Honeycomb Texturing of Silicon Via Nanoimprint Lithography for Solar Cell Applications

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***Abstract*—A novel texturing method to realize a honeycomb texture on multicrystalline silicon solar cells is presented in this paper. The demonstrated process chain is based on nanoimprint lithography (NIL), where an ultra-violet (UV)-curable polymer layer is structured by mechanical embossing in a high-throughput process. This patterned polymer layer can then be used as an etching mask for plasma or wet chemical etching processes to transfer the defined pattern into the silicon substrates. Within this study, the whole process chain of this novel texturing scheme, using interference lithography, cast moulding, NIL, and plasma etching, is described with a focus on the NIL process. The textured substrates are characterized by reflection measurements, which are compared with standard solar cell textures. Besides optical measurements, first results of honeycomb textured solar cells are presented. Short-circuit current densities above 40 mA/cm^2 were achieved on high-quality float zone material. To increase the feasibility of an industrial realization of this process chain, we are developing a roller-NIL tool to structure an etching mask in a continuous in-line process. First results of this novel tool are also shown in this study.**

***Index Terms*—Microstructures, photovoltaic cells, silicon, surface texture.**

I. Introduction

SILICON solar cells featuring a textured front surface were first commercially available in 1960 [1]. These cells, which made for space applications, were textured by mechanical ultrasonic cutting. A textured front surface has the benefit of increasing light absorption in the cell and, thus, increases the collectable current. The absorption is enhanced through two mechanisms: 1) The overall reflectivity is lowered due to multiple reflections within the front surface texture, which typically has dimensions in the microscale, and 2) path lengths within the semiconductor bulk can be enhanced due to a deflection of the incoming light. The second mechanism gains importance for lower cell thicknesses, which are becoming more common in industrial-scale fabrication of wafer-based silicon solar cells. For solar cells with a front-side emitter, a further benefit induced by the second mechanism is that, due to the deflection of incoming light, the excitons are generated closer to the p-n junction, and thus, the required diffusion length is reduced [2]. Nowadays, texturing crystalline silicon solar cells is a standard process in every production line. Both monocrystalline (c-Si) and multicrystalline silicon (mc-Si) are predominantly textured maskless wet chemically leading to a stochastic texture. While alkaline etching of c-Si leads to optically excellent pyramidal textures [3], modern etching of mc-Si is realized using acidic solutions to allow an isotropic etching behavior [4]. This is necessary because of the nonuniform crystal orientation of mc-Si; however, the quality of the resulting texture on mc-Si is inferior to the pyramidal texture on c-Si.

In laboratory-scale high-efficiency solar cell processing, photolithographic processes to generate regular textures are commonly used [5], [6]. Examining the gap between these high-efficiency cells and industrially fabricated ones both for c-Si and mc-Si, the bigger gain of a defined texture can be achieved for mc-Si. The most prominent defined texture on mc-Si is the so-called honeycomb texture, where a hexagonal pattern is etched into the silicon surface. The highest efficiency mc-Si solar cells produced to date incorporates such a texture. The period of the hexagonal pattern was 14 μm, and the hole diameter in the etching mask was 4 μm.

Any process that seeks to realize a honeycomb texture on mc-Si substrates on an industrial scale must fulfill the following requirements: 1) Full wafer patterning on substrate sizes of 156 mm $\times$ 156 mm must be achieved at low cost with high throughput; 2) the period of the hexagonal pattern should not be too high so that not too much material has to be removed to realize a desired aspect ratio; 3) the hole openings that are realized on the etching mask must be as small as possible, perhaps 1-μm diameter or less, so that an optically optimal texture may be fabricated (this allows flat areas in the texture to be minimized later in the process); and 4) the aforementioned requirements must be achieved on rough substrates with considerable total thickness variations; these are typical consequences of the wire sawing process [7].

Conventional photolithography does not, in general, fulfill these requirements and is, hence, not used as an industrial process for Si solar cell fabrication. Achieving the desired resolution is not trivial and requires that wafers be chemically polished to minimize the initial roughness and that expensive photoresist materials be used. What's more, throughput is typically not very high.

Therefore, there is on-going research into the realization of a defined honeycomb texture by industrially feasible processes.

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