Enhanced H_2-Plasma Effects on Polysilicon Thin-Film Transistors with Thin ONO Gate-Dielectrics

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***Abstract*— This letter reports that passivation effects of the H_2-plasma on the polysilicon thin-film transistors (TFT's) were greatly enhanced if the TFT's have a thin Si_3N_4 film on their gate-dielectrics. Compared to the conventional devices with only the SiO_2 gate dielectric, the TFT's with Si_3N_4 have much more improvement on their subthreshold swing and field-effect mobility after H_2-plasma treatment.**

I. Introduction

H_2-PLASMA passivation has become a well-accepted method to improve the electrical properties of polysilicon thin-film transistors [1], [2]. Recently, there has been increasing interest in studying the mechanism of H_2-plasma passivation [2]–[5]. In addition, how to enhance the passivation effect of H_2-plasma on TFT's has also become an important issue [6], [7]. Although it had been reported that H_2-plasma had a better passivation effect on polysilicon TFT's with gate oxynitrides formed by NH_3 [7], the reason of the enhanced hydrogenation has not been clearly found yet. Also the stacked $SiO_2/Si_3N_4/SiO_2$ (ONO) structure has been proposed to reduce the gate leakage [8]. It had been confirmed that an LPCVD silicon nitride layer could act as an effective barrier against hydrogen diffusion [4]. Therefore, it is interesting to study the H_2-plasma effects on the polysilicon TFT's without and with an thin Si_3N_4 film on their gate-dielectrics. In this work, it is found that the H_2-plasma passivation effect is dramatically enhanced on the TFT's with the thin ONO gate dielectric as compared with the devices with only the thermally grown thin gate-oxide.

II. Experimental Procedures

The polysilicon TFT's were fabricated on thermally oxidized silicon wafers. A 60 nm amorphous-silicon film was initially deposited by an LPCVD system at 550°C and then annealed at 600°C for 24 hr. The active regions were defined by plasma etching. After a 19.2 nm bottom oxide was grown in wet O_2 at 850°C, a 10 nm Si_3N_4 film was deposited by a conventional LPCVD reactor with the source gases of SiH_2Cl_2 and NH_3 at 750°C, followed by reoxidation in wet O_2 at 850°C for 5 min. The equivalent oxide thickness of the ONO film is 22.1 nm. Then, another 300 nm polysilicon film was deposited and patterned to be the gate of the device. After the dielectrics above source/drain regions were stripped off, a self-aligned $POCl_3$ doping was performed at 850°C to form the source, drain, and gate electrodes. For comparison, devices with only SiO_2 as the gate dielectric of the thicknesses of 19.2 and 25.8 nm were also made. The gate-oxides were also thermally grown in wet O_2 at 850°C. After contact holes were opened, Al was deposited and then patterned. Finally, plasma hydrogenation was applied with an H_2 and N_2 gas mixture in a commercial 13.5-MHz parallel-plate plasma reactor at 300°C for 20–80 min.

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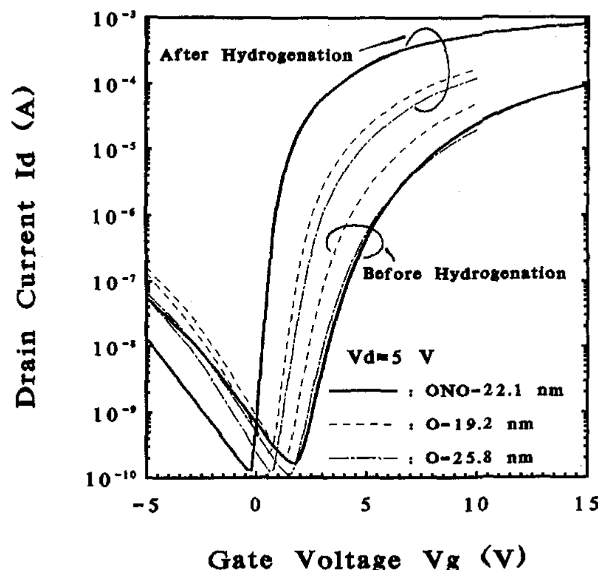

Fig. 1. I_d-V_g characteristics at $V_d = 5$ V of the TFT's without and with a 60 min H_2-plasma treatment. All devices were measured at the dimension of W/L = 40 μm/10 μm.

III. Results and Discussions

Fig. 1 shows the typical I_d-V_g characteristics of the TFT's with and without the H_2-plasma treatment. Table I compiles the values of the subthreshold swing S, the threshold voltage $V_{\rm th}$, the field effect mobility μ, and the effective trap density N_t [9], derived from the corresponding devices of Fig. 1 at $V_d = 0.1$ V. It is seen that for the device with the ONO

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TABLE I
THE VALUES OF S, V_{th}, μ, AND N_t OF THE POLYSILICON TFT'S WITH DIFFERENT GATE-DIELECTRICS

Conditions	S (mV/decade) before H_2-plasma	S (mV/decade) after 1 hr	Vth (V) before H_2-plasma	Vth (V) after 1 hr	μ (cm^2/ Vsec) before H_2-plasma	μ (cm^2/ Vsec) after 1 hr	Nt ($\times 10^{12} cm^{-2} eV^{-1}$) before H_2-plasma	Nt ($\times 10^{12} cm^{-2} eV^{-1}$) after 1 hr
ONO-22.1 nm	642	187	4.75	0.47	4.6	32.2	9.53	2.08
O -19.2 nm	495	302	3.46	1.90	4.5	9.3	8.22	4.58
O -25.8 nm	631	397	4.62	2.33	3.3	10.1	8.03	4.77

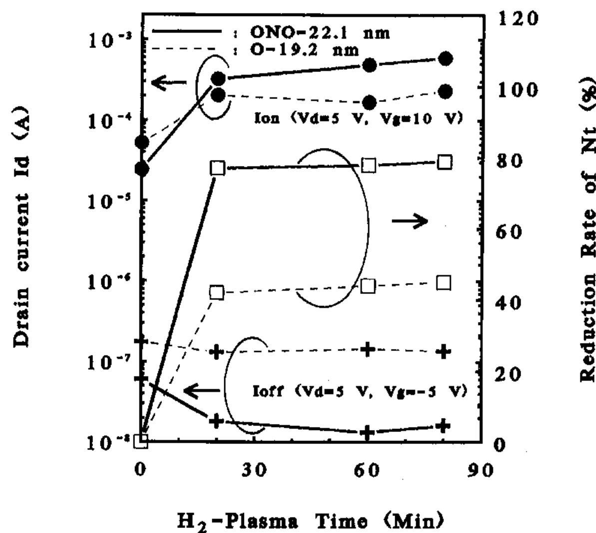

Fig. 2. The ON- and OFF-state drain currents and the N_t reduction rate as a function of the H_2-plasma-exposure time for the devices with different gate-dielectrics.

gate-dielectric, the H_2-plasma effect was drastically enhanced, especially on its improvement of S and μ. Fig. 2 shows the ON- and OFF-state drain currents and the N_t reduction rate as a function of the H_2-plasma-exposure time for the devices with different gate-dielectrics, respectively. It is found that the ONO device had a much better effect in responding to the H_2-plasma treatment. The drivability and leakage of the ONO devices were more effectively improved. Moreover, the N_t reduction rate of the ONO device was also considerably larger than those without a thin Si_3N_4 film on their gate-dielectrics. Fig. 2 also shows that after a 20 min H_2-plasma treatment, the improvements of all the devices almost reached a saturation state and further increasing the H_2-plasma-exposure time did not improve the devices too much. Two possible mechanisms could be used to explain the above results. One is that for the ONO device, the Si_3N_4 film prevented hydrogen out-diffusion during the plasma treatment. This made the hydrogenation effect more effective. On the other hand, since it is generally recognized that the strain-bond band-tail states influence the field effect mobility [2], the large improvement on μ suggests that the thin Si_3N_4 in the ONO gate-dielectric played an important role in reducing the band-tail states during the H_2-plasma. Hence, the other possible mechanism is the relaxation of the strained bonds due to the existence of Si_3N_4. It is speculated that the mechanical stress [10], [11] caused by the existence of Si_3N_4 might be helpful to break the strained bonds at the poly-Si/SiO_2 interface and in the polysilicon film to relax the network. This speculation can be supported further by the fact that for the ONO devices, they had higher N_t before hydrogenation as shown in Table I. During hydrogenation, the H_2-plasma passivated the dangling bonds and relaxed the silicon network more effectively.

IV. CONCLUSION

In this letter, it is reported that the effect of the H_2-plasma hydrogenation on improving the electrical characteristics of the polysilicon TFT's is greatly enhanced if the TFT's have a thin Si_3N_4 film on their gate dielectrics. Compared to the TFT's with only the SiO_2 gate dielectric, the ONO device has a larger N_t before hydrogenation but a much more improved μ after hydrogenation. This experimental result suggests that the deposited thin Si_3N_4 film plays a very important role in further reducing the strained bonds of the active layer during the H_2-plasma treatment.

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