Vol 15 No 6, June 2006
1009-1963/2006/15(06)/1330-05

Chinese Physics

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and IOP Publishing Ltd

The influence of SiN_x substrate on crystallinity of μc-Si film used in thin film transistors*

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(Received 29 September 2005; revised manuscript received 24 January 2006)

This paper found that the crystalline volume ratio (X_c) of μc-Si deposited on SiN_x substrate is higher than that on 7059 glass. At the same silane concentration (SC) (for example, at SC=2%), the X_c of μc-Si deposited on SiN_x is more than 64%, but just 44% if deposited on Conning 7059. It considered that the 'hills' on SiN_x substrate would promote the crystalline growth of μc-Si thin film, which has been confirmed by atomic force microscope (AFM) observation. Comparing several thin film transistor (TFT) samples whose active-layer were deposited under various SC, this paper found that the appropriate SC for the μc-Si thin film used in TFT as active layer should be more than 2%, and X_c should be around 50%. Additionally, the stability comparison of μc-Si TFT and a-Si TFT is shown in this paper.

Keywords: μc-Si:H thin film, SiN_x substrate, crystallinity, bottom-gate TFT
PACC: 7360, 7360F, 7360H, 7360L

1. Introduction

It has been observed that microcrystalline Si (μc-Si) films, deposited directly by plasma enhanced chemical vapour deposition (PECVD), have many advantages over amorphous Si (a-Si) and have been applied in variable thin film devices, such as solar cells, image sensors, and thin film transistors (TFTs).[1−3] As is well known, μc-Si thin film could be deposited on different substrate in these applications. There is evidence that the performance of μc-Si materials is dependant on the deposited substrates. The obvious effect is on its structure, as was pointed out by many other researchers.[4,5] However, most studies on this issue are only for solar cell, seldom for TFT application. Additionally, studies on μc-Si TFT, such as the works done by Schropp and Wagner,[6,7] paid more attention to TFT device structure and interface treatment than the characteristics of μc-Si thin film acting as active layer. But the structure, specially the crystalline volume ratio of μc-Si materials, also plays an important role in improving TFT performance. Hence, in this paper, we mainly focus on the effect of SiN_x substrate on the crystallinity of μc-Si thin film and the performance of resulted TFT. By comparing several TFT samples, the appropriate silane concentration for preparing the active layer of TFT has been discussed.

2. Experiments details

The μc-Si thin films were deposited by very high frequency PECVD (VHF-PECVD) on 7059 glass substrate and on SiN_x film with 7059 glass substrate under the same conditions, of which the excitation frequency was 60MHz, the silane concentration SC diluted by hydrogen (SC was defined as $SiH_4/(SiH_4+H_2)$) was from 2% to 4%. The pressure is from 100Pa–120Pa. The substrate temperature and the excitation power were fixed at 220°C and 15W

*Project supported by the '863' Project of National Ministry of Science and Technology (Grant No 2004AA33570), Key Project of NSFC (Grant No 60437030) and Tianjin Natural Science Foundation (Grant No 05YFJMJC01400).

respectively. The crystallinity of μc-Si was analysed by measured Raman spectra using a 632.8nm He–Ne laser. Here, the crystalline volume fraction (X_c) was used to describe the crystallinity of the films. X_c of the sample was deduced from its Raman scattering spectra by the ratio of $X_c = I_c/(I_c + I_a)$,[8] where I_c is the sum of intensity describing crystalline peak at 520 cm^{-1} and the peak describing crystalline strain at 510 cm^{-1}, but Ia is the amorphous intensity at 480cm^{-1}. Atomic force microscope (AFM) was used to observe the surface topographies of μc-Si samples and different substrates surface.

For the μc-Si bottom-gate (BG) TFT fabrication, a four-mask process with specially designed layout was used. Aluminium (Al) was adopted as the gate electrode. 200 nm of SiN_x was deposited as the gate insulator. After that, 160 nm of intrinsic μc-Si as the channel layer, and ~50 nm of $n^+\mu$c-Si as the contact layer were deposited in sequence without breaking vacuum. Afterwards the channel was defined by photolithography and wet etching. Then, Al was thermally evaporated and patterned by wet etching to form the source and drain electrodes. Finally, we opened the contact holes to TFT gate electrode.

The TFT I–V curves were measured by a HP4156 parameter analyser. The Vth and field mobility were extracted from the measured I–V curves.

3. Results and discussions

Figure 1 shows the comparison of Raman spectra for the μc-Si thin films deposited on Conning 7059 glass substrate and on SiN_x substrate respectively. Through three peak fit according to Gauss distribution function, the calculated X_c values of the μc-Si on glass is 44%, while, that of the μc-Si on SiN_x substrate reaches to more than 64%, which are shown in Fig.2.

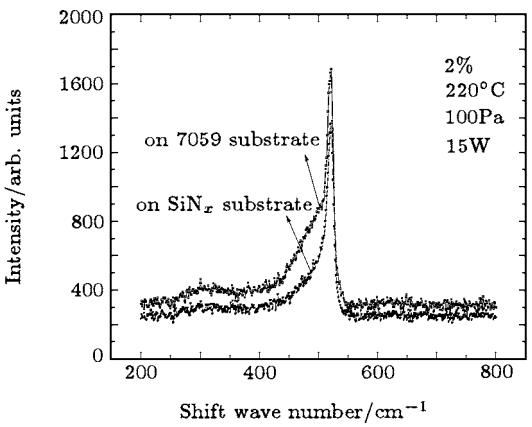


Fig.1. The compare of Raman spectra of μc-Si thin films deposited on 7059 glass substrate and on SiN_x substrate.

It is suggested that SiN_x surface could promote the crystallinity of μc-Si thin film by more than 20%. The surface morphology of SiN_x and 7059 glass measured by AFM were shown in Fig.3.

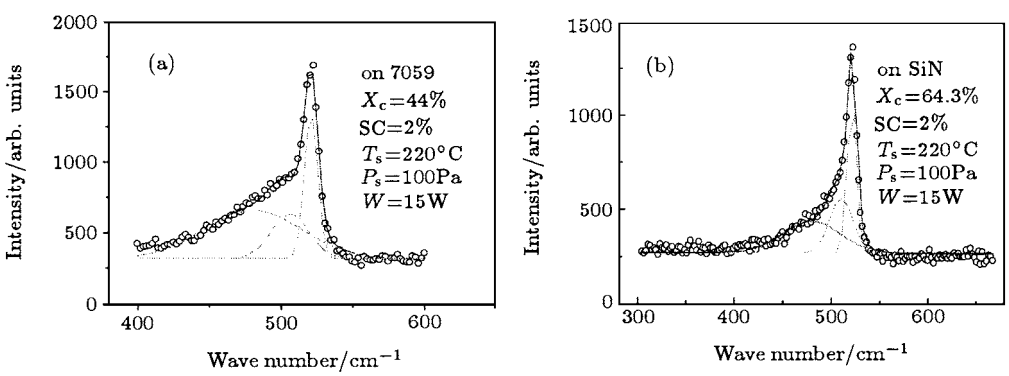


Fig.2. The simulation results of three peak fit using Gaussian analysis for the curves shown on Fig.1.

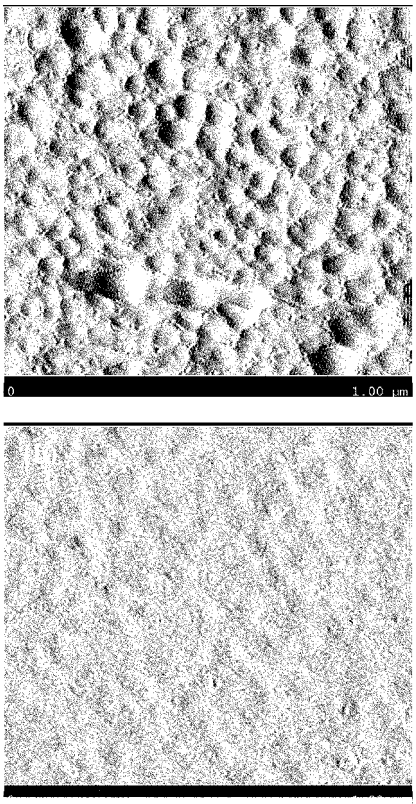


Fig.3. AFM images of SiN_x surface (a) and 7059 glass surface (b).

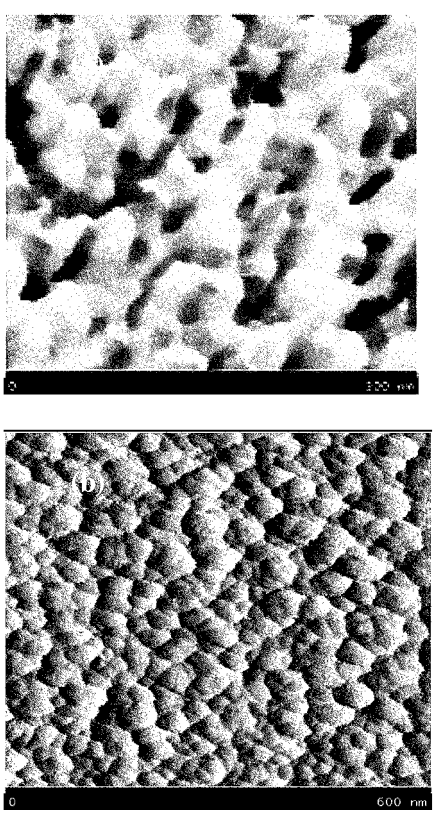


Fig.4. AFM images of μc-Si thin films deposited on SiN_x substrate under SC=2% (a) and SC=4% (b).

It can be observed that the surface morphology of Conning 7059 glass is relatively smooth, whereas that of SiN_x substrate shows roughness: there were many 'hill-like' structures on it.

We think these hills play a role to promote the nuclei formation of μc-Si. Consequently, SiN_x substrate led to the crystallinity increase of μc-Si.

Figure 4 shows the AFM images of μc-Si thin films deposited on SiN_x substrate under SC=2% and SC=4% respectively.

It can be found that the structure of the former is noncompact. There were many cavities between the column grains. That might be contributed from the etching effect of H^o or H^+ when the μc-Si film deposited at low SC diluted by hydrogen, which makes oxygen penetrate into it and leads to high dark conductivity due to the O^+ donor in Si-Si network. The dark conductivity varies with X_c in different orderliness[9] as shown in Fig.5.

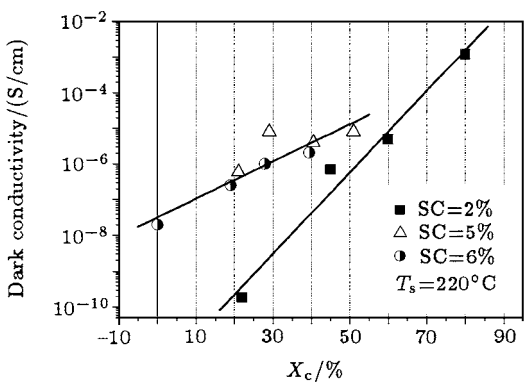


Fig.5. Demonstration of conductivity vs. X_c of several μc-Si deposited on glass.

Consequently, the drawback of too high crystallinity of μc-Si is the high dark conductivity which could degrade the modulating effect of TFT by gate voltage.

On the other hand, the structure of the latter (SC=4%) is more compact, it could prevent from oxygen contamination. As a result, the SC for μc-Si deposited on SiN_x substrate in bottom gate μc-Si TFT should be appropriately higher compared with that on Conning 7059 glass substrate. The above conclusion is being of importance for the μc-Si BG TFT since its active layer is directly deposited on SiN_x insulator. This has also been confirmed by comparing several μc-Si BG TFT samples without any other treatment or LDD (lightly-doped drain) structure, their transfer I–V curves are shown in Fig.6.

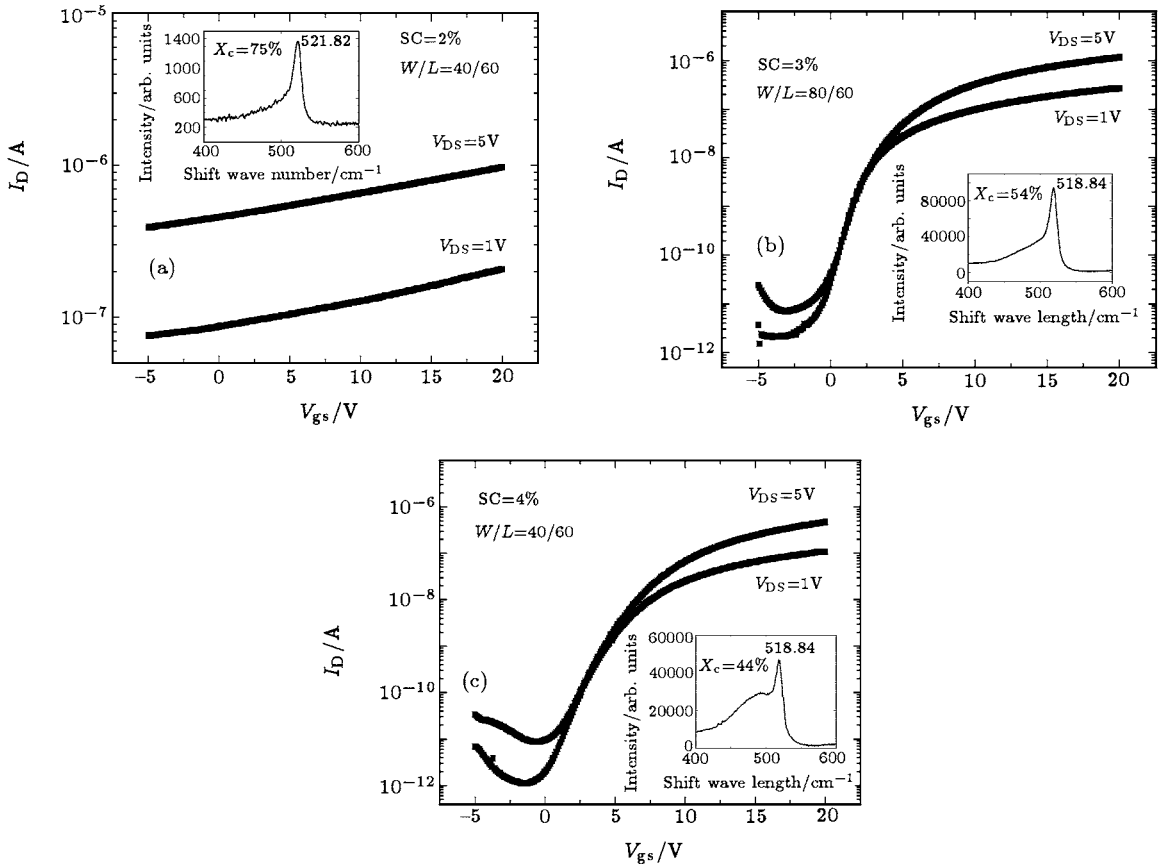


Fig.6. Transfer Characteristics of μc-Si bottom-gate TFTs whose active layer were deposited under SC=2% (a), 3% (b), 4% (c), respectively. The inset shows the Raman spectra of each active layer.

The inset in each picture shows the Raman spectra of the active layer. When SC of the μc-Si used as the active layer of TFT is 2%, the transfer characteristic of the TFT is similar as a line. This means that no more modulating effect in this kind of TFT can be presented. The effect could be attributed to too high dark conductivity of μc-Si deposited at SC=2%. Because very high dark conductivity means that the Fermi level (E_F) is very close to the band-tail in which the huge defectors would trap much induced electrons, therefore the free conductive electrons could not increase any more with the increase of gate bias.

When SC reaches to 3% or 4%, the TFTs show obvious transfer characteristics. For the TFT with SC of 3%, the on-state current Ion is 1.2×10^{-6}A, the ratio of on-state current to the off-state current (I_{on}/I_{off}) is up to 10^6, the mobility is around 0.5cm^2/V·s, and the threshold voltage is about 4.3V. Furthermore, the resulted TFT has a less degradation than a-Si TFT with normal gate-bias stress condition, the comparison is shown in Fig.7. The above results implies that to achieve suitable performances of μc-Si BG-TFT, if its active layer deposited on SiN_x insulator, the appropriate SC of its active layer should be higher than 2%, the X_c should be around 50%.

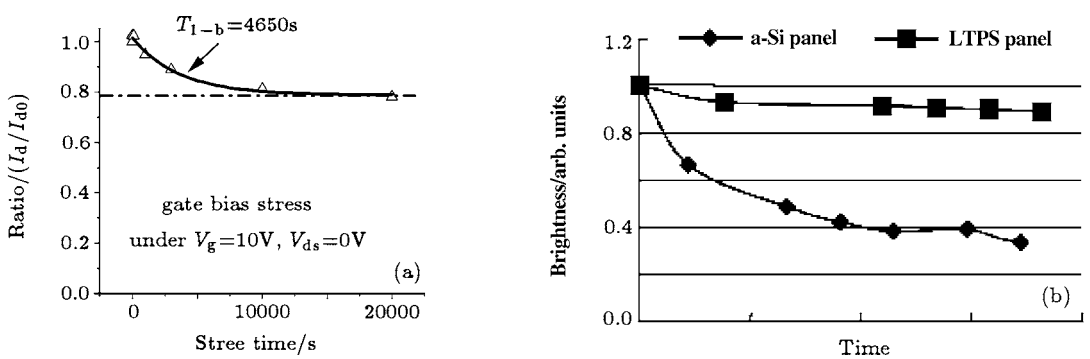


Fig.7. The comparison of degradation between different TFT: (a) μc-Si TFT, (b) a-Si TFT.

4. Conclusion

The X_c value of the μc-Si deposited on SiN_x substrate is higher than that on Conning 7059 glass. Through AFM images, we found many 'hills' on the SiN_x surface. These 'hills' could promote the crystalline growth of μc-Si thin film, which make it with high crystalline volume ratio. Comparing several TFT samples whose active-layers were deposited under various SC, it is indicated that the appropriate SC for the active layer should be higher than 2%, the X_c should be around 40%–50%.

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