Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 124 (2017) 138–145

Energy Procedia

www.elsevier.com/locate/procedia

7th International Conference on Silicon Photovoltaics, SiliconPV 2017

Comparison of iron-related recombination centers in boron, gallium, and indium doped silicon analyzed by defect parameter contour mapping

Tine U. Nærland[a,]*, Simone Bernardini[a], Nathan Stoddard[b], Ethan Good[c], André Augusto[d] and Mariana Bertoni[a]

[a]*Ira A. Fulton Schools of Engineering, Arizona State University, 650 E. Tyler Mall, Tempe, AZ 85287, USA*
[b]*Solar World Industries America, 25300 NW Evergreen Rd Hillsboro, OR 97124, USA*
[c]*SunEdison, 7832 N Leadbetter Rd, Portland, OR 97203, USA*
[d]*Solar Power Lab, Arizona State University Research Park, 7700 South River Parkway, Tempe, AZ 85284, USA*

Abstract

In this work, we are showing that iron (Fe) related defects in mono-silicon have very different recombination characteristics depending on the doping element employed. While the defect characteristics of the Fe in its dissociated state is comparably the same in the materials of investigation, the defect characteristics of the associated state vary considerably. By using, defect parameter contour mapping (DPCM), a newly developed method for analyzing temperature and injection dependent lifetime data, we have for the first time, been able to show that in the case of gallium doping it is the orthorhombic state of the Fe-acceptor complex that is dominating the lifetime.

Peer review by the scientific conference committee of SiliconPV 2017 under responsibility of PSE AG.

Keywords: Fe-contamination; Boron-doping; Gallium-doping; Indium-doping; Lifetime Spectroscopy; DPCM

---

1. Introduction

It is well known that replacing boron (B) with gallium (Ga) as a p-type dopant in silicon (Si) suppresses the light-induced degradation (LID) originated by B-O related defects [1]. Indium (In) doped Si was for a long time believed to have the same un-degrading behavior as Ga-Si but was recently reported to have a similarly degrading behavior as B-doped silicon [2]. Ga nor In are, however, commonly used as a dopant in crystalline Si solar cells due to their low segregation coefficient, which causes large resistivity variations in the silicon ingot after solidification. Lately,

1876-6102
Peer review by the scientific conference committee of SiliconPV 2017 under responsibility of PSE AG.
10.1016/j.egypro.2017.09.321

however, new methods for overcoming this problem have been developed, enabling low resistivity variation over the crystal height. It has been shown that Ga-doped and In-doped Si wafers exhibit very high minority carrier lifetimes (MCL) [3],[4]. A shift to Ga-Si that does not degrade with light, in existing p-type processing lines could, therefore, have a massive impact on the levelized cost of electricity. Iron contamination in p-type silicon has, for a long time, been known to be severe to electronic performance [5]. In contrast to LID, however, iron is known to reduce the minority carrier lifetime irrespective of the doping agent. There has, however, been few studies on the extent of the problem with iron contamination in Ga-Si or In-Si [6] and in this paper, we intend to give more insight into this topic.

In crystalline p-type silicon, we know that highly mobile Fe atoms are forming electrically active pairs with shallow substitutional acceptors (A_s) such as boron, aluminum, gallium, and indium [5]. The chemical reaction for the dissociation/association process is:

$$\mathrm{Fe_i^+} + \mathrm{A_s^-} = \mathrm{FeA_s} \tag{1}$$

By optical, thermal or electronic stimulation the pairs will dissociate into their individual constituents. The two different states of Fe have markedly different injection dependence of the minority carrier lifetime, enabling investigation of these defects by lifetime spectroscopy. In the following, we are comparing the defect energies (E_t) and the capture cross section ratios (k) for the $\mathrm{Fe_i^+}$ and the $\mathrm{FeA_s}$ defects in B-Si, Ga-Si and In-Si respectively.

Nomenclature

ARV	Average Residual Value
DPCM	Defect Parameter Contour Mapping
IDLS	Injection Dependent Lifetime Spectroscopy
LID	Light Induced Degradation
TIDLS	Temperature and Injection Dependent Lifetime Spectroscopy
E_t	Energy Level of Defect
k	Capture Cross Section Ratio

2. Experimental and analysis

In the study we investigated three types of mono-silicon material: B-doped silicon ($N_\mathrm{B} = 9.9 \times 10^{15}$ cm^{-3}), Ga-doped silicon ($N_\mathrm{Ga} = 1.2 \times 10^{16}$ cm^{-3}), and In-doped silicon ($N_\mathrm{In} = 7.6 \times 10^{15}$ cm^{-3}). Two sets of samples were prepared for each doping type; one set to be intentionally contaminated with Fe and one set to serve as a reference. The intentionally Fe-contaminated wafers were first annealed at 400˚C on an iron covered hotplate for 1h with a subsequent 1h annealing in a muffle furnace at 800˚C to ensure uniform Fe distribution throughout the wafer thickness. Prior to lifetime measurements, the wafers were etched, cleaned, textured, and thereafter subjected to a 50 nm double side passivation by plasma-enhanced chemical-vapor-deposited (PECVD) hydrogenated amorphous silicon (a-Si:H). To measure the temperature and injection level-dependent effective carrier lifetimes, a contactless quasi-steady-state photoconductance QSSPC technique was applied.

In this work, we have used our recently developed defect parameter contour mapping (DPCM) method to determine the difference in recombination behavior of intentionally Fe-contaminated B, Ga, and In-doped wafers. The method is a novel and comprehensive way of analyzing temperature and injection dependent lifetime spectroscopy (TIDLS) data that enables direct comparison of the defect energies (E_t) and capture cross section ratios (k) associated with the Fe-related defects in these materials. A detailed description of this method can be found in [7].