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Fabrication of Group ⅣSemiconductor Alloys on Si substrate by Screen-Printing

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Abstract

Silicon-based alloy semiconductors on large area Si substrates are fabricated by applying Al-Sn-Ge paste using conventional screen-printing process and high temperature treatment steps. The impact of the Sn and Ge ratio in the pastes are investigated. From the XRD patterns, crystalline SiSn with 0.35% Sn contents and SiGe peaks up to 10% Ge contents have been detected. From the FE-SEM images, both of SiSn and SiGe with 10 μm thick **layer were found.**

1. Introduction

In the last few years, the photovoltaic industry showed the highest growth rate among renewable energy industries and the total installed capacity reached over 500GW, providing almost 2% of the world's electricity supply [1]. Although crystalline silicon technology has the dominant share in the market, its efficiency is approaching their theoretical limits stated by Shockley and Queisser [2]. Meanwhile multi-junction (MJ) solar cells with different bandgaps have led the way to achieving higher power conversion efficiencies [3]. However, the main reasons for their limited use so far are the high cost and other technical drawbacks associated with the Ge substrate on which these cells are fabricated. The transition from Ge to low cost Si wafer platform is desired and several approaches such as wafer bonding, lift-off, sample recycling and growing sacrificial thick buffer layers of SiGe/Ge have been introduced [4]. Nevertheless these processes are still costly from the state-of-art photovoltaic industry point of view.

Recently, our group has demonstrated 10 μm thick and almost uniform relaxed SiGe layer with over 20% Ge content by screen-printing technique. [5,6] This material could be applied for the bottom cell in an InGaP/InGaAs structure instead of a typical Ge substrate. In addition, incorporating Sn atoms into the Ge or Si lattice will allow the formation of a direct-bandgap semiconductor, a better absorber for solar spectra [7]. Therefore, in this work, we attempt to fabricate SiGeSn layers by screen-printing technique using the same approach we developed for SiGe layers fabrication.

2. Experimental method

Different Sn and Ge contents pastes were fabricated as summarized in Table 1, and screen-printed on (100) Si substrates. Subsequently, the samples were dried at 100 ℃ for 10 min, in a conventional batch oven. The samples were annealed at 900 ℃ for 60 sec in Ar ambient using an IR image furnace. Finally, the paste residue on the surface was removed by wet etching with an acid solution of H_3PO_4 : CH_3COOH : HNO_3 : H_2O = 16 : 1 : 1 : 2 at 60 ℃. X-ray diffraction (XRD) was performed to characterize the structure of the fabricated films. The uniformity and atomic composition were characterized by field emission scanning electron microscope (FE-SEM) and energy dispersive X-ray spectroscopy (EDX).

Table1. Sn and Ge contents in the Al paste

Paste	P1	P2	P3	P4	P5	P6	P7
Al (mol%)	70	70	70	70	70	70	70
Sn (mol%)	30	25	20	15	10	5	0
Ge (mol%)	0	5	10	15	20	25	30

3. Results and discussion

The Al-based paste matrix printed on Si surface, provides not only the source of material, but also the means to melt the Si at a relatively lower temperature below 900 ℃ when compared to the Si and Ge melting point. During the temperature ramp up, the Al starts to melt at 660 ℃, dissolving the silicon wafer surface and the Sn and Ge inside the paste, forming an Al-Si-Sn-Ge liquid phase, which recrystallizes epitaxially to form Al-Doped SiGeSn layer.

Fig. 1 shows the XRD patterns of the ω-2θ scans from 2θ=55° to 70° after applying P1, P4 and P7 pastes. The diffraction intensity is drawn on a logarithmic scale to identify small peaks. The XRD angles of the SiSn [400] peaks are located between 56.7°and 69.2°with respect to the α-Sn [400] peaks and Si [400] respectively, and the SiGe [400] peaks are located between 66.1°and 69.2°with respect to the Ge [400] peaks and Si [400]. There were no peaks observed below 2θ of 68.5° suggesting only SiGe layers were formed. On the other hand, Fig. 2 shows the detail peaks around Si [400] and clear peaks of the SiGe [400] printed P7 paste were observed. In addition, their main peaks are shifted to a higher angle with decreasing the Ge content in the paste from P7 to P1, suggesting the Ge contents in the SiGe layer were decreased. Meanwhile, SiSn peaks were observed from the printed P1 paste sample and Sn content from the Vegard's law was calculated approximately 0.35%

Fig. 3 shows the FE-SEM and EDX images of the SiSn layer formed using paste P1. Not only was the uniform SiSn layer observed, but several precipitates of SiSn were also formed.

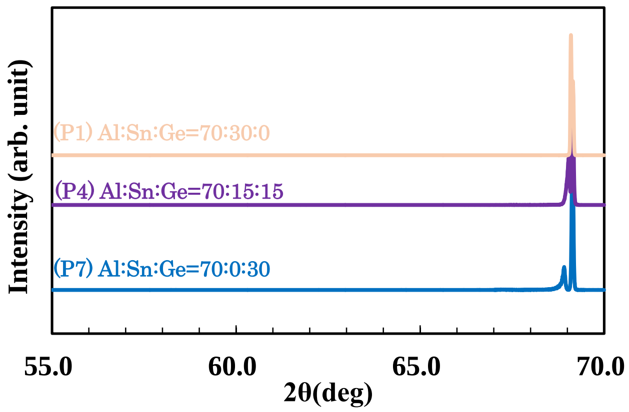

Fig. 1. XRD patterns of fabricated films grown by using P1, P4 and P7 pastes.

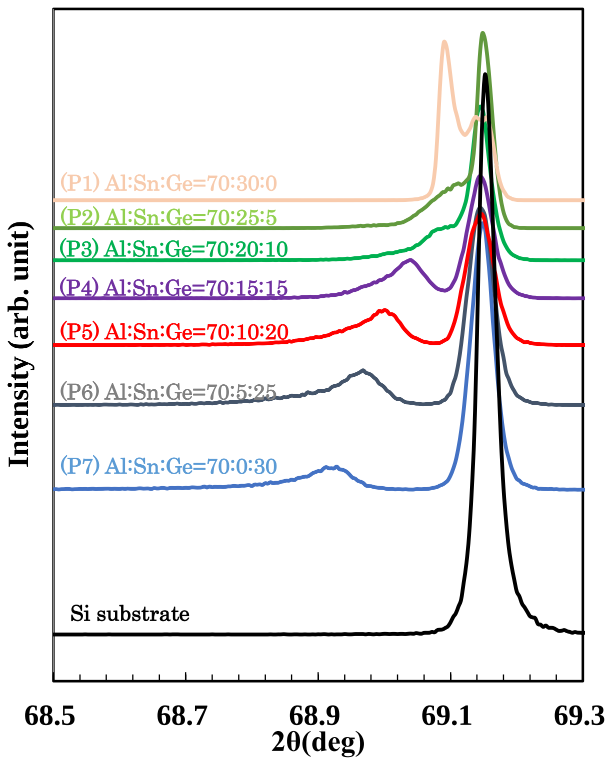

Fig. 2. XRD patterns of fabricated films around Si [400] .

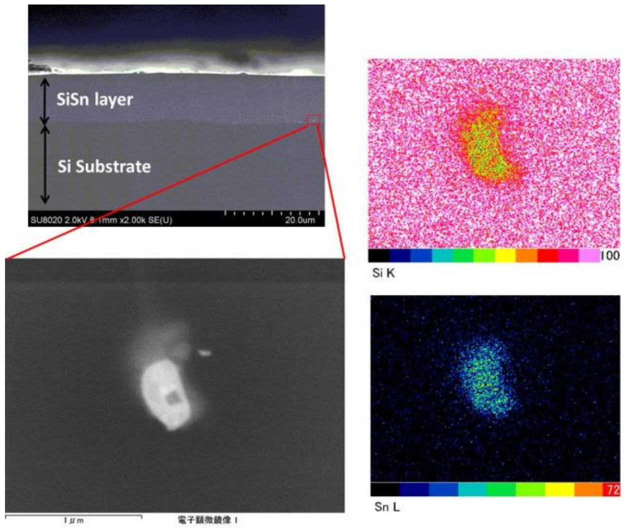

Fig. 3. FE-SEM and EDX images applying P1 paste.

4. Conclusions

The impact of the Sn and Ge ratio in the Al-Sn-Ge paste to fabricate Si based alloy semiconductors by screen-printing on large area Si substrate was investigated. It was shown that SiSn and SiGe layers were formed respectively and Sn ratio in the SiSn layer was estimated approximately 0.35% close to the level of solid solubility of Sn in Si. On the other hand, Ge ratio in the SiGe layer was decreased with decreasing the Ge ratio in the paste. Regarding the uniformity, Sn-rich SiSn precipitations was found in the SiSn layer and needed further optimization of paste chemistry and process control.

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