Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Solar Energy Materials & Solar Cells 90 (2006) 276–282
Solar Energy Materials & Solar Cells
www.elsevier.com/locate/solmat

A thin-film solar cell of high-quality β-$FeSi_2$/Si heterojunction prepared by sputtering

Zhengxin Liu[a,*,1], Shinan Wang[b,2], Naotaka Otogawa[b], Yasuhito Suzuki[a,3], Masato Osamura[a], Yasuhiro Fukuzawa[b], Teruhisa Ootsuka[a,1], Yasuhiko Nakayama[b], Hisao Tanoue[c], Yunosuke Makita[c,1]

[a]*Technology Development Department, System Engineers' Co., Ltd., AIST Tsukuba West, 16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan*
[b]*Kankyo Semiconductors Co., Ltd., AIST Tsukuba West, 16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan*
[c]*National Institute of Advanced Industrial Science and Technology (AIST), AIST Tsukuba Central 2, 1-1-1 Umezon, Tsukuba, Ibaraki 305-8568, Japan*

Received 20 January 2005; accepted 23 March 2005
Available online 10 May 2005

Abstract

High-quality (1 1 0)/(1 0 1)-oriented epitaxial β-$FeSi_2$ films were fabricated on Si (1 1 1) substrate by the sputtering method. The critical feature was the formation of a high-quality thin β-$FeSi_2$ template buffer layer on Si (1 1 1) substrate at low temperature. It was demonstrated that the template is very important for the epitaxial growth of thick β-$FeSi_2$ films and for the blocking of Fe diffusion into the Si at the β-$FeSi_2$/Si interface. Hall effect measurements for β-$FeSi_2$ films showed n-type conductivity, with residual electron concentration around $2.0 \times 10^{17}\,cm^{-3}$ and mobility of 50–400 cm^2/V s. A prototype thin-film solar cell was fabricated by depositing n-β-$FeSi_2$ on p-Si (1 1 1). Under 100 mW/cm^2

*Corresponding author. Tel.: +81 29 861 8066; fax: +81 29 861 8010.
E-mail address: zxliu@ni.aist.go.jp (Z. Liu).

[1]Current affiliation: Tsukuba Laboratory, Tateyama Kagaku Industry Co., Ltd., AIST Tsukuba West, 16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan.
[2]Current affiliation: NEMS Platform Research Department, Leading-Edge Technology Development Headquarters, Canon Inc., 5-1, Morisato-Wakamiya, Atsugi, Kanagawa 243-0193, Japan.
[3]Current affiliation: FiBest Limited, 4-14-1 Myojin-Cho, Hachioji, Tokyo 192-0046, Japan.

0927-0248/$ - see front matter
doi:10.1016/j.solmat.2005.03.014

sunlight, an energy conversion efficiency of 3.7%, with an open-circuit voltage of 0.45 V, a short-circuit current density of 14.8 mA/cm^2 and a fill factor of 0.55, was obtained.

PACS: 73.50.Pz

Keywords: Iron silicide; Template; Sputtering; Heterojunction; Solar cell

1. Introduction

Because of its high optical absorption coefficient ($>10^5\,cm^{-1}$ at 1.0 eV) and abundant element resources in the earth's crust, semiconducting iron disilicide (β-$FeSi_2$) is expected strongly as a novel photovoltaic material with theoretical energy conversion efficiency about 16–23% [1–4]. However, up to now, there were only limited reports on β-$FeSi_2$ solar cell devices, and the highest conversion efficiency was only 0.35%, which was obtained from a β-$FeSi_2$/Si heterojunction formed by the ion implantation method [5–7]. This value was far from practical application. The poor features of β-$FeSi_2$ solar cell devices might be due to the low quality of β-$FeSi_2$ films and un-sharp interfaces between the β-$FeSi_2$ films and the Si substrates, which was mainly induced by the significant interdiffusion of Fe and Si atoms during β-$FeSi_2$ formation. It is well known that the diffused Fe impurities in Si form deep energy levels that locate, depending on the quenching rate, at 0.10, 0.33, 0.40, 0.43 and 0.52 eV above E_v, and they work as efficient trap centers for photo-generated carriers [8,9]. This results in high series resistivity and large leakage current of β-$FeSi_2$/Si heterojunction devices.

In this work, in order to testify the solar energy conversion ability of β-$FeSi_2$ thin films, we first fabricated high-quality β-$FeSi_2$ films by introducing a thin β-$FeSi_2$ template layer pre-formed on Si (1 1 1) substrates at low temperature. Then we deposited high-quality β-$FeSi_2$ films on Si to form heterojunctions as solar cell structures. For the first time, an energy conversion efficiency as high as 3.7% was obtained from an n-β-$FeSi_2$/p-Si cell under sunlight of air mass (AM) 1.5, 100 mW/cm^2.

2. Experimental

β-$FeSi_2$ thin template layers and thick films were fabricated by a facing-target sputtering (FTS) method. The details about the preparation of β-$FeSi_2$ films as well as the FTS are described elsewhere [10]. Fe (purity: 4 N) and Si (purity: 9 N) targets were installed in two FTS sputtering units for the thin template and thick β-$FeSi_2$ film deposition. Silicon (1 1 1) wafers were used as substrates and cleaned by standard RCA process with hydrogen-terminated surfaces. In order to obtain high-quality β-$FeSi_2$ film and to reduce the diffusion of Fe atoms into the Si, a 20 nm β-$FeSi_2$ thin template layer was formed on the Si substrate by the reactive deposition