Direct Deposition of high quality nanocrystalline Silicon Films by Catalytic CVD at Low Temperatures (<200)K

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Abstract

We attempted modulation of the hydrogen dilution ratio in a Cat-CVD system to achieve both the minimal incubation layer and the high throughput. We obtained the incubation layer thickness of 3 nm, and were able to grow a 200 nm-thick film having a 70 % crystallinity in 18 minutes.

1. Introduction

Nanocrystalline silicon (nc-Si) thin films have been expected as an active layer material for thin film transistors (TFTs) [1]. Nc-Si thin films have a high stability under a bias stress and a field effect mobility in comparison with amorphous Si (a-Si) films [2]. Nc-Si films can also be deposited at lower substrate temperatures than polycrystalline silicon films [3]. If nc-Si thin films can be prepared at sufficiently low temperatures, flexible substrates such as plastic will be applicable [4]. However, in nc-Si thin films deposited at low temperatures, an incubation layer in the amorphous phase exists at the interface with the substrate. It is reported that the incubation layer lead to a degraded field effect mobility and the threshold voltage shift for bottom gate TFTs [5].

Catalytic chemical vapor deposition (Cat-CVD) technique may be effective to decrease the thickness of an incubation layer. It is expected that the radicals decomposed at the high temperature catalyst can arrange themselves readily on the low temperature substrate. However, the higher the catalyst temperature, the higher the substrate temperature will be. In order to obtain a minimal incubation layer at a substrate temperature of < 200 , modulation of a the hydrogen dilution ratio was attempted in this study.

2. Experimental

The nc-Si thin films were deposited by using a Cat-CVD system as illustrated in our previously report [6]. The source gas was a mixture of silane and hydrogen. The composition of the source gas was controlled by mass flow controller (MFC). The hydrogen dilution ratio (HDR) was calculated from the following equation :

$$HDR=[H_2]/(\,[H_2]+[SiH_4]) \quad (1)$$

where $[H_2]$ and $[SiH_4]$ are flow rates in standard cubic centimeter per minute of hydrogen and silane, respectively.

The catalyst was a tungsten wire of 0.4 mm diameter and was placed over the substrate at a distance of 5 cm. The temperature of the catalyst was 1740 . In spite of the high catalyst temperature, the substrate temperature was maintained no higher than 200 as described in our previously work [7]. The film thickness was measured by a surface profilometer(α-step). The incubation layer thickness was estimated by the ellipsometry and was confirmed by transmission electron spectroscopy (TEM). The crystallinity of nc-Si thin films was characterized by Raman spectroscopy [8].

3. Results and discussion

Fig. 2 shows the dependence of the crystalline volume fraction on the hydrogen dilution ratio. The crystalline volume fraction was increased by increasing the hydrogen dilution ratio. It is known the excessive hydrogen atoms etch Si clusters that are bound weakly on the growing surface [9]. The higher the hydrogen dilution ratio, the higher the crystalline volume fraction was.

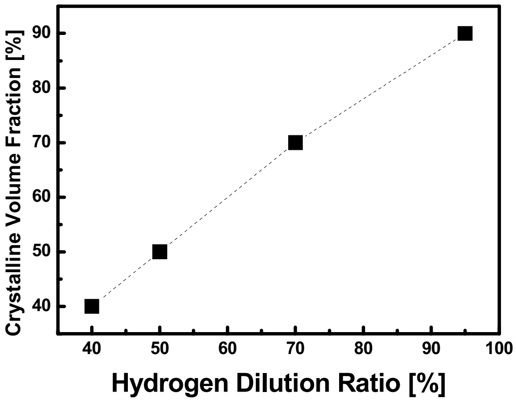

Fig. 2. Crystalline volume fraction of nc-Si films as function of the hydrogen dilution ratio.

Fig. 3 shows the dependence of the deposition rate and the incubation layer thickness on the hydrogen dilution ratio. The deposition rate was decreased by increasing the hydrogen dilution ratio. Also, the incubation layer thickness was diminished with the high hydrogen dilution ratio. It is implied that the enhanced crystallinity in the bulk can reduce the incubation layer at the interface.

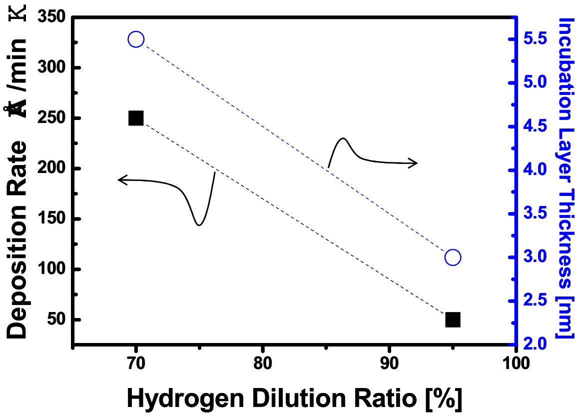

Fig. 3. Deposition rate and incubation layer thickness as a function of the hydrogen dilution ratio.

We obtained an incubation layer thickness of 3 nm at the hydrogen dilution ratio of 95 %. However, in this condition, the deposition rate was as low as 5 nm/min. To obtain a high deposition rate and a minimum incubation layer thickness simultaneously, we used modulation of the hydrogen dilution ratio as shown in Fig. 4. First, the hydrogen dilution ratio was fixed at of 95 % for 10 min. Then, it was ramped down to 70 % in 2 min. The hydrogen dilution ratio was maintained at 70 % for 6 min. As a result, the deposition time for a 200 nm-thick layer was reduced from 40 min to 18 min.

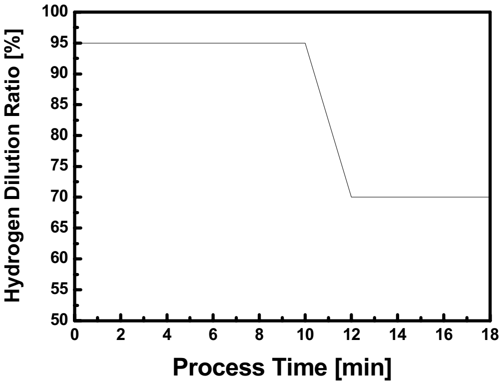

Fig. 4. Change in the hydrogen dilution ratio with deposition time.

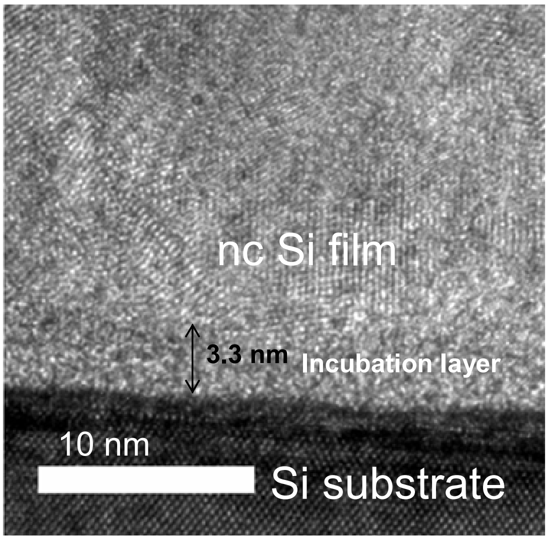

Fig. 5. HRTEM cross section image of the as-deposited nc-Si film with a modulation of the hydrogen dilution ratio.

In Fig. 5, high resolution cross-sectional images of the TEM are shown for the films prepared with a modulated HDR. the incubation layer thickness was reduced to 3.3 nm for the film with modulated hydrogenation

4. Summary

Nc-Si films were directly deposited by Cat-CVD at substrate temperatures (<200). The incubation layer thickness of nc-Si films was diminished with the high hydrogen dilution ratio. However, the deposition rate of the nc-Si films was degraded at the same time. To obtain a high deposition rate and a minimum incubation layer simultaneously, modulation of the hydrogen dilution ratio was attempted. We achieved nc-Si film of 200 nm in thickness, having a 3 nm-thick incubation layer in 18 min. This technique is expected to enhance the field effect mobility of the bottom-gate nc-Si thin film transistors fabricated at a low temperature.

5. References

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