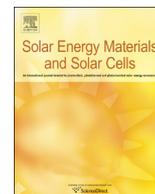




ELSEVIER

Contents lists available at ScienceDirect

## Solar Energy Materials &amp; Solar Cells

journal homepage: [www.elsevier.com/locate/solmat](http://www.elsevier.com/locate/solmat)

# Aluminum-induced crystallization for thin-film polycrystalline silicon solar cells: Achievements and perspective

Dries Van Gestel\*, Ivan Gordon, Jef Poortmans

Imec, Kapeldreef 75, B-3001 Belgium

## ARTICLE INFO

## Keywords:

AIC  
MIC  
Thin-film  
Photovoltaics  
Polycrystalline silicon  
Aluminum induced crystallization

## ABSTRACT

Thin-film polycrystalline silicon (pc-Si) solar cell technology tries to combine the cost benefit of thin-film technology and the quality potential of crystalline Si technology. For this type of solar cells the challenge is to fabricate high quality coarse-grained (grain size of 1–100  $\mu\text{m}$ ) layers on non-silicon substrates in combination with superb light management. One possible material fabrication approach is metal induced crystallization (MIC). Many metals lower the crystallization temperature of a-Si but for photovoltaic (PV) solar cell applications aluminum seems to be the most interesting. Approximately a decade after the suggestion of Nast et al. to use aluminum induced layer exchange for thin-film solar cells, this paper will discuss the aluminum induced crystallization process itself as well as the implementation into workable solar cells. The record aluminum induced crystallization (AIC) solar cell today features an energy conversion efficiency of 8.5%, too low to be competitive with other PV technologies. The main problems and limitations as encountered today will be described. We believe that an energy conversion efficiency of 8.5% is not the limit of AIC solar cells. Different possible solutions to improve the AIC process as well as the resulting solar cells will be discussed together with our vision on the direction and future of AIC solar cell research.

© 2013 Elsevier B.V. All rights reserved.

## 1. Introduction

In the beginning of the 21st century a shortage in the silicon feedstock induced a movement towards thinner bulk silicon solar cells. As a large part of the module cost (40–50%) is due to the cost of the silicon wafers, using less silicon would result in a reduced cost. In addition, a reduction of the solar cell thickness theoretically enables an increase of the device performance of bulk silicon solar cells [1]. Thin-film technologies, like amorphous silicon, exhibit much lower module production costs per surface area than bulk Si but the energy conversion efficiencies are drastically lower [2]. A crystalline silicon thin-film technology seems particularly promising since it combines the low-cost potential of a thin-film technology with the high efficiency potential of crystalline silicon technology [3]. In the thickness region of interest the silicon absorber layers are not self supporting anymore. An inexpensive substrate is needed as mechanical support.

Thin crystalline silicon layers can either be exfoliated from a parent substrate or be grown directly onto a substrate. Direct deposition of Si on a non-silicon substrate is closer to thin-film processing technologies than a layer transfer method. Without any

measures taken, direct deposition results in micrometer or sub-micrometer size grained material [4]. An enhanced material quality is expected with increasing grain size since the high densities of defects typically present at grain boundaries lead to increased carrier recombination. Nucleation control during direct deposition is one approach to increase the grain size [5]. Better material quality can also be obtained by applying different (re)crystallization processes after the deposition of the Si layer, e.g. solid phase crystallization (SPC) [6], laser induced crystallization (LIC) [7], e-beam crystallization [8], joule heating [9], very high frequency microplasma jet crystallization [10] and metal induced crystallization (MIC) [11]. The recrystallized layers can directly be used as absorber layer in a solar cell. An alternative 2-step approach is to form a so-called seed layer followed by epitaxial growth. If a decent epitaxial growth method is used, a two step approach allows decoupling the doping profile/type and final layer thickness from the crystallographic layer properties (like, e.g. grain size or preferential orientation).

Crystallization of silicon induced by the presence of a metal was already reported in the late 70s [12]. Using this phenomenon as a key mechanism for thin-film crystalline silicon solar cell absorber layer fabrication was only proposed around the turn of the century by Nast et al. [13]. They published various papers on the topic of aluminum-induced crystallization (AIC), laying the foundation of a new subgroup of thin-film silicon solar cells.

\* Corresponding author. Tel.: +32 475818803.

E-mail address: [dries.vangestel@gmail.com](mailto:dries.vangestel@gmail.com) (D. Van Gestel).

Approximately a decade later we will discuss in this paper some of imec's achievement on AIC solar cells. We will briefly compare our own relevant results with these of other groups worldwide and we will give our vision on what we see today as the future of AIC solar cells.

## 2. Metal induced crystallization of silicon for solar cell applications

The time and temperature to crystallize amorphous silicon (or germanium) can be reduced by the presence of a metal and this process can roughly be divided into two groups [11]. Some metals like Ni, Pd, Ti and Cu form compounds with silicon while others like Al, Au, Sb, In and Ag result in a eutectic metal–silicon system.

For compound-forming metals, the crystallization only occurs after the formation of the most stable Si rich silicide phase [11]. In the case of Ni for instance, the crystallization is happening by a NiSi<sub>2</sub> silicide phase moving through the a-Si and not by the metal itself. The chemical potential of Ni and Si is different at the a-Si/NiSi<sub>2</sub> interface compared to the pc-Si/NiSi<sub>2</sub> interface. As a result, Ni atoms will diffuse through the NiSi<sub>2</sub> toward the a-Si/NiSi<sub>2</sub> interface while Si atoms diffuse toward the pc-Si/NiSi<sub>2</sub> interface [11].

For eutectic metals, the solubility of Si in the metal film appears to be the limiting factor [11]. For metals like Al the crystallization results from a weakening of the silicon bonds and promotion of silicon nucleation. The metal acts rather as a catalyst. The higher chemical potential per atom of amorphous silicon compared to crystalline silicon can lead to a supersaturation of Si in the Al layer, above the saturation concentration given by the Al–Si phase diagram, which can be released by nucleation and growth of c-Si [14]. The difference in chemical potential provides a constant driving force for dissociation, diffusion and nucleation.

For all metal induced crystallization process the chemical potential can be seen as the driving force. The applicability of MIC for thin-film photovoltaic solar cell applications is mainly determined by the position of the metal after crystallization, the incorporation of the metal in the crystallized Si layer, the electronic effect of the metal on the silicon layer and the possibility to obtain a homogeneous crystalline silicon layer.

Ni is the most frequently used metal for compound forming MIC. Annealing of Ni droplets on top of an a-Si layer results in lateral disk shape crystallization [15]. The remaining NiSi<sub>2</sub> phase can hardly be removed. In contrast to small area devices like thin-film transistors, for large area devices like solar cells the NiSi<sub>2</sub> phase will be incorporated in the active part of the solar cell. Compound forming MIC is therefore in general not attractive for classical solar cell design. Eutectic forming metals are better candidates. Due to the limited solubility of the metal in the growing c-Si layer, the metal will be repelled from the silicon. Especially Al is suitable because the associated defect level, 60 mV below the conduction band, results in p-type doping of around  $3 \times 10^{18} \text{ cm}^{-3}$  [13]. However not all eutectic forming metal systems are useful. Similar as for Ni, also Au and Ag will form deep level defects in the forbidden bandgap of Si which are detrimental for the electrical quality of the pc-Si layer. Due to this intrinsic high doping and the thickness limitation of the AIC process, the layers cannot be used directly as absorber layer. However, epitaxial thickening of the seed layer allows to produce coarse-grained silicon layers on non-silicon substrates suitable as solar cell absorber. The MIC seed layer will determine the grain size of the final layer, while the doping profile and absorber layer thickness are depending on the epitaxial growth parameters.

To use MIC layers as seed layer for further epitaxial growth, the pc-Si layer needs to be continuous and free of residual metal clusters. The lack of clusters is especially important when a high temperature epitaxial growth method is used. Silicon layers made by MIC do not necessarily fulfill that requirement. A process known as metal induced layer exchange (MILC) however does. In Fig. 1, a schematical overview of a MILC process is given with Al as metal. By oxidizing the aluminum layer (Fig. 1c) before the deposition of the a-Si layer (Fig. 1d), a layer exchange process will take place during annealing of Al/Si layer stack below its eutectic temperature [16]. The result is a pc-Si layer with on top an aluminum layer (Fig. 1e). The aluminum layer can be easily removed by selective etching (Fig. 1f). Not only for Al but also for Ag the introduction of an oxide leads to a layer exchange process instead of intermixing [17]. It was found that continuous pc-Si layers with grain diameters up to 100  $\mu\text{m}$  can be obtained with the aluminum induced layer exchange process [18]. Together with the relative harmless electronic effect of Al in silicon, Al is probably the most suitable metal for MIC pc-Si solar cells.

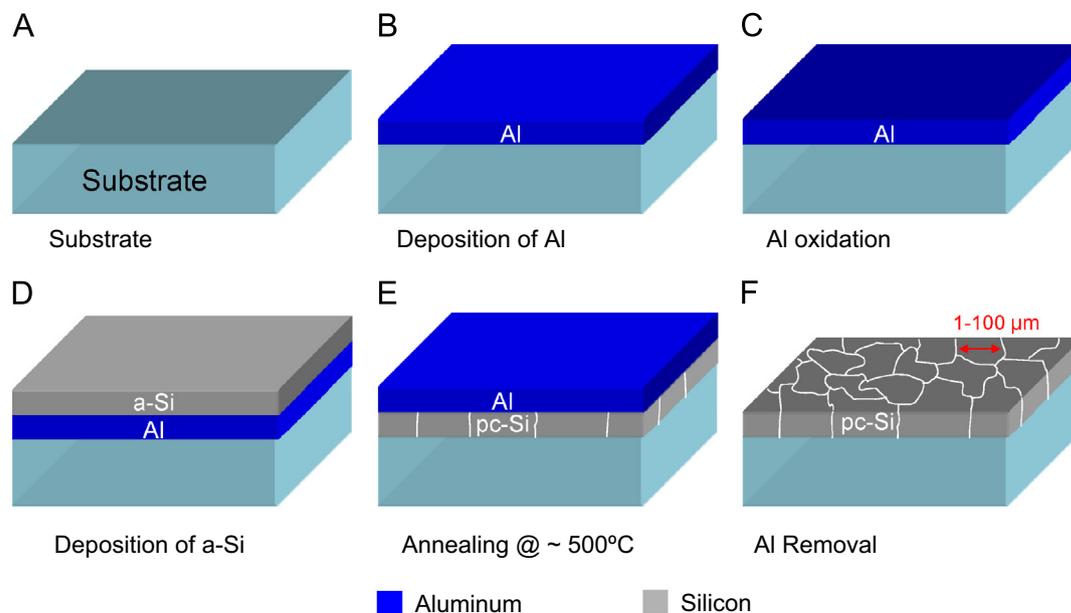


Fig. 1. Schematic representation of the aluminum induced layer exchange process.

Download English Version:

<https://daneshyari.com/en/article/6536019>

Download Persian Version:

<https://daneshyari.com/article/6536019>

[Daneshyari.com](https://daneshyari.com)