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Scaling of black silicon processing time by high repetition rate femtosecond lasers

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Abstract: Surface texturing of silicon substrates is performed by femtosecond laser irradiation at high repetition rates. Various fabrication parameters are optimized in order to achieve very high absorptance in the visible region from the micro-structured silicon wafer as compared to the unstructured one. A 70-fold reduction of the processing time is demonstrated by increasing the laser repetition rate from 1 kHz to 200 kHz. Further scaling up to 1 MHz can be foreseen.

1. Introduction

The ever increasing demand for energy and the depletion of fossil fuels have propelled the research for renewable and clean energy sources [1]. The field of photovoltaics has given a major contribution towards such clean, renewable energy sources and in particular silicon-based solar technology can be considered as the most mature [2, 3]. In recent years there have been significant efforts, which on one side are focused on improving efficiencies and on the other side on reducing manufacturing costs of photovoltaic panels [4]. Among various approaches to increase the efficiency, one of the possible ways is surface texturing of silicon. Surface structuring involves creation of micrometer-sized structures on the surface of silicon wafers. These structures are able to trap solar radiation owing to multiple reflections, reducing the energy lost by reflection at the silicon – air interface, thus increasing the absorption of the material [5]. The same approach opens interesting perspectives also in the field of Si-based detectors [6].

Wet chemical etching is used to produce this effect on commercial solar cells. The technique strongly depends on the crystallographic orientation of the substrate, hence different etchants are needed for mono-crystalline and polycrystalline silicon wafers. Alkaline solutions (KOH or NOH) are commonly used for crystalline substrates, providing anisotropic etching which creates randomly distributed pyramids on the surface of the material. On the other hand for polycrystalline silicon mixtures of HF and HNO_3 are used. Chemical texturing makes it difficult to raise absorptance over a value of roughly 85 %; moreover, it is characterized by low reproducibility [7]. Precise control of temperature and composition of the chemicals is required [8].

With the advent of high power lasers, laser material processing has gained importance and in turn laser surface structuring has become an efficient tool for micro-texturing silicon wafers, as it inherently overcomes the limitations presented above [8]. It also provides flexibility on the choice of the substrate and the patterns to be realized. Laser texturing is a simple technology where a series of parallel and equi-spaced line irradiations are performed on the surface of a silicon substrate to obtain the formation of an ordered grid of micro-structures of roughly conical shape and consistent size and spacing. Laser texturing can be performed by using nano, pico and femtosecond laser pulses, but femtosecond laser texturing has advantages over the former as it works in the non-thermal regime [9]. Due to its very low reflectivity, femtosecond laser structured silicon is named as black silicon.

2. Discussion

Black silicon has been demonstrated using 1 kHz repetition-rate femtosecond lasers, but the high processing times required for its production currently make the use of this technique not suitable for industrial applications. In order to reduce the sample processing time a study of the effect of high repetition rate femtosecond laser pulses on silicon micro-structuring was performed. This scaling is non-trivial since high repetition rates may trigger thermal cumulative phenomena that could wash-out the surface texturing; in addition, an increase in the repetition rate typically implies a reduction of the available pulse energy, which is a key parameter for creating black silicon.

The relevant parameters , in particular fluence of the laser, speed of sample translation, and distance between two adjacent lines, were optimised for various repetition rates of the laser ranging from 1 kHz to 1 MHz.

The optical and morphological characterization of the microstructured samples was carried out using optical microscope and scanning electron microscope (see Fig. 1.(a-d)). The total absorptance of the microstructured samples are obtained and compared to unstructured silicon wafers (see Fig. 1.(e)) and the samples show an increase of absorptance from 60% (unstructured) to 95 % (for microstructured samples).

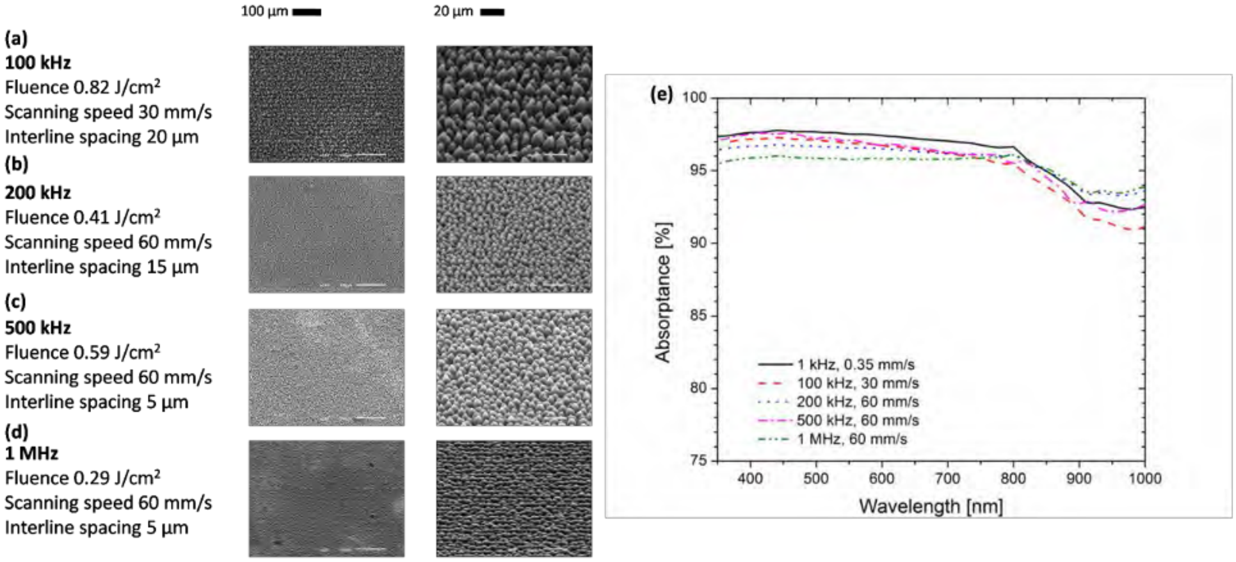

Fig. 1. Microstructuring at high repetition rates, SEM images (a-d) and their corresponding absorption spectra are shown in (e) compared to microstructuring at 1 kHz.

3. Conclusions

Femtosecond laser microstructuring of silicon substrate surface was performed by varying the repetition rate from 1 kHz up to 1 MHz. The critical parameter that needs to be kept constant is the laser fluence on the sample surface, while the fabrication process can be scaled for faster speeds with increasing repetition rates of laser pulses.

By employing high repetition rate laser pulses, the fabrication time was reduced by a factor of 70 working at 200 kHz and a further potential reduction up to 350 times can be foreseen at 1 MHz.

4. References

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