Thinner Liquid Phase Deposited Oxide for Polysilicon Thin-Film Transistors

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Abstract—**To scale down the gate insulator thickness of polysilicon thin-film transistors (poly-Si TFT's), a thinner oxide is developed by liquid-phase deposition with a small quantity of H_2O added, producing a rather high-quality oxide. Poly-Si TFT with such a thin oxide reveals good performances in electric characteristics. Thus, the novel thinner oxide is a good candidate as a poly-Si TFT gate insulator in the near future.**

I. INTRODUCTION

THERE has been great interest recently in liquid-phase deposition (LPD) oxide films because of their potential application as gate insulators in polysilicon thin-film transistors (poly-Si TFT's) [1], [2]. Scaling down the thickness of the gate insulator improves electrical properties of poly-Si TFT's; it reduces the effects of trapped charges on the threshold-voltage increases [3] and reduces the gate swing factor [4]. Thus, a thinner LPD oxide with high quality will be indispensable for improved poly-Si TFT's.

In conventional LPD processing [1], [2], both H_2O and boric acid (H_3BO_3) were added into saturated H_2SiF_6 solution to grow LPD oxide. The deposition rate dependent on the quantity of boric acid added is fast (80 ~ 120 nm/hr [5]). Also, we found that a thinner LPD oxide deposited with such a high deposition rate exhibited poor quality. According to a newly developed LPD method [6], deposition rate can be controlled by H_2O addition only. In this letter, we clarify the influences of adding quantities of H_2O to develop a thinner high-quality film for the first time. Then, the poly-Si TFT's with such a thin-film as gate insulator are characterized to investigate the feasibility of thin LPD oxide.

II. EXPERIMENTAL

The detailed apparatus and experimental flow for LPD process were the same as reported in [7]. N-type, (100) 1 ~ 5 Ω cm silicon substrates were used to prepare LPD oxide. Twenty-five ml to 150 ml of H_2O was added to the 100 ml saturated H_2SiF_6 solution at 15°C to investigate the effects of H_2O on the properties of LPD oxide.

Conventional poly-Si TFT's ($L/W = 8\ \mu m/10\ \mu m$) with different LPD-oxide thickness as gate insulator were prepared. All the fabrication and characterization methods were the same as in our previous studies [1]. The maximum processing temperature was 625°C.

TABLE I
CHARACTERISTICS OF LPD OXIDE DEPOSITED WITH DIFFERENT QUANTITIES OF H_2O ADDED ($H_2SiF_6 = 100$ ml, DEPOSITION TEMPERATURE = 15°C)

H_2O Quantity (ml)	Deposition Rate (nm/hr)	Refractive Index (n)	P-etch Rate (nm/sec)	Electric Breakdown Field (MV/cm)
25	4.9	1.438	1.71	8.3
50	20	1.436	1.76	7.2
75	25.9	1.429	1.81	4.3
100	31.8	1.417	1.95	2.9
125	37.4	1.410	2.01	<2

III. RESULTS AND DISCUSSION

The physicochemical and the electrical properties of LPD oxides deposited with various H_2O quantities were investigated and summarized in Table I. The different H_2O quantities yielded lower deposition rate than boric acid addition in all cases. The deposition rate can be made as low as possible because H_2O is a kind of reactant. The refractive indexes decrease a little with increasing H_2O quantity and are lower than the 1.46 of thermal oxide. The lower refractive index can be attributed to the dual effects of a less dense structure [8] and fluorine incorporation in the film [9]. Because the LPD oxide deposited with larger H_2O quantities will incorporate fewer fluorine atoms in the film [10], the decreases in refractive index with increasing quantities of H_2O is due to the less dense structure. The fact that the p-etch rates increase with increasing H_2O quantities further implies that the LPD oxide deposited with larger quantities of H_2O added will be less dense in structure.

The electric breakdown field (E) also reveals strong dependence on H_2O quantity; that is, E decreases with increasing H_2O quantity. When adding H_2O to saturated H_2SiF_6 solution, the intermediate polysilicic acids will be formed by the polymerization of the silicic monomer $Si(OH)_4$ and then absorbed onto the substrate surface. Acid-catalytic dehydration occurs between these absorbed polysilicic acids, followed by Si-O-Si bond formation. The larger the H_2O quantity is, the faster the polysilicic acid formed and absorbed onto the substrate surface. In that case, the dehydration reaction cannot be completely finished in time, and many residual Si-OH bonds may exist in the film. On the contrary, the LPD oxide prepared with less H_2O added will have fewer residual Si-OH bonds and will exhibit better properties.

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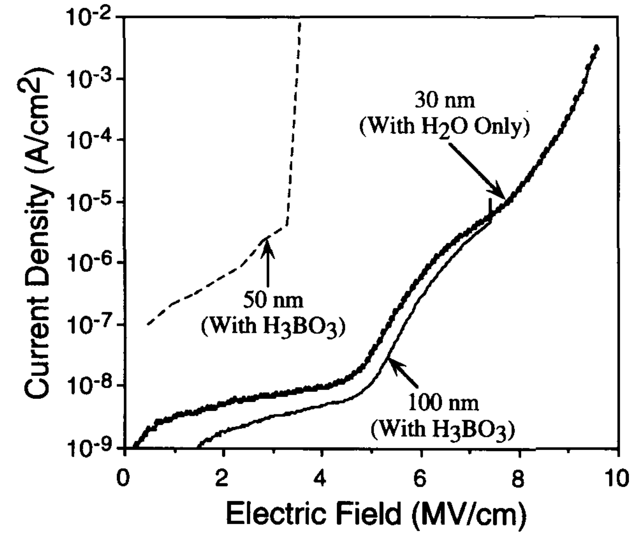

Fig. 1. I-V characteristics of MOS capacitors with different thicknesses of LPD oxide. The most severe thermal condition during capacitor fabrications was 400°C, 20 min for sintering. The size of capacitor is 1.77×10^{-4} cm^2. The voltage ramp rate was 0.67 V/sec.

From the above discussion, we can conclude that the best way to prepare a thin high-quality LPD oxide is to reduce the quantity of H_2O added to saturated H_2SiF_6 solution. By this method, a 30 nm thick LPD oxide was successfully developed. Its I-V characteristics are shown in Fig. 1. The I-V curves for a thick (100 nm) and a thin (50 nm) film deposited with boric acid addition are also shown for comparison. The electrical characteristics of the new thin oxide show comparable leakage current and higher breakdown electric field than the thick ones. It is evidently worth applying such a thin LPD oxide as the gate insulator in poly-Si TFT's.

The I_{DS}-V_{GS} characteristics of Poly-Si TFT with 30 nm LPD oxide as gate insulator was shown in Fig. 2. An ON/OFF current ratio of 1×10^6, threshold voltage of 7.2 V, and subthreshold swing of 1.08 V/decade were obtained. In Fig. 2, the I_{DS}-V_{GS} characteristics of the devices with 50 and 80 nm oxides were also shown for comparison. For the device with 30 nm-oxide, because the grain barrier height can be lowered much more, both ON- and OFF-currents become larger. However, the ON/OFF current ratio (1×10^6) has been achieved, while they are 6.45×10^5 and 2×10^5 for the devices with 50 nm and 85 nm thick, respectively. The dependence of the threshold voltage and subthreshold slope on the thickness of the gate insulator were also characterized, as shown in Fig. 3. Both the threshold voltage and the subthreshold slope show nearly linear decreases as the thickness of LPD gate oxide is reduced. This is because scaling down the oxide thickness effectively increases the inversion carrier density, which consequently lowers the grain barrier height. The lower the grain barrier height is, the steeper the subthreshold slope will be [4]. The linear decreases also indicate that the trap-state densities are constant in these devices [11]. Because the trap-state densities are independent of gate oxide thickness, the field effect mobility, which is mainly influenced by the trap-state density, is nearly the same (30 cm^2/V · sec) for the three samples.

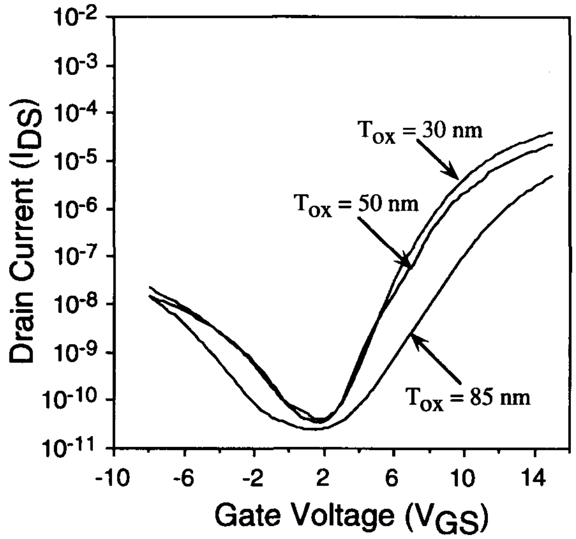

Fig. 2. Typical I_{DS}-V_{GS} characteristics of poly-Si TFT's with different thicknesses (T_{OX}) of LPD oxide as gate insulator.

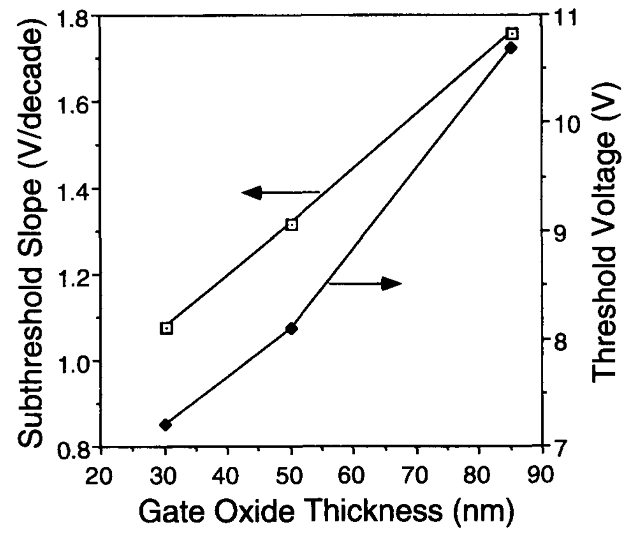

Fig. 3. Dependence of threshold voltage and subthreshold slope of poly-Si TFT's on thickness of LPD gate oxide.

IV. CONCLUSION

A thinner high-quality oxide has been developed using the LPD method with addition of small quantities of H_2O. Poly-Si TFT with a thin LPD oxide shows good performances. It reveals the feasibility of applying the thin LPD oxide as gate-insulators in small-geometry poly-Si TFT's in near future.

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