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High fidelity transfer of nanometric random textures by UV embossing for thin film solar cells applications

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ABSTRACT

We investigate the transfer of random nanostructures commonly used in thin film silicon solar cells onto inexpensive substrates, such as glass or flexible polyethylene sheets. Morphological and optical analyses of masters and replicas show the successful transfer of details with sizes much below 1 μm. These high-quality replicas are obtained by UV nano-imprinting, avoiding the use of PDMS as an intermediate mold, which has been identified as being responsible for the lack of resolution found in previous works.

1. Introduction

Light trapping techniques play an important role in increasing the efficiency of thin film amorphous silicon (a-Si:H) solar cells by improving light absorption without requiring thicker devices. The use of thinner active layers leads to solar cells with better carrier collection and higher stable efficiencies. The most common approach to confine the light relies on natural structures that either the substrate or the contact layers develop under specific deposition conditions during their growth. These rough interfaces cause the light to scatter, increasing its optical path inside the active layer and leading to devices with higher short circuit current. While there is still debate on the type of the ideal roughness, high currents (~17.5 mA/cm^2) have already been obtained in superstrate configuration (p–i–n) a-Si:H devices using the as-grown boron doped zinc oxide (ZnO:B) pyramidal texture deposited on glass by low pressure chemical vapor deposition (LPCVD) [1], or F-doped SnO_2 deposited by atmospheric pressure chemical vapor deposition (AP-CVD) [2]. Likewise, the texture that develops when silver is deposited by sputtering on substrates heated to ~400 °C is widely used to efficiently scatter light in substrate configuration (n–i–p) solar cells, where the substrate transparency is not a requirement [3–5]. However, these kinds of texture are extremely difficult or even impossible to be applied on inexpensive plastic foils due to the low thermal resistance, or the higher dilatation coefficient of the plastics compared to glass, which results in the peeling of the layers. Nowadays, the interest in the use of plastics as substrates for thin silicon solar cells is increasing in order to reduce the manufacturing costs by means of roll to roll deposition [6], and because flexible light weight modules offer novel possibilities in building integration. Thus, alternative ways to obtain suitable photovoltaic textures on plastics as polyethylene naphtalate (PEN) have to be found.

Ultraviolet nanoimprint lithography (UV-NIL) and hot embossing lithography (HEL) techniques are possible options to transfer in a controlled way a master texture on top of plastic substrates. Good results concerning resolution and reproducibility have been reported using these techniques [7,8]. Note that both techniques require the fabrication and use of an intermediate mold with the negative texture of the original master. Electrochemically deposited nickel and poly-dimethyl siloxane (PDMS) are employed as intermediate molds in HEL and UV-NIL, respectively. Moreover, both techniques are easily scalable to large areas and can be implemented in roll to roll systems [9,10]. UV-NIL avoids possible thermal limitations imposed by the substrate and requires less time and lower pressure (~1 bar) to obtain high quality replicas than hot embossing. Nowadays, UV-NIL is mostly used in the transfer of regular and periodic nanometric structures rather than in the replication of random multiscale textures, which is probably a more challenging task. In a previous work [11] we studied the UV-NIL stamping of random textures using PDMS intermediate molds. A lack of resolution for sub-micrometer size features was noticed. Several reports point out the fabrication of the PDMS mold as the limiting factor to high fidelity replication; either its high viscosity

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[12] or its easy deformability [13] seems to be an important drawback for an optimum sub-micron resolution. However, different approaches in the intermediate mold fabrication lead to resolutions around 50 nm, which have been achieved by working with more favorable master textures consisting of periodical arrangements of dots [12] and square shaped pillars [14].

In this work we present results concerning the stamping of random textures by means of UV-NIL using two different types of intermediate molds. The first one consists of the traditional soft undiluted PDMS, while the second one is made from a UV curable sol–gel material that we apply to a flexible substrate in order to facilitate demolding. A rigorous comparison was carried out for both stamping methods, identifying the use of PDMS as problematic in order to achieve high fidelity replicas of random nanometric textures.

2. Experimental

Glass (0.5 mm thick, Schott AF45) with a size of 4 × 4 cm^2 was used as a substrate in the replication process. Two different types (A and B) of as-grown textured ZnO:B by LPCVD were used as masters in the replication tests. Both textures exhibit a similar pyramidal shape but with different feature sizes. Type A presents smaller and shallower pyramids than type B. All the steps followed to transfer the master textures on glass are shown in Fig. 1. Two

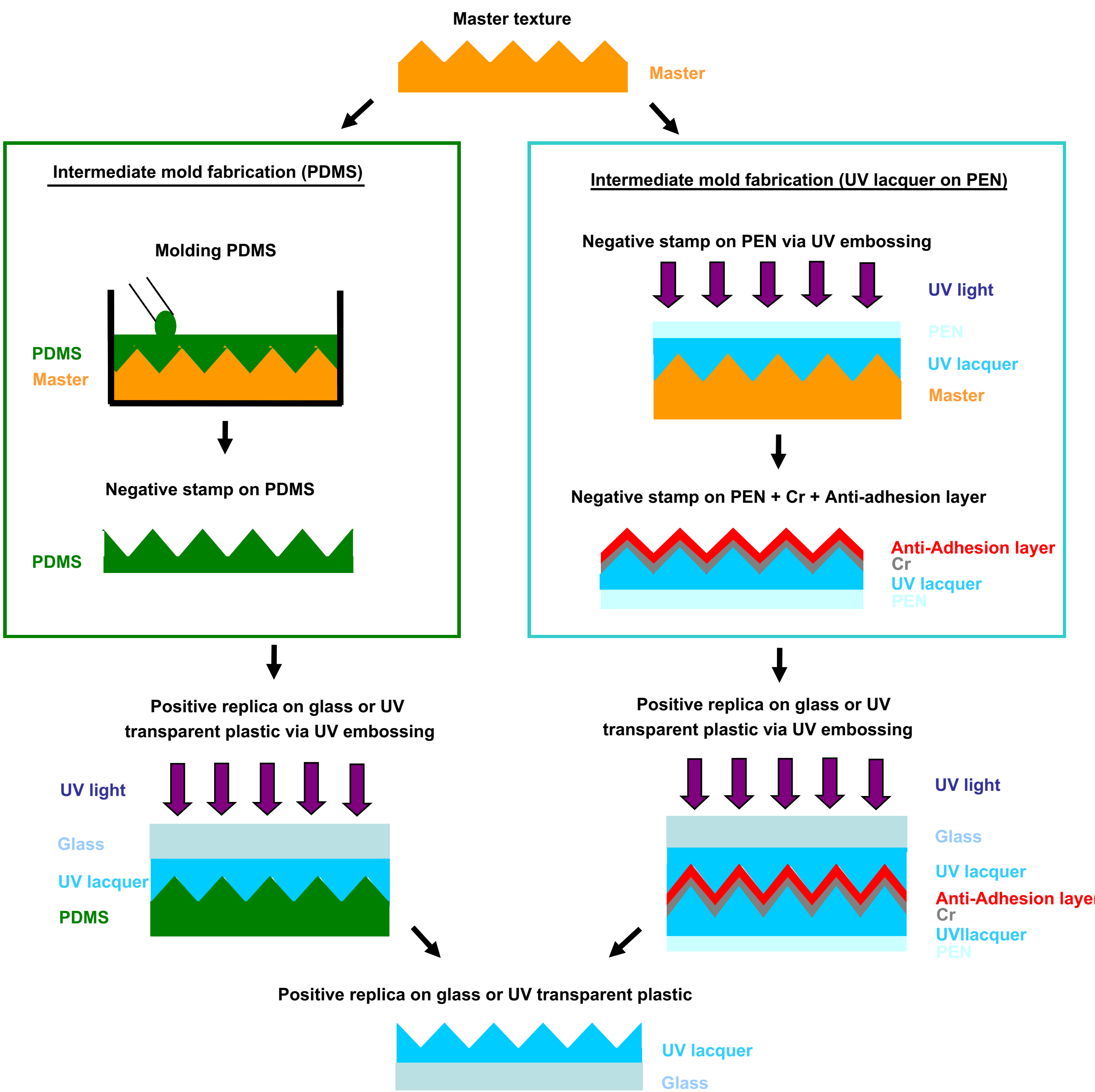

Fig. 1. Replication process steps followed for the transfer of the master texture on glass by UV embossing.