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## Thin-film silicon solar cells on dry etched textured glass

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### Abstract

In this work, we report on the development of thin-film silicon solar cells on textured glass substrates. The textured glass substrates are fabricated by ion beam etching using a wet-chemically textured three-dimensional etching mask. The development of transparent and conductive front contact ZnO:Al films on textured glass is presented. The optimum of the front contact layer thickness was found to be 60 nm. For this thickness deteriorating reflection maxima are avoided, which occur due to the interferences in the front contact layer. The glass texture is adjusted to achieve better light trapping in the near infrared range. In addition, ITO instead of ZnO:Al film was investigated to surpass the decreased fill factor of solar cells deposited on ZnO:Al thin front contacts.

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### 1. Introduction

Thin-film silicon solar cells are made of hydrogenated amorphous and/or microcrystalline silicon layers. In order to absorb efficiently incident light in the optically thin silicon absorber layers, these solar cells, deposited in superstrate (pin) configuration, make use of advanced light-trapping textures at the front side. Conventionally, these textures are introduced at the transparent and conductive front contact. Various transparent conductive oxide (TCO) materials are available such as SnO<sub>2</sub>:F and ZnO:B layers [1-3] as well as magnetron sputtered ZnO:Al layers that is used in this work. The texture is commonly introduced by post wet-chemical etching in diluted

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hydrochloride (HCl) solution [4-6]. The wet-chemical etching not only requires an additional air-break during the whole vacuum fabrication process, but also adds higher requirements to the sputtering parameters. The conductivity, transmission and the etching behavior of ZnO:Al films must compromise with each other to achieve an optimum layer for solar cells.

Textured glass raised interest for thin-film photovoltaic applications in recent years, as the scattering properties can be decoupled from the TCO front contact layer. Using textured glass, there is no necessity to perform post wet chemical etching e.g. of the ZnO:Al. Furthermore, the ZnO:Al front contact development is simplified since the film has “only” to be optimized regarding optical and electrical properties (i.e. transmission and sheet resistance) but not regarding the etching behavior for the realization of optimal light trapping features. Numerous attempts to create textured glass in recent years were carried out for the incorporation in solar cells, such as nano-imprinting [7-10], cast glass operation [11], aluminum induced texture (AIT) process [12], ion beam etching of mask on glass [13-15], sand-blasting [16], as well as wet chemical etching by hydrofluoric acid (HF) [17]. In this work, textured glass was prepared by combining wet-chemical etching and ion beam etching. The aim is to demonstrate the development of thin-film microcrystalline silicon ( $\mu\text{-Si:H}$ ) solar cells deposited on textured glass. It is focused on the light management especially of the transparent and conductive front contact layer. The TCO thickness was optimized to improve light incoupling. To achieve efficient light trapping, the texture of glass substrate was optimized by using alternative processing methods.

## 2. Experimental

Microcrystalline silicon solar cells were deposited in superstrate (pin) configuration on glass substrates (Corning Eagle 2000). The complete process flow of the solar cell fabrication with focus on the glass texturing is schematically illustrated in Fig. 1.

Wet chemically textured ZnO:Al films were used as 3d etching mask. The texture was induced by etching as-deposited ZnO:Al films in 0.5w/w% HCl [18] or in 1w/w% HF [19] (see Fig. 1(1)). The mask was prepared by etching 800 nm thick ZnO:Al in HCl solution for 40 s or etching 1000 nm thick ZnO:Al in HF solution for 200 s. After wet chemical etching process ion beam etching with Ar ions was performed (see Fig. 1(2)) in an in-line vacuum system (Lion, VISS 300, supplied by von Ardenne Anlagentechnik GmbH) to transfer the texture in the glass substrate. The substrate was not intentionally heated. The ion beam was generated by a linear anode layer ion source. The discharge voltage of the ion source was 3 kV, and the source gas flow was 30 sccm. The ion beam etching was stopped after the ZnO:Al etching mask was totally removed as shown in Fig. 1(3). Afterwards, the substrate was re-cleaned in acidic solution. An alternative process was investigated for glass texturing in which CF<sub>4</sub> ions were used. Therefore, the etching mask was prepared by etching 600 nm as-deposited ZnO:Al film in 0.5w/w% HCl solution for 50 s. The ion beam etching was performed in a reactive ion beam etching system (Ionfab300 plus, supplied by Oxford Instruments). The beam voltage was 600 V, and the CF<sub>4</sub> flow rate was 10 sccm. After 30 min etching, the sample was dipped into diluted HCl solution to remove residuals of the etching mask.

Thin layer of ZnO:Al films were deposited on the textured glass as shown in Fig. 1(4). The front contact ZnO:Al films were deposited in an in-line sputtering system for a substrate size up to 30×30 cm<sup>2</sup> (VISS 300, supplied by von Ardenne Anlagentechnik GmbH). The ZnO:Al films were sputtered from a ceramic ZnO:Al<sub>2</sub>O<sub>3</sub> (1 wt%) target. 50 sccm Ar was used as process gas. The power of the generator was 1.5 kW and the substrate was heated to 300°C.

Microcrystalline silicon p-doped, intrinsic (i-) layers and amorphous silicon n-doped layer were deposited on the front contact ZnO:Al films using plasma enhanced chemical vapor deposition (PECVD) in a 30 x 30 cm<sup>2</sup> system at 13.56 MHz. The microcrystalline silicon i-layer is around 1.1  $\mu\text{m}$  thick. More details of our deposition process of the  $\mu\text{-Si:H}$  layers can be found elsewhere [20]. 80 nm ZnO:Al film was sputtered at room temperature on the n-doped Si layer to serve as back reflector. 700 nm Ag were thermally evaporated through a shadow mask which defined the active cell area. The solar cell area was 1 x 1 cm<sup>2</sup>. In addition to the  $\mu\text{-Si:H}$  pin solar cells deposited on textured glass substrates, reference solar cells were fabricated on wet-chemically etched ZnO:Al front contacts which exhibit the (Jülich) state-of-the-art texture for light trapping in  $\mu\text{-Si:H}$  thin-film solar cells [6, 18].

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