LAYER TRANSFER OF LARGE AREA MACROPOROUS SILICON FOR MONOCRYSTALLINE THIN-FILM SOLAR CELLS

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ABSTRACT

We produce uniform macroporous double-layers on 6 inch n-type silicon substrates by electrochemical etching under rear side illumination in a hydrofluoric acid (HF)-based electrolyte. The etched area is circular with a diameter of 13 cm. We demonstrate the detachment of 20 µm thick free-standing macroporous silicon layers with an area of 8 x 8 cm^2.

INTRODUCTION

The standard thickness of Si wafer-based solar cells is approximately 200 µm with a kerf loss of about 100 µm caused by wire sawing. However, lower wafer thicknesses are sufficient for achieving high solar cell efficiencies exceeding 20 % [1]. A reduction of cell thickness and kerf loss, e. g. as in our case to 20 µm and 5 µm respectively, could significantly reduce material and fabrication costs.

The layer transfer process of epitaxially-grown thin crystalline silicon films has been investigated since more than one decade [2], [3]. Although high efficiencies over 15 % were reported for layer thicknesses of 25 µm, the barrier for industrial use is the cost-intensive epitaxial growth process [4], [5]. Recently, a layer-transfer process based on proton implantation and lift-off at a depth of a few tens of µm was demonstrated, yielding (111)-oriented layers, thus preventing anisotropic etching for light trapping [6].

Lehmann *et al.* suggested electrochemical etching for the formation and separation of thin macroporous silicon layers from a wafer and then using this layer as an absorber for thin-film solar cells [7]. According to the International Union of Pure and Applied Chemistry (IUPAC), pore sizes > 50 nm are termed as macroporous [8]. According to Lehmann's process, small holes (macropores) are etched into the silicon substrate, which are broadened in a depth of about 20 µm from the surface to form a cavity. The thin macroporous layer is then detached from the substrate wafer that could be reused. The concept is based on pre-patterned wafers prepared by photolithography which results in an ordered macroporous structure. However, photolithography is not a low-cost process.

We recently demonstrated the detachment of thin macroporous silicon (MacPSi) layers with randomly distributed macropores [9]. This process has the advantage of avoiding the photolithographic step. In contrast to Lehmann's concept, our etching process keeps the MacPSi layer attached to the substrate. Only weak bridges remain between the MacPSi layer and the substrate. The layer is subsequently detached from the substrate by gluing a glass carrier to the layer and pulling it off. Alternatively free-standing layers may be fabricated. In this paper, we demonstrate the detachment of large-area free-standing macroporous silicon layers for the first time in the literature.

EXPERIMENTAL

Sample preparation

We use an electrochemical etching cell to form macropores on 6 inch (100)-oriented n-type silicon substrates under rear side illumination [10] from an 890 nm LED array in 3 wt.% hydrofluoric acid at 20°C. The non-illuminated edge of the wafer is about 1 cm wide. In this area the wafer is held by a vacuum that is established in between two rubber ring seals at the rear side. The rear side of the wafer is contacted with platinum. The etched circular area is 133 cm^2.

The CZ substrates have a resistivity of (2.0 ± 0.2) Ωcm. The thickness of the wafers is (305 ± 20) µm. A phosphorous diffusion with a sheet resistance of 10 Ω/sq. improves the rear contact during electrochemical etching.

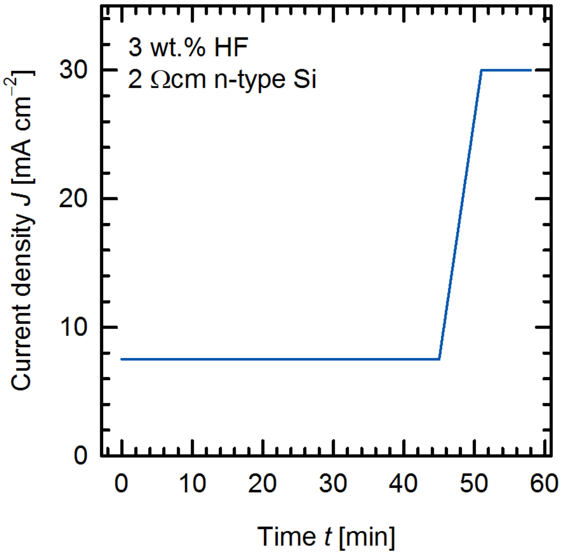

Figure 1 Current density *J* versus etching time *t*

Figure 1 shows the applied current density that varies with etching time. The current is the set value and controlled by the illuminations intensity. We apply a current density of 7.5 mA cm^{-2} for 45 min. Pore nucleation takes 15 minutes. In this phase, a thin mesoporous silicon layer is formed on top of the macroporous layer during pore nucleation and small etch pits are formed where the macropores start growing. After the 15 minutes of pore nucleation, the pores grow at a rate of 0.67 µm min^{-1}. The pore radius is a function of the current density and an increase in the current density broadens the pores. The current density is therefore increased linearly to 30 mA cm^{-2} within 6 min. At this value the current stays for 7 min to form a highly-porous separation layer underneath the low-porosity absorber layer.

Figure 2 shows a 6 inch silicon substrate after forming a uniform macroporous double layer. The low-porosity macroporous layer is still attached to the substrate. The mesoporous layer that forms during pore nucleation is removed in 1 mol l^{-1} potassium hydroxide (KOH) solution at 20°C. The non-illuminated edge is clearly visible. The porosity of the absorber layer is measured gravimetrically and is (23 ± 2) %. The porosity of the separation layer is nearly 100 % as revealed by scanning electron microscopy.

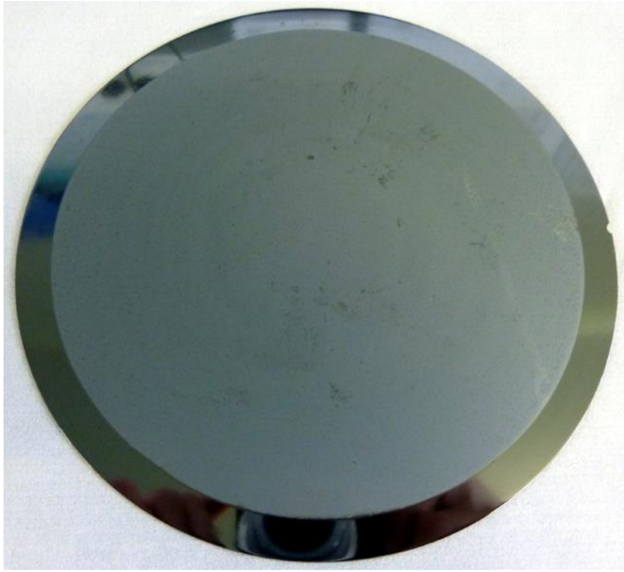

Figure 2 Optical image of a 6 inch substrate with a uniformly etched macroporous double-layer. The grey color is the result of the rough-textured surface left after pore nucleation. The non-illuminated area at the edge is still shiny.

Detachment

We cut a square with an edge length of 8 cm in the macroporous layer region using a short pulse laser beam with a pulse energy of approximately 3 mJ. A small repetition rate of 100 Hz assures that the macroporous layer does not stick to the substrate.

We use a vacuum chuck to detach the thin macroporous layer from the substrate by applying mechanical stress. Figure 3 shows an optical image of a detached and free-standing macroporous silicon layer. This layer is from the wafer shown in Figure 2. The average thickness of the detached absorber layer is (21 ± 1) µm as determined with a micrometer gauge.

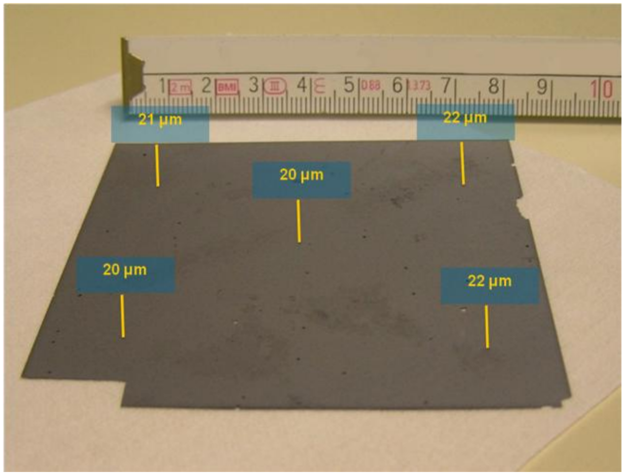

Figure 3 Optical image of a detached and free-standing 21 µm thick macroporous silicon layer

Structure of thin MacPSi films

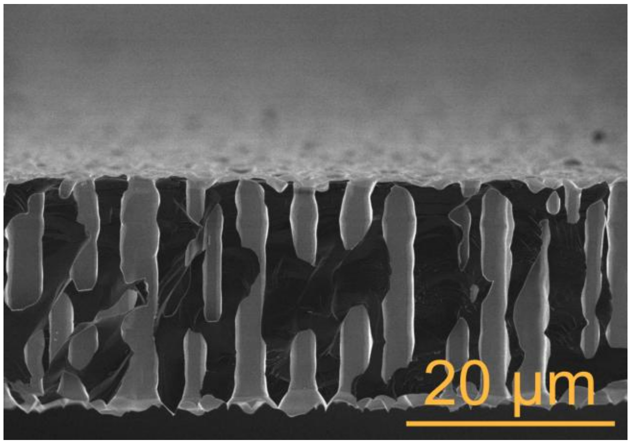

Figure 4 SEM-image of a free-standing and detached 21 µm thick macroporous silicon layer.

A scanning electron microscope (S4800 from Hitachi) is used to inspect the morphology and uniformity of the macroporous layers. Figure 4 shows a SEM-image of a detached and free-standing macroporous silicon layer that was fabricated using the same etching profile as the wafer shown in Figure 2. The thickness of the MacPSi layer is 21 µm and the ‘kerf’ loss is 5 µm per absorber layer. The average pore radius is (1.2 ± 0.1) µm and the average pore distance is (5.2 ± 0.6) µm.

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