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Thin silicon solar cells: Pathway to cost-effective and defect-tolerant cell design

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Abstract

Thinner silicon wafers are a pathway to lower cost without compromising the efficiency of solar cells. In this work, we study the recombination mechanism for thin and thick silicon heterojunction solar cells, and we discuss the potential of using more defective material to manufacture high performance thin solar cells. Modelling the performance of silicon heterojunction solar cells indicates that at open-circuit voltage the recombination is dominated by Auger and surface, representing nearly 90% of the total recombination. At maximum power point, the surface is responsible for 50 to 80% of the overall recombination, and its contribution increases inversely with the wafer thickness. The experimental results show that for lower quality CZ material with 1 ms bulk lifetime, 60 µm-thick cells perform better than 170 µm-thick cells. The potential efficiency gain is 1% absolute. The gains in voltage of using thinner wafers are significantly higher for the lower quality CZ material, 25 mV, than for standard CZ material, 10 mV.

Keywords: Thin silicon; solar cells; defect; heterojunction

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1. Introduction

The spot price of polysilicon, which peaked in 2008 ($475/kg), has been relatively flat in the last five years (<$20/kg) [1]. However, in a scenario of rapid growth, materials cost and CapEx will determine the growth pace [2]. Silicon is the largest single cost-component of a module and over half of total module, capex lies in feedstock production, crystallization, and wafering [3]. The wafer requirements to produce high efficiency solar cells limit the usage of n-type ingot to as much as 75%, due to non-uniform resistivity and oxygen concentration across the ingot

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[4]. Thinner wafers are a pathway to lower manufacturing cost and CapEx without compromising efficiency. By combining suitable light trapping and high-quality passivation, the optimum wafer thickness is estimated to be below 110 µm, depending on the resistivity of the wafer and dopant type [5]. For very high-resistivity (>50 Ωcm) and n-doped wafer the optimum thickness is around 100 µm, while for lower resistivities (<5 Ωcm) the optimum thickness is around 50µm [6]. Thinner solar cells operate at higher voltages, as the excess carrier density increases inversely with the thickness. They are also inherently more defect-tolerant (shorter diffusion lengths required for excellent carrier collection), an opportunity to increase ingot usage, and to use more defective and lower-cost materials (e.g. UMG-Si).

Decreasing the thickness carries new challenges including fabrication yield. Microcracks induced during the sawing process and handling are the main cause of breakage [7]. Recently [8] CEA-INES, presented their results on integration of 80 µm-thick wafers in their existing silicon heterojunction pilot line, showing efficiencies comparable to cells manufacture on standard wafers. Moreover, they claim with minor adjustments they could run 80 µm-thick cells in their pilot line.

In this work, we present the recombination mechanism at open-circuit voltage and at maximum power point for thin silicon heterojunction solar cells, and we discuss the potential of using more defective materials to manufacture thin solar cells.

2. Experimental details

At the Arizona State University pilot-line, thin heterojunction solar cells are prepared on commercial grade n-type CZ wafers with 3-5 Ωcm resistivity and initial thickness of 200 µm. The wafers are thinned and textured using alkaline wet etching, followed by wet chemical cleaning and conditioning. The heterojunction is formed using plasma enhanced chemical vapor deposition to grow intrinsic and doped hydrogenated amorphous layers (5-10 nm), forming a pi/CZ/in stack. Indium tin oxide (ITO) is sputtered on both sides of the wafer, and silver on the rear as a mirror and rear contact, Fig. 1. The samples are than annealed at 200 ^{0}C for 45 min.

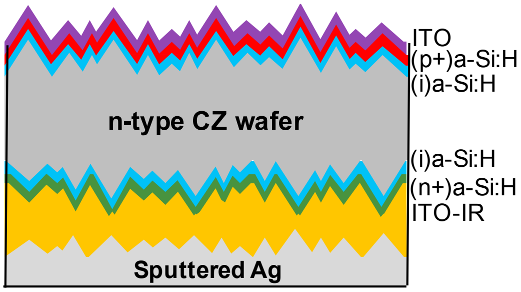

Fig. 1. Silicon heterojunction structure used in this study.

3. Results and discussion

3.1. Recombination modeling

To study the recombination mechanism in our cells, the effective minority-carrier lifetime is measured using the QSSPC technique after forming the pi/CZ/in stack on wafers with different thicknesses. The effective minority-carrier lifetime is than modeled and broken down into its component parts: Auger, radiative, Shockley-Read-Hall (SRH) and front and rear surfaces lifetimes, Fig. 2. The Auger and radiative lifetimes are calculated using Richter parametrization [9], which includes the Schenk bandgap narrowing model [10] and injection dependent radiative recombination [11]. SRH recombination was calculated using a standard SRH model with symmetric recombination parameters for electrons and holes and a single trap state in the middle of the bandgap. The bulk lifetime is measured in sister samples using thick intrinsic amorphous passivation to suppress surface recombination. The surface lifetimes are fitted to the experimental data.