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TFT and Physical Properties of Poly-Crystalline Silicon Prepared by Very Low Pressure Chemical Vapour Deposition (VLPCVD)

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This paper investigates the role of silane partial pressure (P_{SiH_4}) in VLPCVD on the as-deposited poly-Si film quality. The film quality strongly depends on the P_{SiH_4} when deposition temperature is kept constant. Higher pressure and excessively lower pressure have been found not to be adequate for thin film transistors (TFTs). By optimizing the deposition conditions, excellent TFTs can be fabricated through a low temperature process without relying on any other special processes. This paper also suggests the possibility of further improvement of as-deposited poly-Si films.

1. INTRODUCTION

The characteristics of poly-crystalline silicon thin film transistors (poly-Si TFTs) are mainly determined by the quality of the poly-Si film[1] which constitutes the semiconductive channel layer of the transistor. In order to obtain poly-Si films, low pressure chemical vapour deposition (LPCVD) utilizing pyrolitic decomposition of silane (SiH_4) is the simplest and most common method[2][3] although its actual usage is limited to the high temperature process for TFTs because of the low quality of as-deposited poly-Si films. The present work reveals that as-deposited poly-Si films can be improved and applied to the low temperature process for TFTs if the parameters of the LPCVD are optimized.

2. EXPERIMENT

By changing the deposition conditions, several kinds of as-deposited poly-Si films were prepared by LPCVD and were examined from the view points of transistor and physical properties. The LPCVD reactor is a vertical type with a volume of 184 l and can hold at least 35 300mm□ glass substrates horizontally. Its pumping speed satisfies the following relations when inert gases are introduced to the reactor chamber at 600° C.

$$P(\text{mtorr})=0.365(\text{mtorr}) + 0.4993\ (\text{mtorr/sccm})Q \qquad 0 \leqq Q \leqq 10\ \text{sccm}$$

$$P(\text{mtorr})=2.260(\text{mtorr}) + 0.3100\ (\text{mtorr/sccm})Q \qquad 10\ \text{sccm} \leqq Q \leqq 100\text{sccm}$$

$$P(\text{mtorr})=24.04(\text{mtorr}) + 0.1626\ (\text{mtorr/sccm})Q \qquad 200\ \text{sccm} \leqq Q \leqq 900\ \text{sccm}$$

The pumping speed does not depend on the kinds of gases since the pumping system consists of a mechanical booster pump and a rotary pump. The pressure is measured by a capacitance manometer. The base pressure when the chamber is isolated is on the order of 10^{-4} torr. As-deposited poly-Si TFTs with ordinary non-self-aligned structure were fabricated by a low temperature process in which the maximum temperature was during the poly-Si deposition step, i.e. around 600° C to 620° C. Grain size and morphology of the films have been observed by electron microscopy such as TEM, SEM and STM. Crystallinity was optically measured by Raman spectroscopy and spectroscopic ellipsometry. X-ray diffraction intensities were also used to evaluate crystallinity and preferred orientation of the films.

3. RESULTS and DISCUSSION

One of the most influential parameters of the LPCVD method on as-deposited poly-Si films is the deposition temperature. Fig. 1 shows how the temperature affects the transistor property I_{on}. As can be seen from this figure, higher deposition temperature generally tends to draw higher I_{on}. Another important parameter is the partial pressure of silane (P_{SiH_4}) during the Si deposition. Different transistors have been obtained in Fig. 2 by changing P_{SiH_4} of LPCVD with temperatures of 600° C and 620° C. At both temperatures, decreasing P_{SiH_4} from the conventional level which was roughly higher than 50 mtorr leads to an increase of I_{on}. The I_{on} values have their peaks at P_{SiH_4} of 4 mtorr for 600° C and 7 mtorr for 620° C. When further lowering P_{SiH_4}, I_{on} will suddenly fall. In this experiment P_{SiH_4}

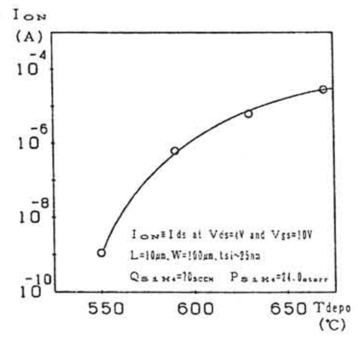

Fig. 1 I_{on}-T_{depo} curve.

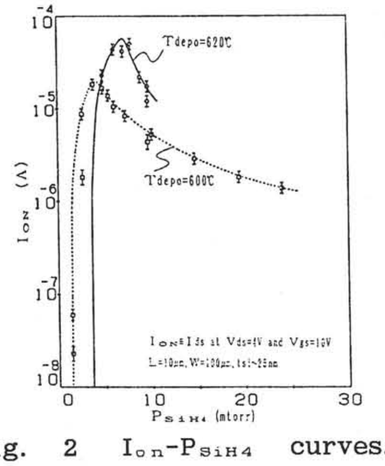

Fig. 2 I_{on}-P_{SiH_4} curves.

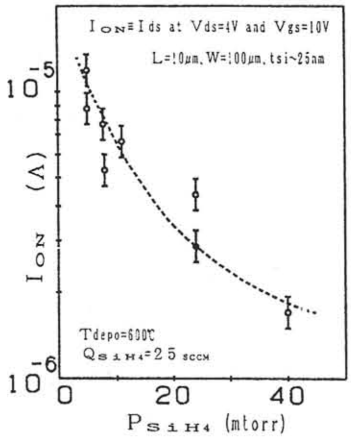

Fig. 3 I_{on}-P_{SiH_4} curve.

was adjusted by controlling the flow rate of SiH_4 (Q_{SiH_4}). The same result was also obtained in Fig. 3 when a dilution gas was introduced to reduce P_{SiH_4} or the pumping speed of the system was decreased while keeping Q_{SiH_4} constant.

The reason P_{SiH_4} affects as-deposited poly-Si TFTs was studied through the analysis of physical properties. First of all, change of preferred orientation of the crystals has been observed by XRD. Films deposited at higher pressure only show {220} diffraction while lower pressure deposited films have shown preferred orientation of {111}. The peak intensity of {111} diffraction gets stronger as P_{SiH_4} decreases. This change seemed to be related to the I_{on} values at first sight, but {111} diffraction intensity does not show a peak but continues to increase monotically as P_{SiH_4} decreases and is the strongest at very low pressure, i.e. $P_{SiH_4} \leqq 4$ mtorr for 600° C and $P_{SiH_4} \leqq 8$ mtorr for 620° C.

On the other hand, optically measured crystallinity has been found to be reflected on the transistor properties. Fig. 4 shows film crystallinity indicating the presence of maximum crystallinity peaks at the same P_{SiH_4} as the I_{on} values. This figure also reveals that transistor properties of the poly-Si films are strongly related with the optically measured crystallinity, that is, higher crystallinity results in better transistor properties. Thus, one of the reasons that transistor properties are improved by low pressure deposition may be because of improved crystallinity.

Optical property of the as-deposited poly-Si films again changes drastically below the peaks, corresponding to the sudden fall of the I_{on} values. How the absorption coefficient decreases as a function of P_{SiH_4} is drawn in Fig. 5. At both deposition temperatures poly-Si films become more and more transparent as P_{SiH_4} decreases below the I_{on} peaks. Very transparent films deposited, for example, at 620° C and P_{SiH_4} of less than 4 mtorr do not show semiconductive properties but are only insulators. In addition, these transparent films can be easily etched by chemical dry etching using CF_4 and O_2 plasma. These etching rates are two to three times faster than normal as-deposited poly-Si films.

The grain size of the as-deposited poly-Si films has been determined from the surface roughness measured by STM and the change of surface morphology is seen through SEM photographs in Fig. 6 in which samples with thickness of about 500 nm were deposited at 620° C with changing P_{SiH_4}. Fig. 6-a shows higher P_{SiH_4} produces smaller grains while lower P_{SiH_4} forms larger grains (Fig 6-b). These results are exactly coincident with STM observation, i.e. Rz=11.7 ± 3.0 nm for P_{SiH_4}=33 mtorr, Rz=14.0 ± 3.0 nm for P_{SiH_4}=17.8 mtorr, and Rz=22.9 ± 3.0 nm for P_{SiH_4}=8.5 mtorr. On the contrary, disagreement between SEM observation and STM becomes clear when the film is deposited at excessively low pressure such as P_{SiH_4}=2.9 mtorr. While STM measures Rz of the films as 28.2 ± 3.0 nm which means the existence of the largest grains, SEM photograph (Fig. 6-c) shows low quality and porous Si film formation.

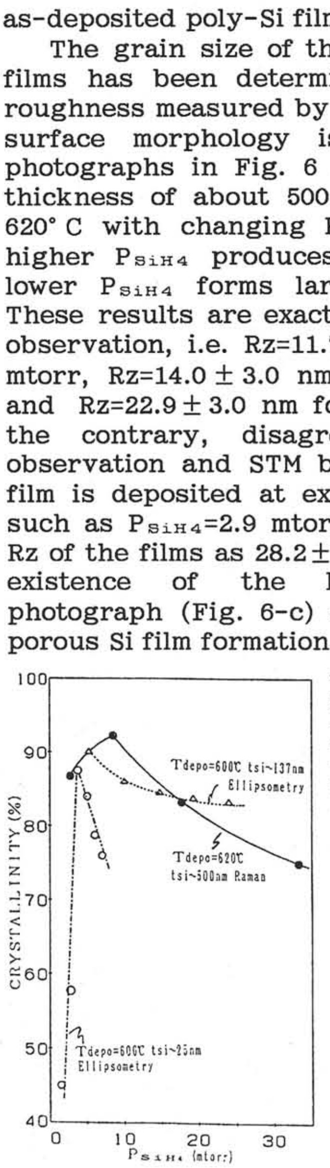

Fig. 4 Crystallinity.

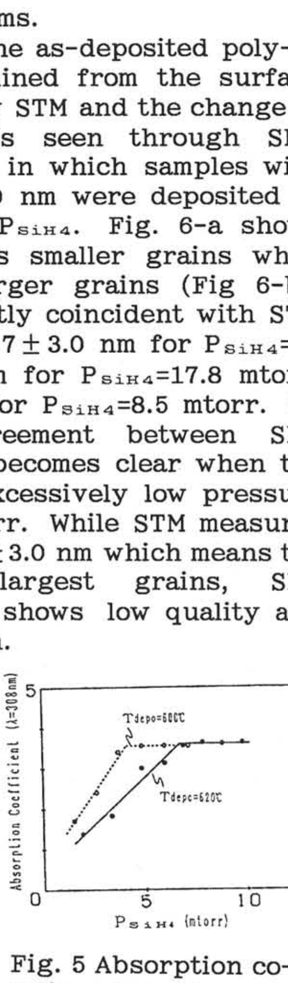

Fig. 5 Absorption coefficient vs. P_{SiH_4}.

Crystalline textures have also changed noticeably, depending on the partial pressure of silane (Fig. 7). At the higher pressure, P_{SiH_4}=17.8 mtorr, the crystal shows tufty structure (Fig. 7-a). When the pressure is reduced to 8.5 mtorr, at which the corresponding transistor yields ON/OFF current ratio of 10^7 and mobility of ~ 11 $cm^2/V \cdot sec$, the film exhibits tooth-shaped structure. At excessively low pressure, no specific structure has been observed. The film seems to have lost its crystal order and many defects and voids can be seen.

From all these facts, it can be deduced that very low pressure deposition may potentially form high crystallinity poly-Si films having large grains with preferred orientation of {111}. The films deposited at excessively low pressure, however, contain some voids and are so porous that the corresponding transistor shows poor electrical properties, that the film becomes transparent, and that the film is very easily etched. Thus, if the films not possessing any voids can be deposited at even very low pressure, the as-deposited poly-Si film quality may be further improved as will the transistor properties.

4. CONCLUSION

In conclusion, transistor properties of as-deposited poly-Si can be improved drastically by the VLPCVD method without relying on any other special processes, and yields an on/off current ratio of 10^7 and mobility of ~ 11 $cm^2/V \cdot sec$ for T_{depo}=620° C. Maximum I_{on} values of several mtorr of P_{SiH_4} have been observed at each temperature. Below this pressure, film quality rapidly decreases and is not adequate for TFTs. These phenomena have been comprehensible from changes in crystallinity, grain size and void ratios in the films in accordance with deposition conditions.

The present study has shown the high potential of as-deposited poly Si films prepared by the VLPCVD method for high quality TFTs fabricated by the low temperature process. This study also suggests that as-deposited poly-Si films may be further improved if void generation can be avoided during deposition at even lower pressure.

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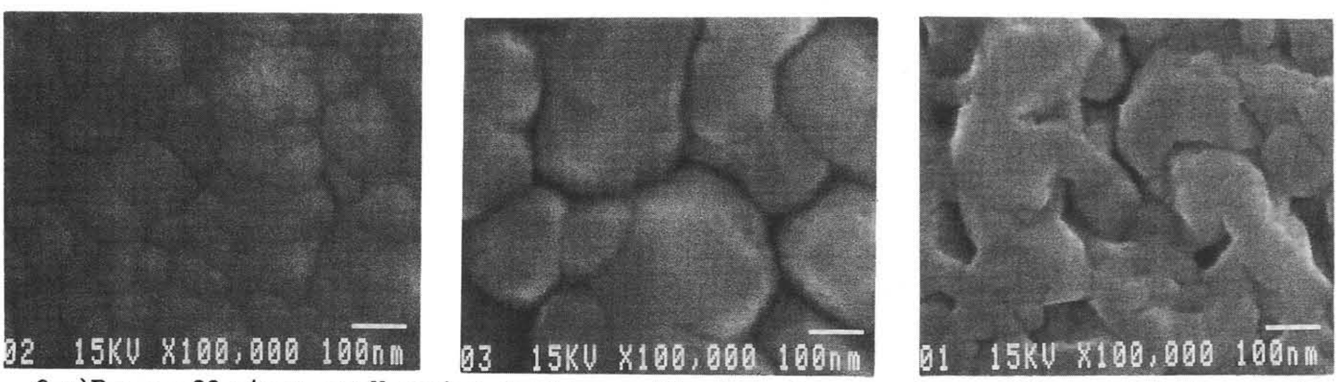

6-a)$P_{SiH_4}\sim$33 mtorr, small grains 6-b)$P_{SiH_4}\sim$8.5 mtorr, large grains 6-c)$P_{SiH_4}\sim$2.9 mtorr, voids

Fig. 6 SEM photographs of the surface morphology of the Si films deposited at 620° C.

⟷ 100 nm

7-a) $P_{SiH_4}\sim$17.8 mtorr, tufty 7-b) $P_{SiH_4}\sim$8.5 mtorr, tooth-shaped 7-c) $P_{SiH_4}\sim$2.9 mtorr, disordered

Fig. 7 Cross-sectional TEM photographs of the Si films deposited at 620° C.