

## Wettability of Silicon Oxide by Poly-Crystalline Silicon

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Stoichiometric change of underlying silicon oxide has been found to have a great influence upon the properties of the thin poly-crystalline silicon (poly-Si) films deposited on the underlying silicon oxide, resulting in important characteristics changes of the poly-Si thin film transistors (TFTs) made on it. The silicon oxides containing excessive silicon atoms have fairly good wettability by silicon so that the thin poly-Si deposited on it is in a continuous film state. The thin poly-Si on the stoichiometrically perfect silicon dioxide is in a separate island-like state but consists of large crystallites. The best TFTs will be fabricated by optimizing the amount of silicon content in the underlying silicon oxide, the poly-Si deposition condition, and the thickness of poly-Si film.

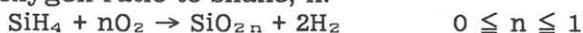
### INTRODUCTION

Low temperature processed poly-crystalline silicon (poly-Si) thin film transistors (TFTs) are currently very attractive, not only because they can be practically applied to high quality liquid crystal displays with large areas,<sup>(1)</sup> but also because the CMOS circuits can be integrated on conventional glass substrates using the TFTs<sup>(2)</sup>. Since the poly-Si films are formed on underlying insulative materials such as silicon oxide and since the wettability of underlying material by poly-Si can affect the quality of the poly-Si films, the underlying silicon oxide can improve the poly-Si film quality and, consequently, electrical characteristics of low temperature processed poly-Si TFTs. Based on this idea, this paper will discuss the effect of underlying silicon oxide both on poly-Si film quality and on TFT characteristics.

### PREPARATION OF UNDERLYING SILICON OXIDE AND POLY-Si

Various kinds of underlying silicon oxides ( $\text{SiO}_x$  with various value of  $x$ ;  $0 < x \leq 2$ ) have been prepared by an electron cyclotron resonance plasma enhanced chemical vapour deposition (ECR-PECVD) system with changing mono-silane ( $\text{SiH}_4$ ) and oxygen ( $\text{O}_2$ ) flow rate, while the total quantity of these gases was fixed to 120 sccm ( $Q_{\text{SiH}_4} + Q_{\text{O}_2} = 120$  sccm). Poly-Si films were deposited on these oxides by an infra low pressure chemical vapour deposition (ILPCVD)<sup>(3)</sup>.

The oxide formation is described by the following chemical equation for the small value of oxygen ratio to silane,  $n$ .



This chemical equation tells that the silicon oxide can contain excessive silicon atoms ( $x=2n < 2$ ) when it is deposited with  $n \leq 1$ . The infra-red absorption measurement shows that no hydroxyl (Si-OH) exists in any of the oxides and that the silicon oxides deposited with  $0 \leq n \leq 1$  are not complete silicon dioxide but contain a large amount of hydrogen in the form of

hydride (Si-H). When poly-Si films are deposited on these oxides in an LPCVD system, the oxide films will have been warmed up to about 600° C for 1 or 2 hours just before and during poly-Si deposition. This heat environment will remove many hydrogens from the oxides, increasing the silicon ratio in the oxide. Thus, the silicon oxides deposited with a small value of  $n$  are in a silicon excess state and are expected to have rather good wettability by poly-Si.

### TFT CHARACTERISTICS

Conventional non-self-aligned NMOS TFTs have been fabricated through low temperature process. Channel layers are formed on the underlying oxides by 25 nm thick as-deposited intrinsic poly-Si films prepared by ILPCVD. The maximum processing temperature during the TFT fabrication was 600° C, which corresponds to  $n^+$  poly-Si deposition for source/drain regions and channel formation. The Levinson's equation offers an electron mobility ( $\mu_0$ ) and trap density at poly-Si grain boundaries ( $N_t$ )<sup>(4)</sup>.

Figure 1 shows the dependence of the electron mobility on the underlying silicon oxide, indicating that the poly-Si films on  $\text{SiO}_x$  ( $x < 2$ ) have large mobility values. The mobility values vary from 0.41  $\text{cm}^2/\text{v}\cdot\text{sec}$  to 13.28  $\text{cm}^2/\text{v}\cdot\text{sec}$  only depending on the underlying oxide. The dependence of the trap density at grain boundaries on the underlying oxide is shown in Fig. 2. A sudden sharp increase in  $N_t$  values is observed at  $n \leq 1$ . As a result, the preferable effect of a large mobility value is cancelled by a large trap density at grain boundaries. The best TFTs are obtained on the underlying silicon oxide with  $n=1$ , namely on the oxide film deposited with 60 sccm of silane and 60 sccm of oxygen.

### PHYSICAL ANALYSIS OF THE POLY-Si FILMS

25 nm and 150 nm Poly-Si films deposited on underlying silicon oxides have been physically analyzed by Raman spectroscopy, X-ray

diffraction (XRD), and transmission electron microscopy (TEM).

Raman spectroscopy measures crystallinity change of the poly-Si films (Fig. 3). The thin poly-Si films ( $t_{Si} \sim 25$  nm) deposited on  $SiO_x$  ( $x < 2$ ) undergo a serious loss of crystallinity as silicon content increases in the underlying oxides. The same trend is observed for thick poly-Si films ( $t_{Si} \sim 150$  nm), though the crystallinity dependence on the underlying oxides is weaker than that of thin poly-Si films. The underlying oxide has a stronger influence on thin poly-Si films than on thick poly-Si films.

Direct contradiction to the Raman analysis is seen in the XRD results which point out that the crystallinity of thin poly-Si film improves as silicon content increases in the underlying silicon oxide (Fig. 4). Since all the poly-Si films were deposited simultaneously, and therefore have the same thickness, the different XRD intensities originate in the different crystallinity among the poly-Si films. The XRD measurement is due to the possibility that the crystallinity of poly-Si film improves as the silicon content of the underlying silicon oxide increases. This result is quite contrary to Raman analysis. These contradicting physical analyses remind us of the relation between electron mobility and trap density at grain boundaries observed in the TFT measurements.

Figure 5 presents TEM photographs of thin poly-Si films ( $t_{Si} = 25$  nm) on the underlying silicon oxides. The thin poly-Si films on  $SiO_2$  consist of gray island-like amorphous parts, black spotted crystallites, and white, open spaces (Fig. 5-a). These poly-Si films are not actually in a continuous film state, but in a separate island-like state. In contrast, the thin poly-Si films on  $SiO_x$  ( $x < 2$ ) consist of light gray thin amorphous parts, dark gray thick amorphous parts, and small black dotted crystallites (Fig. 5-b). The grain size of these crystallites is smaller than that of the crystallites on  $SiO_2$ , though these films are really in a continuous film state. Plane TEM photographs of 150 nm thick poly-Si films show that the poly-Si films on  $SiO_x$  ( $x < 2$ ) are made up of small grains, while the poly-Si films on  $SiO_2$  are made up of large grains. The effect of the underlying oxide on thick poly-Si films is not as large as on thin films.

#### DISCUSSION

Stoichiometric change in the underlying silicon oxide changes the wettability of the underlying silicon oxide by silicon. These changes cause the thin poly-Si on it to have many different physical states.  $SiO_x$  ( $x < 2$ ) has fairly good wettability with silicon and thus the even very thin poly-Si on it can be in a continuous film state with strong XRD intensities. These properties of the poly-Si improve carrier mobility of the TFT. The same

poly-Si, however, consists of small crystallites and shows poor crystallinity, which may cause large value of  $N_t$ . In contrast, stoichiometrically perfect  $SiO_2$  does not have as good wettability by silicon as  $SiO_x$  ( $x < 2$ ). Since poor wettability limits the initial nucleation rate of growing silicon on  $SiO_2$ , the thin poly-Si on  $SiO_2$  is in a separate island-like state but consists of large crystallites with high crystallinity. The limitation of the initial nucleation rate makes large grains of thick poly-Si film. Therefore, thick poly-Si films, which are at least thick enough to be in a continuous film state, prefer poor wettability of underlying material by silicon to good wettability, though the effect is not as large as on thin poly-Si films. TFT characteristics generally improve as the channel poly-Si decreases in thickness<sup>(5)</sup>. Very thin films, however, are not in a continuous film state but in an isolated island-like state, unless the wettability of the underlying material is optimized. The current study happens to show the best underlying oxide is deposited with  $Q_{SiH_4} = Q_{O_2} = 60$  sccm ( $n=1$ ) for 25 nm thick poly-Si, though the best wettability of the underlying material is strongly dependent on the thickness of the poly-Si deposited on it. Further the nucleation rate is a function of poly-Si deposition condition as well as the wettability. Therefore the best TFT is fabricated by simultaneously optimizing these three parameters; namely, the wettability of underlying material, the poly-Si deposition condition, and the poly-Si thickness.

#### CONCLUSION

The wettability of underlying material by silicon has a great influence on the thin poly-Si deposited on it.  $SiO_x$  has fairly good wettability so that even very thin poly-Si can be in a continuous film state. This poly-Si film, however, consists of small crystallites with poor crystallinity. The simultaneous optimization of the wettability, poly-Si deposition condition, and poly-Si thickness offers the best TFT.

#### REFERENCES

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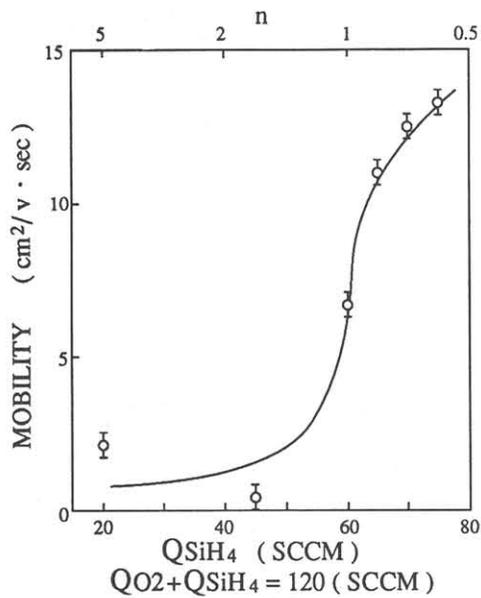


Fig.1

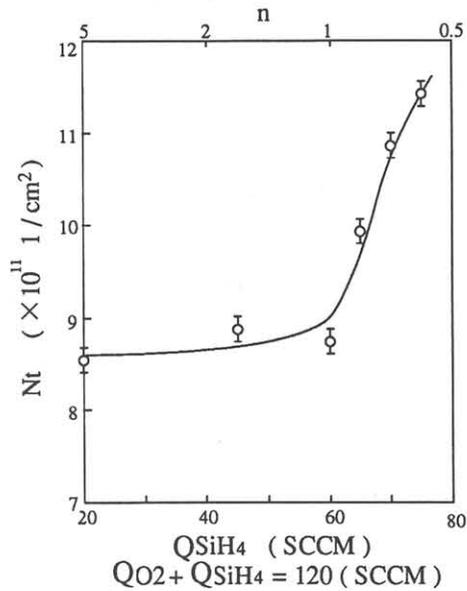


Fig.2

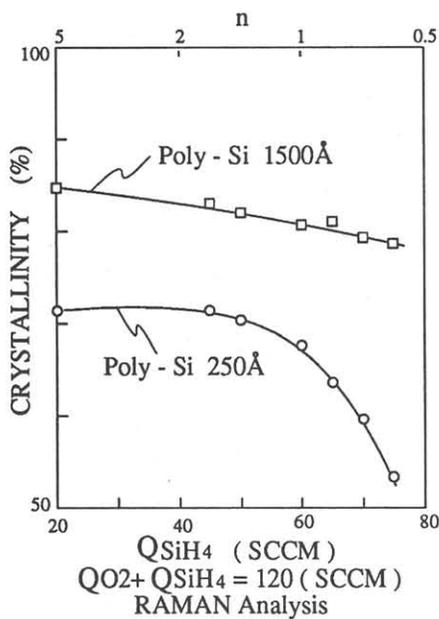


Fig.3

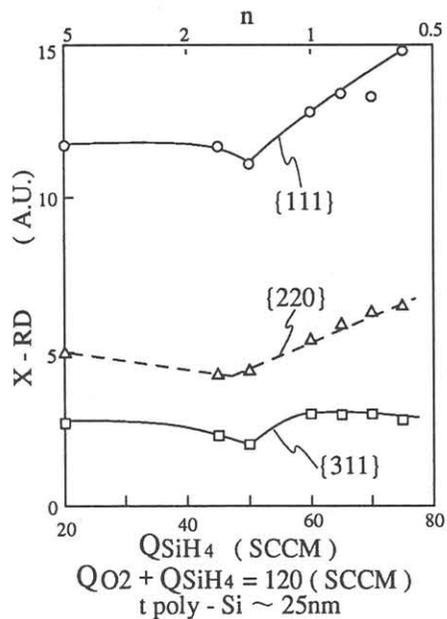


Fig.4

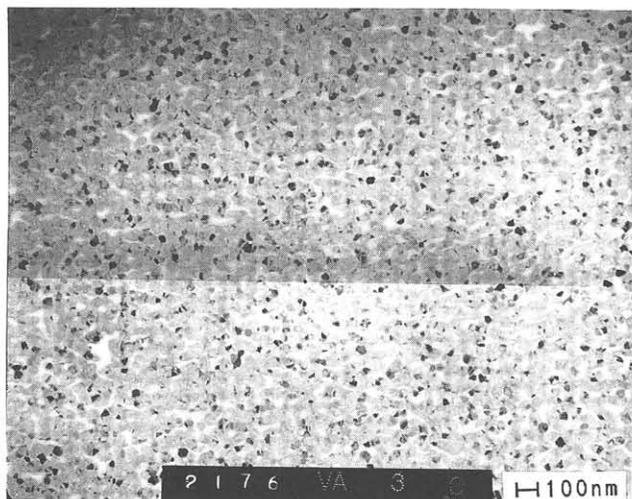


Fig5 - a (on SiO<sub>2</sub>)

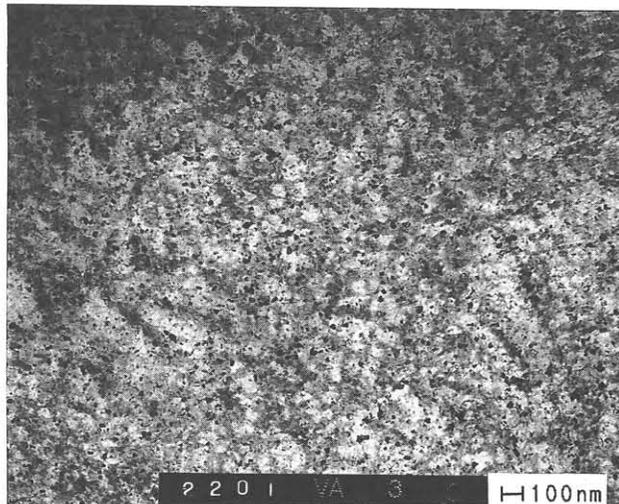


Fig5 - b (on SiO<sub>x</sub>)