The Combined Effects of Low Pressure NH_3-Annealing and H_2. Plasma Hydrogenation on Polysilicon Thin-Film Transistors

Chien Kuo Yang, *Student Member, IEEE* Tan Fu Lei, and Chung Len Lee, *Senior Member, IEEE*

***Abstract*—The low pressure NH_3-annealing and the H_2. plasma hydrogenation were jointly used to improve the characteristics of polysilicon thin-film transistors (TFT's). It was found that the TFT's after applying the above treatments achieved better subthreshold swings, threshold voltages, field effect mobilities, off currents, and reliability. It is believed that the improvement was due to the gate oxynitride formation and the H_2-plasma had a better passivation effect on the oxynitride.**

I. Introduction

PLASMA hydrogenation has been found to be effective to reduce trap-states in polysilicon films and in the oxide/polysilicon interface [1]. Recently, O_2. plasma has also been found to be effective to enhance the hydrogen passivation effect [2]. Moreover, it has been shown that nitrogen pile-up at the SiO_2/Si interface can improve the metal-oxide-semiconductor (MOS) device characteristics [3]–[4].

Nevertheless, little work has been done about the nitrogen effects on polysilicon TFT's. In this work, ammonia was used as the nitrogen source to study the combined effects of ammonia-annealing and plasma hydrogenation on polysilicon TFT's. It was found that the polysilicon TFT, after a pre-oxidation ammonia annealing and a plasma hydrogenation treatment, can improve its characteristics better than with a plasma hydrogenation only.

II. Experimental Procedures

The polysilicon TFT's were fabricated on thermally oxidized silicon wafers. A 60 nm amorphous silicon was initially deposited by an LPCVD system at 550 °C and then annealed at 600 °C for 24 h to be transformed to polysilicon. After the active island was defined and annealed in a low pressure (270 mtorr) NH_3 ambient at 850 °C for 30 min, a gate oxide was grown in wet O_2 at 850 °C. Then, another 300 nm polysilicon film was deposited and patterned to be the gate of the device. A self-aligned $POCl_3$ doping was performed at 850 °C to form the source, drain, and gate electrodes. The devices were denoted as NOP devices. For comparison, control devices were also made without the NH_3 annealing step (denoted as OP devices), or by applying the NH_3 annealing after the gate oxide was formed (denoted as ONP devices), or by applying the NH_3 annealing after the $POCl_3$-doping (denoted as OPN devices), respectively. The effective oxide thicknesses for the NOP, OP, ONP, and OPN devices were 26 nm, 27.5 nm, 29 nm, and 27.4 nm, respectively. After contact holes were opened, Al was deposited and then patterned. Finally, plasma hydrogenation was applied with a H_2 and N_2 gas mixture in a commercial 13.5-MHz parallel-plate plasma reactor at 300 °C for 60 min, and then followed by N_2 annealing at 300 °C for 20 min.

Manuscript received April 15, 1994; revised July 19, 1994. The authors would like to acknowledge the financial support of the National Science Council of the Republic of China through the contract of NSC-83-0404-E009-017 for this research.

The authors are with the Department of Electronics Engineering and Institute of Electronics, National Chiao Tung University, and National Nano Device Laboratory, Hsinchu, Taiwan, R.O.C.

IEEE Log Number 9405140.

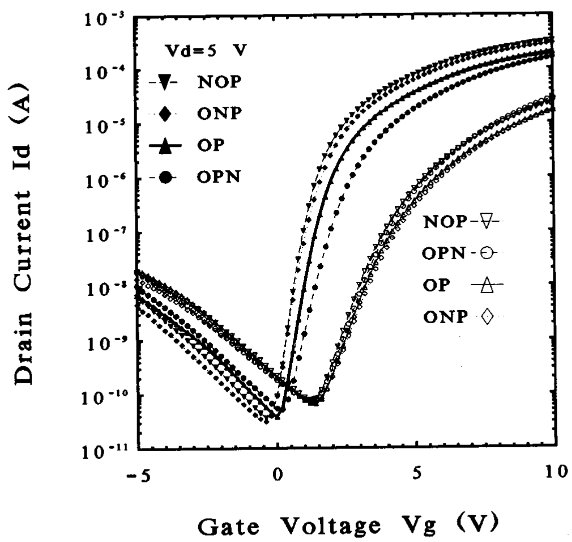

Fig. 1. $I_d - V_g$ characteristics at $V_d = 5$ V of the TFT's before (the open dots) and after (the black dots) H_2. plasma treatment. All devices were measured at the dimension of W/L = 40 μm/10 μm.

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_{th}, the field effect mobility μ, and the minimum leakage current I_{off}, derived from Fig. 1. It is seen that for all the devices, the H_2-plasma treatment improved the characteristics on S, V_{th}, μ, and I_{off}. However, the NH_3-annealing enhanced the hydrogenation effect for the NOP and

0741-3106/94$04.00 ©1994 IEEE

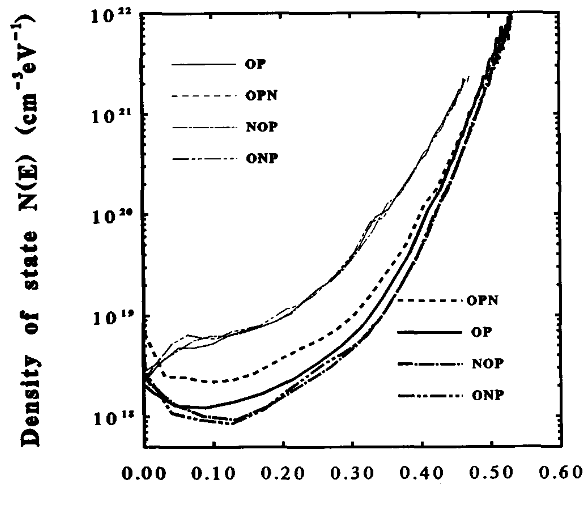

Fig. 2. The derived distributions of the trap-state densities for the devices of Fig. 1.

TABLE I
THE VALUES OF S, V_{TH}, MOBILITY, AND I_{MIN} OF THE POLYSILICON TFTs FOR DIFFERENT PROCESS CONDITIONS.

Devices	S (mV/decade)		Vth (V)		μ (cm²/Vsec)		Imin (pA)	
	before hydrogenation	after hydrogenation	before hydrogenation	after hydrogenation	before hydrogenation	after hydrogenation	before hydrogenation	after hydrogenation
OP	692	320	4.95	1.51	3.5	15.2	66.5	38.0
OPN	690	422	4.69	2.10	4.1	11.3	74.0	52.0
NOP	654	266	4.55	1.00	4.2	21.8	78.2	36.7
ONP	733	285	5.18	1.13	3.9	22.3	68.9	30.8

ONP devices, but degraded the hydrogenation effect for the OPN devices. It is specially noticed that, for the NOP and ONP devices, unlike the conventional MOS case [5]–[7], the NH_3-annealing increases their peak μ values. Fig. 2 shows the extracted density of states in the energy band gap of the devices. It is seen that all devices had improvements on the density of states after the hydrogenation, but the NOP and ONP devices had the most improvements and the OPN devices had the least improvement. The above results show that the NOP and ONP devices, with nitrogen residing in the grown oxides and/or in the polysilicon channel [8], had a much better effect in responding to the H_2-plasma treatment. A recent paper by Momose *et al.* [8] showed that with the low concentration (< 1 atom%) nitrogen incorporation in the NH_3 rapid thermal nitrided-oxide, both drivability and hot carrier reliability of MOSFET could be improved. For the OPN devices, it is expected that after the NH_3-annealing, a Si_3N_4 film had formed on the surface of the devices. This film would have hindered the passage of hydrogen atoms into the SiO_2/poly-Si interface and the active channel [9]. Thus a less hydrogenation effect was obtained for the OPN devices.

The low-pressure NH_3-annealing also improved the reliability of the devices. Table II shows the V_{th} shift, the driving current degradation, and the ON/OFF current ratio (I_{on}/I_{min}) for the above devices after they were stressed at $V_d = V_g = 15$ V for 0.5 hr and 1.5 hr. In contrast to the previously reported results [2] on MOS devices, whose reliability was degraded after the NH_3-annealing due to incorporation of hydrogen in the oxide and the oxide/Si interface, the NOP and ONP devices here showed less degradation in the above device parameters than did the OP devices, for which no NH_3-annealing was applied. This suggests that, although hydrogen existed in the gate oxynitrides and the oxynitride/poly-Si interface for the NOP and ONP devices, the nitrogen incorporated by the NH_3-annealing, still can strengthen the interface and improve the device reliability [10].

TABLE II
THE V_{TH} SHIFT, DRIVING CURRENT DEGRADATION AND $I_{ON}(V_G = 15\text{ V})/I_{MIN}$ VARIATION AFTER 0.5 HR AND 1.5 HR VOLTAGE SRESSING AT $V_D = v_G = 15$ V FOR THE NH_3-ANNEALED TFT'S WITH HYDROGENATION.

Devices	ΔVth (mV)		ΔIon/Ion (Vg=Vd=5V)		ON/OFF current ratio (x10⁷)	
	0.5h	1.5h	0.5h	1.5h	fresh	1.5h
OP	58	71	1.9%	3.4%	0.9	1.2
OPN	39	77	2.6%	5.7%	0.4	0.6
NOP	31	40	1.8%	2.6%	1.5	2.2
ONP	43	31	2.0%	2.4%	1.4	1.6

IV. CONCLUSION

In this letter, it is reported that the combined effects of the low pressure NH_3-annealing and H_2-plasma hydrogenation can improve the characteristics and the reliability of polysilicon TFT's. The improvement is believed due to the gate oxynitride formed by the NH_3-annealing and the H_2-plasma has a better passivation effect on the oxynitride.

REFERENCES

[1] S. Batra, K. Park, C. Kyono, S. Bhattacharya, S. Banerjee, C. Maziar, D. Kwong, A. Tasch, M. Rodder, and R. Sundaresan, "Rapid thermal annealing for H passivation of polysilicon MOSFETs from Si_3N_4 overcoat," in *IEDM Tech. Dig.*, 1989, p. 455.

[2] H. N. Chern, C. L. Lee, and T. F. Lei, "The effects of $H_2 - O_2$-plasma treatment on the characteristics of polysilicon thin-film transistors," *IEEE Trans. Electron Devices*, vol. 40, pp. 2301–2306, 1993.

[3] G. W. Yoon, A. B. Joshi, J. Kim, and D.-L. Kwong, 'MOS characteristics of NH_3-nitrided N_2O-grown oxides," *IEEE Electron Devices Lett.*, vol. 14, pp. 179–181, 1993.

[4] I. Rahat, J. Shappir, and D. B. Atar, "Novel interface nitridation process for thin gate oxides," *IEEE Trans. Electron Devices*, vol. 40, pp. 2047–2053, 1993.

[5] T. Hori, "Inversion layer mobility under high normal field in nitrided-oxide MOSFET's, *IEEE Trans. Electron Devices*, vol. 37, pp. 2058–2069, 1990.

[6] A. T. Wu, T. Y. Chan, V. Murali, S. W. Lee, J. Nulman, and M. Garner, "Nitridation induced surface donor layer in silicon and its impact on the characteristics of n- and p-channel MOSFET's," in *IEDM Tech. Dig.*, 1989, p. 271.

[7] A. B. Joshi, G. O. Lo, D. K. Shih, and D.-L. Kwong, "Effect of rapid thermal reoxidation on the electrical properties of rapid thermally nitrided thin-gate oxides," *IEEE Trans. Electron Devices*, vol. 39, pp. 883–892, 1992.

[8] H. S. Momose, T. Morimoto, Y. Ozawa, K. Yamabe, and H. Iwai, "Electrical characteristics of rapid thermal nitrided-oxide gate n- and p-MOSFET's with less than 1 atom% nitrogen concentration," *IEEE Trans. Electron Devices*, vol. 41, no. 4, pp. 546–552, 1994.

[9] W. B. Jackson, N. M. Johnson, C. C. Tsai, I.-W. Wu, A. Chiang, and D. Smith, "Hydrogen diffusion in polycrystalline silicon thin films," *Appl. Phys. Lett.*, vol. 61, pp. 1670–1672, 1992.

[10] M. Bhat, G. W. Yoon, J. Kim, and D. L. Kwong, "Effects of NH_3 nitridation on oxides grown in pure N_2O ambient," *Appl. Phys. Lett.*, vol. 64, pp. 2116–2118, 1994.