thickness increases with pulse number and energy. Based on optical properties the layer becomes more and more amorphous as pulse no. increases, however in case of the larger pulse energies fitting quality decreases.

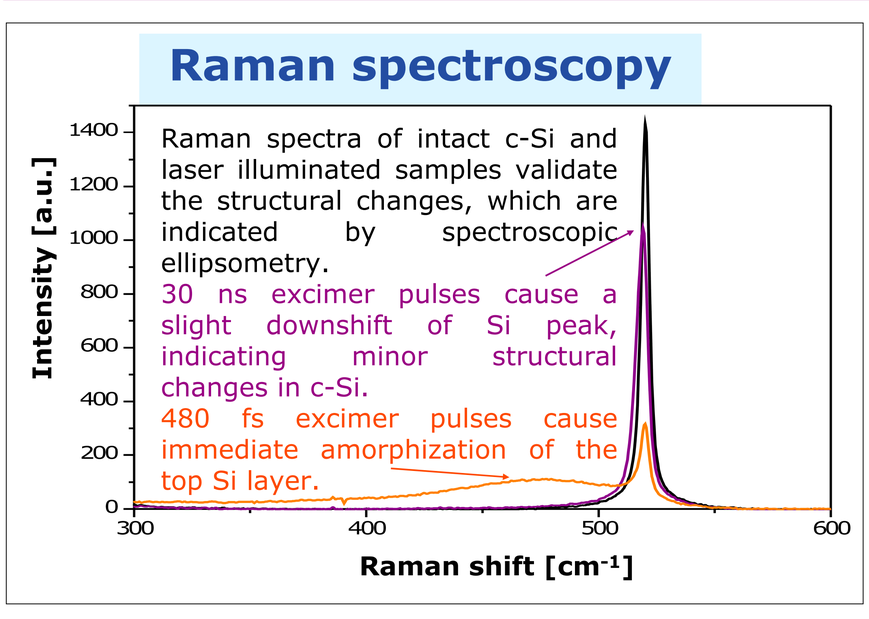
I=1.84·10¹¹ W/cm² **I=2.24·10¹¹ W/cm²**

Depolarization measurements



Depolarization increases with pulse energy and pulse number in accordance with SEM images indicating large structures giving rise to the pure fitting quality.

Raman spectroscopy



Conclusions

The main difference in the two laser irradiation processes is caused by the difference in the pulse length. In case of the fs laser irradiation the first laser pulses melt the top domain of Si within the penetration depth as there is no time for heat diffusion and also due to the short pulse length there is no enough time for recrystallization of the top layer, therefore amorphous silicon phase develops on the surface. However, in case of ns irradiation heat is transferred deeper into the structure, thus the surface is melted by the first laser pulses and the top oxide layer is thickened. As more and more pulses reach the surface, partial amorphization occurs within the molten and recrystallized region as indicated by ellipsometry. In case of both lasers the structure is altered by the laser pulses so that ablation threshold is decreased and material removal can take place at higher number of pulses. Finally the surface is structured, indicated by the decreasing fitting quality.

References

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