Doctoral Dissertation

Study on Material Properties of Si Thin Films Crystallized on Yttria-Stabilized Zirconia in Solid Phase by Pulsed Laser Annealing

(パルスレーザアニールによりイットリア安定化ジルコニア上に固相結晶化したSi薄膜の膜質に関する研究)

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Abstract

In the last several decades, thin film transistors (TFTs) have been much attractive for using as switching devices in active matrix flat panel displays (AM-FPD) and in silicon-on-insulator (SOI) technologies. In order to improve properties of TFTs such as higher mobility and higher reliability, and to lower production costs to meet application needs, many studies on TFTs channel materials using oxide, organic, and crystallized silicon (c-Si) have been carried out extensively. Among them, polycrystalline silicon (poly-Si) TFTs have great advantages of stability, higher reliability, and mobility. In order to satisfy the demands for low cost and high performance, it is necessary to develop a low-temperature fabrication process of poly-Si TFTs with uniform grain size, uniform orientation of grain and smooth Si surface.

The main purpose of my study is to improve crystallization technique of Si thin film on non-heat resistant and cheap insulating substrates of glass or plastic for state-of-the-art electronic device applications by using a yttria-stabilized zirconia [$(ZrO_2)_{1-x}(Y_2O_3)_x$: YSZ] crystallization-induction (CI) layer combined with pulsed laser annealing (PLA) methods to crystallize Si films in solid phase.

In order to achieve the purpose, we investigated the crystallization of a-Si films on YSZ layers by PLA. This study includes the two main parts. The first part is investigating and comparing crystalline quality of Si films crystallized on YSZ layers and on glass substrates by PLA. Thence, crystallinity information of the Si film including the CI effect of YSZ layer can be obtained. The second one is the proposal of a new irradiation method or the two-step method for further improving the crystallinity of Si films. The crystalline quality of Si films crystallized by the two-step method is investigated. After investigation, we have obtained the following results:

For the Si/YSZ/glass structure, at a low irradiation energy density, nucleation occurred faster at the YSZ interface than in the bulk of the a-Si film, which is considered thanks to the CI effect of the YSZ layer. This suggests that the nucleation sites can be controlled on the YSZ interface to make crystallization growth proceed to the film surface smoothly without random nucleation. At the same crystallization degree, crystalline quality of the Si film on the YSZ layer was better than that on the glass substrate. It can be considered that, in the Si/YSZ/glass, Si atoms are arranged more orderly during the phase transition from amorphous to crystalline and the defect density is lower than in the Si/glass. This may be due to the CI effect of the YSZ layer.

On the basis of the aforementioned results, we proposed the two-step method to further improve the crystallinity of the Si films, and crystallized a-Si films on YSZ CI layers by the two-step method with PLA without intentional melting. It was found that the crystallization growth from the YSZ interface is more enhanced by the two-step method than by the one-step (or conventional) method. A higher crystallization degree, better crystalline quality, and a larger grain size were obtained by the two-step method, compared with the one-step method at the same total annealing time and lower total irradiation energy density. Comparing the two structures of Si/YSZ/glass and Si/glass at their own optimized irradiation conditions, we obtained a better crystalline quality in the former.

By applying the two-step method, we succeeded in crystallization of a-Si films on YSZ CI layers under the crystallization condition for area expansion. Their film crystalline quality was investigated and compared with those of the one-step method. It was revealed that the crystallinity of the Si films is improved by the two-step method in the case of the sample moving during the irradiation as well as the static case. The smooth surface of the crystallized Si film and no incubation layer at the interface was obtained. The diffusion of Zr and Y from the YSZ layer into the crystallized Si film was found to be as small as or lower than the order of 10^{17} atoms/cm^3. However, these impurities should be further suppressed for device application. We also measured the carrier concentration, Hall mobility, and conductivity of the crystallized Si films by using the AC Hall effect measurement. The results for both the undoped and doped Si films revealed that the higher mobility and carrier concentration (therefore higher conductivities) are obtained for the Si/YSZ/glass structure compared with those of the Si/glass.

From the obtained results, it is believed that Si films crystallized on the YSZ layers are more suitable for application in electronic devices than on the glass substrates. We can expect a high performance of TFT made from an Si film crystallized on the YSZ layer by the two-step method.

Keywords: poly-Si, pulsed laser, YSZ, crystallization-induction layer, low temperature, solid phase crystallization, TFT.

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