Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 77 (2015) 665 – 676

Energy Procedia

5th International Conference on Silicon Photovoltaics, SiliconPV 2015

Doping level effect on sample temperatures in infrared belt furnace firing

Evert E. Bende, John Anker

ECN – Solar Energy, Westerduinweg 3, 1755 LE, Petten, The Netherlands

Abstract

A firing study has been conducted for a variety of samples with different surface morphologies as well as with different bulk and emitter doping concentrations. In this study the firing settings were fixed and the temperature profile on the sample was measured with thermocouples. We have observed that the measured peak temperature on solar-cell R&D samples in an infrared (IR) conveyer belt firing furnace is strongly dependent on the surface morphology of the sample and its doping level. The surface morphology determines the coupling of IR radiation into the substrate. Samples with a random pyramids (RP) surface texture have reached temperatures that were 150°C higher than that of their polished counterparts. In addition to that, the doping level determines the free carrier absorption (FCA) and thus the heating up due to absorption of IR radiation. We have derived an analytical expression for a Planck-spectrum weighed FCA coefficient that is inversely proportional with the absolute black-body temperature (T) squared. Since the total energy radiated by a black body scales with T^4, the radiation absorption is proportional with T^2. The total doping level of a sample was quantified by G_{tot}, the summation of the sheet conductance values [Ω^{-1}/sq] of the base and emitter region(s). For a sample with a base resistivity of 3 Ωcm and two emitters of 100 Ohm/sq on either side, yielding Gtot=0.028 Ω^{-1}/sq, the measured peak temperature was found to be 150°C higher than that of a 'bare' (lifetime) sample of 10 Ωcm with Gtot=0.0016 Ω^{-1}/sq.

Peer review by the scientific conference committee of SiliconPV 2015 under responsibility of PSE AG

Keywords: Firing, conveyor belt furnace, free carrier absorption, solar cells, lifetime measurement, Planck distribution, black-body radiation

1. Introduction

Firing with a conveyor belt infrared furnace is the last step in the manufacturing process of industrial silicon solar cells. In such a belt firing furnace, cells with screen printed metal contacts are positioned on the belt and the belt moves underneath or in between infrared heaters. Usually the belt furnace is divided into a number of zones where the power of the IR heaters of each zone can be set to a desired power output or to a desired temperature. The

Peer review by the scientific conference committee of SiliconPV 2015 under responsibility of PSE AG
doi:10.1016/j.egypro.2015.07.096

temperature is measured with thermocouples inside the firing furnace and through an electronic feed-back loop the power is adjusted to obtain the set ambient temperature in the firing furnace.

During the firing process the metallic contacts are formed. Contact formation is determined by intricate physical and chemical processes of migration of metallic particles, interaction of metallic particles with silicon as well as interaction of metallic particles and glass frit with dielectrics. For aluminum paste used on the rear side of standard industrial p-type solar cells processes like dissolution of silicon in molten aluminum, aluminum and silicon diffusion as well as recrystallization of silicon, denoted as epitaxial growth, leading to the well-known Al-BSF [1], are the important physics processes.

At the same time the elevated temperature prevailing in the silicon solar cell during firing triggers processes like hydrogen diffusion inside or outside dielectric layers like a:SiN_x:H and Al_2O_3. Diffusion towards silicon can lead to hydrogen bulk passivation and the passivation of dangling bonds at the surface. Effusion to the ambient results in hydrogen depletion. For Al_2O_3 or Al_2O_3-SiNx layers hydrogen migration is known to lead to blister formation of the dielectric layer [2]. At the same time elevated temperatures can lead to re-arrangement of atoms of the dielectric layer and the silicon surface thereby possibly changing the density of surface states and the surface charge of the dielectric layer. This the will affect the surface passivation quality of the dielectric layer.

In photovoltaics R&D a firing parameter study on either solar cells, samples or half-fabricates is an important instrument to optimize solar cell performance and to investigate phenomena like contact formation, Aluminum BSF formation, surface passivation and bulk passivation as a function of temperature. Often half-fabs (e.g. solar cells without metallization) and samples (e.g. symmetric structures with double-sided diffusions or a dielectric layers double-sided deposited) are manufactured and subjected to a firing study.

Many research papers report solar-cell characterization parameters like effective lifetime, recombination current density $j_{0,}$ or implied-V_{oc} as a function of firing temperature. However, quite often one implicitly refers to the firing *set*-temperature of the hottest zone, rather than the *measured* peak temperature. It is evident that these parameters are different and the measured temperature can deviate substantially from the set-temperature. One of the most obvious parameters that determines the difference between set and measured peak temperature is the belt speed.

The heat transfer inside a firing furnace is determined by conduction, between air and wafer, and between wafer and belt, and by absorption of IR radiation. In this work we do not aim to set up a full model that quantifies the prevailing temperature on a wafer during the firing process. Rather we show some experimental results illustrating how cell properties like surface morphology and doping level affect the temperature on the wafer. In addition we present some theoretical building blocks for a future model that illustrates the underlying physics. We will show that absorption of IR radiation in the silicon wafer plays a key role. We describe the absorption rate of radiation in a wafer by analytic means and we derive a formula for the absorption coefficient of IR radiation.

Nomenclature

IR	Infrared
BSF	Back Surface Field
FCA	Free Carrier Absorption
RP	Random Pyramids

2. Physics of IR radiation heat transfer to wafers

In this work we assume that absorption of IR radiation is the dominant factor for the heating up of wafers in a belt firing furnace. This holds particularly when the silicon wafer has little contact with the belt. The belt is expected to be a bit colder than the wafer due to its big thermal mass. This can sometimes be witnessed as belt marks in photoluminescence pictures. Nowadays conveyer belts exist that ensure only little contact of the wafer with the belt. Examples are belts where the wafer rests on typically five dimples or V-shaped belts where the wafer only contacts the belt at the wafer edges.