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Influence of laser texturization surface and atomic layer deposition on optical properties of polycrystalline silicon

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ABSTRACT

Reducing the reflectance of light as a result of texturing the front surface of the silicon and depositing an antireflection coating allows to increase the efficiency of the solar cell by up to several percent. In the present paper, the surface texturing of polycrystalline silicon based on the laser treatment and Al_2O_3 antireflection coating (ARC) deposited by atomic layer deposition ALD is discussed. Polycrystalline silicon wafers are characterized by their different grain sizes and orientation (grains are randomly oriented). Much effort has recently been devoted to the development of techniques for creating more isotropic textures further reducing the reflectance of polycrystalline wafers. Therefore in the present work polycrystalline silicon surface was shaped with a laser beam. In order to further reduce the reflectance of light R(λ) to the surface of the solar cell Al_2O_3 antireflection coating was deposited by ALD method. Al_2O_3 thin film in the structure of finished solar cell functions as both an antireflection and the passivation coating, which simplifies the process. A unique advantage of ALD method is the ability to uniformly deposition on geometrically complex surfaces. For this reason, atomic layer deposition method may be used for deposition of the optical thin film on the silicon solar cells as antireflection coating. There are many methods of optical thin films, for example, sol–gel, CVD, PVD but with the advantage of ALD, earlier mentioned, seems to be the most promising.

Introduction

Optical losses by reflection of the incident light should be reduced to improve the efficiency of solar cells. This is typically achieved with combination of antireflection coating and surface texturing. The standard texturing process in the production of monocrystalline silicon with (100) surface orientation solar cells is alkaline texturing. The pyramidal structures are formed on the surface of silicon because this kind of alkaline solution has a higher etching rate on (100) planes than on (111) plane [1,2]. On the surface forms square based upright pyramids of random size which are distributed randomly as shown in Fig. 1.

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There are many publications of the methods of shaping the surface and structure of materials to improve their properties [3–5]. In order to get the isotropic texturing method applicable to polycrystalline wafers, several technologies have been introduced, including wet chemical isotropic etching [2,6], reactive ion etching RIE [7], mechanical grooving [8]. The present work reports the experimental results of the laser texturing process and Al_2O_3 antireflection coating deposition for polycrystalline silicon solar cells fabrication.

Nowadays, lasers of different types are used in a variety of materials processing applications for a wide range of materials. Laser techniques have the advantage of noncontact processing and are already well established in a couple of industrial solar-cell processes, such as edge isolation [9], doping process for achieving shallow highly doped junction [10,11], selective emitter formation [8], dielectric layer ablation [10,12], laser texturization for reduction of reflection losses [13,14], etc. Laser texturing of silicon wafers allows for significant decreasing of reflectance. Moreover, the additional technological operation consisting in etching of laser-damaged layer introduced into technology of the photovoltaic cells allows for improvement in their electrical performance compared to cells produced from the non-textured wafers. Detailed results of optical and electrical properties of laser textured surface can be found in the literature [15,16].

In order to further reduce the reflectance of light $R(\lambda)$ from the surface of the solar cell antireflection coating are deposited. Antireflection coating reduces the reflection and by that increases the efficiency of the finished solar cell. About 8% of the energy losses are related with the reflection of light, but by the application of the antireflection coating, this number can be reduced to 3–5%. Antireflection coatings consist of one or more dielectric layers. The kind of materials and thickness of layers used depend on the kind of substrate, wavelength range, properties of incident light and customer requirements. There are many methods of optical thin films, for example, sol–gel, CVD, PVD but with the advantage of ALD, it seems to be the most promising [17–20]. Atomic layer deposition (ALD) has been wide interest as an advanced thin film growth technique for many applications in modern surface engineering. The strength of the method based on its unique growth process where convertible, self-limiting surface reactions of the precursors, separated by inert gas purging, form a growth cycle where upon thin, up to one atomic monolayer of depositing material. In the simplest process, one deposition cycle consists of four steps illustrated in Fig. 2. Precise thickness control can be achieved by repeating the growth cycle a desired number of times. A unique advantage of ALD method is the ability to uniformly deposition geometrically complex surfaces. For this reason, atomic layer deposition method may be use in optics, electronics, photovoltaics, and many other applications. Used of atomic layer deposition processes allow the design of antireflection coatings with very low reflection. Reducing the reflectance of light as a result of texturing the front surface of the silicon and depositing an antireflection coating allows to increase the efficiency of the solar cell by up to several percent [21–26].

The method of atomic layer deposition can also be used for the deposition of nanocrystalline metal oxides used in dye sensitized solar cells. Low-temperature processing of dye-sensitized solar cells (DSCs) is crucial to enable commercialization with low-cost, plastic substrates [27–30]. We have developed a low-temperature processing route for photoanodes where crystalline TiO_2 and Al_2O_3 is deposited onto well-defined, mesoporous templates. The TiO_2 and Al_2O_3 are grown by atomic layer deposition (ALD).

In the present paper, the surface texturing of polycrystalline silicon based on the laser treatment and Al_2O_3 antireflection coating deposited by atomic layer deposition ALD is discussed.

Experimental

The material used in this study is p-type polycrystalline silicon. The main characteristics are: thickness ~330 μm, area 5 cm × 5 cm, resistivity 1 Ωcm, boron doped. The wafers are obtained by wire sawing of polycrystalline ingot that were used as a base material had highly distorted layers on both sides. Therefore, about 11 μm of material has been etched off in KOH solution to remove damages resulting from sawing. In the present work polycrystalline silicon surface was shaped with a laser beam. Texturization was performed by Q-switched Nd:YAG laser operating at wavelength of 1064 nm. Laser texturization was conducted for the following parameters: maximum output power 50 W, pulse repetition frequency 15 kHz, diameter of the laser spot 10 μm and laser beam speed 60 mm/s. The texture consisting of parallel grooves as well grid of grooves with spacing of 50 μm were produced. A wet

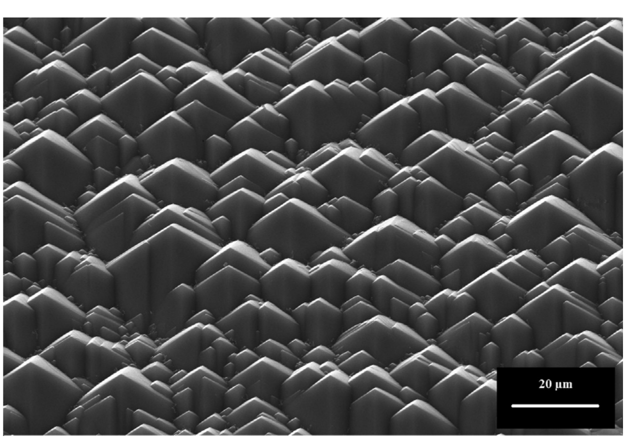

Fig. 1 – SEM image of alkaline textured monocrystalline silicon surface.

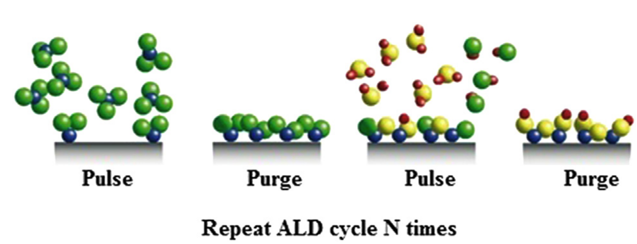

Fig. 2 – A diagram illustrating one cycle of ALD deposition process.