Electrical Properties of Pulsed-Laser Crystallized Poly-Si Thin Films Grown on YSZ Crystallization-Induction Layers by Two-Step Irradiation Method

Mai Lien Thi Kieu and Susumu Horita
Japan Adv. Inst. Sci. & Tech. (JAIST), 1-1 Asahidai, Nomi, Ishikawa, 923-1292, Japan

Introduction: In the previous JSAP Meetings,[1,2] we have reported that crystalline quality of Si films was further improved by using the yttria-stabilized zirconia [$(ZrO_2)_{1-x}(Y_2O_3)_x$:YSZ] crystallization-induction (CI) layer combined with two-step irradiation method in PLA. In the two-step method, a-Si films were firstly irradiated at a low energy to generate nuclei, following by irradiation at a high energy to accelerate nuclei growth and film crystallization.

In this Meeting, we present detailed investigation results about electrical property of the Si films crystallized on YSZ layers by the two-step method. The measurement was performed by using AC Hall effect and the Van der Pauw method. From the results, we will discuss the CI effect of YSZ layer on the measured conductivity σ, including the carrier concentration n and Hall mobility μ_H.

Experimental: A 60-nm YSZ−CI layer was deposited on a quartz substrate at a substrate temperature of 50 °C by sputtering. Then, an a-Si film was deposited on a YSZ/glass substrate by e-beam evaporation method at 300 °C. For comparison, an a-Si film was also deposited directly on a glass without YSZ layer. For investigating electrical properties, undoped and doped samples were prepared. In the doping case, a 55-nm-thick SiO_2 capping layer was deposited, and then P ion implantation was performed on the whole Si films at an acceleration voltage and ion dose of 40~50 kV and 4.44×10^{12} ~ 5.56×10^{14} cm^{-2}, respectively. The average estimated doping concentration in the Si film is about 3.7×10^{17} ~ 4.9×10^{19} cm^{-3}. Subsequently, the capping layer was removed, following by crystallization of the a-Si films in solid phase by PLA together with activation of the implanted P ions in N_2 ambient. The pulsed laser is Nd:YAG laser (λ = 532 nm) with a repetition frequency of 10 Hz and a pulsed duration of 6~7 ns. After crystallization, AC Hall effect measurement was performed, where the measurement temperature was varied from room temperature (RT) to 300 °C, and activation energies of n, μ_H, and σ were estimated.

Results: Figures 1 and 2 show the Arrhenius plots of conductivity σ with respect to the reciprocal of the measurement temperature T for the crystallized undoped and P-doped Si/YSZ/glass and Si/glass structures, respectively, with different doping concentrations. The activation energies $E_{\sigma i}$ for σ are also shown in these figures, where i = 1 to 5. It was found that all of Si films are n-type. On the whole, excepting at high doping concentration of 4.9×10^{19} cm^{-3}, the conductivity exhibits the behavior of an activation process for both the undoped and P-doped films on both Si/YSZ/glass and Si/glass structures. For the films at the highest doping concentration of 4.9×10^{19} cm^{-3}, the saturation tendency of conductivity can be attributed mainly to the saturation of carrier concentration.

In Fig. 1, the activation energy of the undoped Si/YSZ/glass film is changed from 0.25 to 0.55 eV around 100 °C. Since $E_{\sigma2}$ is near half of energy gap $E_g/2$ or intrinsic energy level E_i, the carrier may be generated from carrier traps at grain boundaries due to thermal excitation. On the other hand, in the low temperature region (T ≤ 100 °C), carriers are excited from the some donors with an impurity level around 0.46 eV (data are not shown). Also, at the low temperature, free carriers are hardly excited from the trap levels at the grain boundaries. For the doped Si/YSZ/glass cases, the activation energies are lower than $E_{\sigma2}$ = 0.55 eV of the undoped film and decrease with increasing doping concentration. This is probably because P doped ions segregate mainly into grain boundaries and passivate electrical defects. The amount of passivated defects increases with doping concentration, as a result, the conductivity increases. However, at higher doping concentration, the amount of dopant for

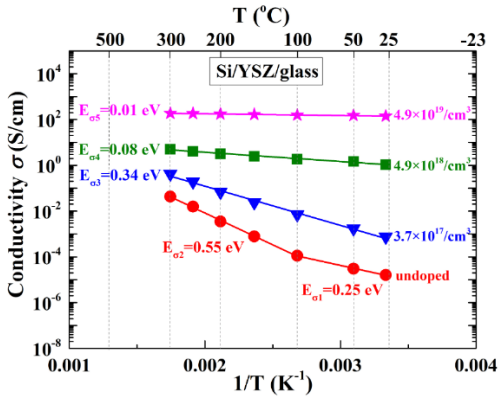

Fig. 1. *Measurement temperature dependences of conductivity σ for the undoped and doped Si/YSZ/glass structures crystallized by the two-step method.*

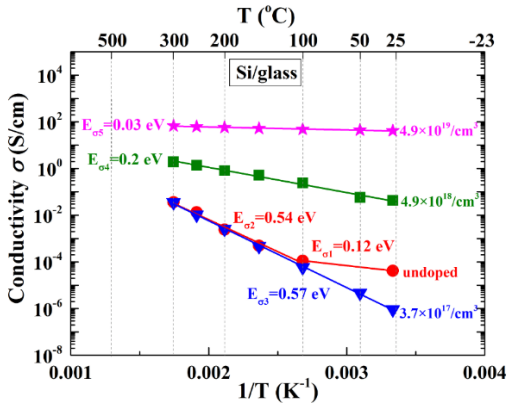

Fig. 2. *Measurement temperature dependences of conductivity σ for the undoped and doped Si/glass structures crystallized by the two-step method.*

passivation is enough and some doped P atoms are thermally activated from the normal donor level of 0.044 eV. For example, for the doping concentration of 4.9×10^{19} cm^{-3}, almost dopant P atoms give free electron carriers at RT. Therefore, E_σ is lower value of 0.01 eV (Si/YSZ/glass) or 0.03 eV (Si/glass).

In Fig. 2, the conductivities are almost the same for both the undoped and low P-doped (3.7×10^{17} cm^{-3}) Si/glass films, which means that the P-doping is not effective. Although the obtained Hall mobility for the low P-doped film is a little higher than that of the undoped one, the carrier concentrations (e.g., ~1.5×10^{14} cm^{-3} at 100 °C) are nearly the same for both cases (the data are not shown). This is probably because the amount of the P dopant atoms are not so much to passivate most of the defects in the Si/glass film, compared with the Si/YSZ/glass one. The higher defect density in the Si/glass than in the Si/YSZ/glass also leads to the lower conductivity and higher activation energy in the former than in the latter at the same doping concentration.

From the above results, it can be concluded that electrical property of the Si films on YSZ layers are much better than those on the glass substrates.

Remarks: In the presentation, we will show the data about electrical properties of n and μ_H.

References: [1] M. T. K. Lien et al., Abstract JSAP 61 st Spring Meeting, 2014, 20a-E14-8. [2] Mai T. K. Lien et al., Abstract JSAP 62nd Spring Meeting, 2015, 13a-P14-3.