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Hydrogenation of Polysilicon Thin Film Transistors Using Inductively Coupled Plasma

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Inductively coupled plasma (ICP) hydrogenation has been investigated for the improvement of electrical characteristics in polysilicon thin film transistors (poly-Si TFTs). It is found that ICP hydrogenation is more effective in improving poly-Si TFT's characteristics than electron cyclotron resonance (ECR) hydrogenation. Both threshold voltage and subthreshold slope change quickly during the first 30 minutes of hydrogenation and saturate around 60 minutes. Mobility has a larger dependence on RF power than on hydrogenation time. ICP can be a viable plasma source for large area plasma processing.

1. Introduction

Hydrogenation is widely used to improve electrical characteristics of polysilicon thin film transistors (poly-Si TFTs). There are several methods for hydrogenation; hydrogen implantation, deposition of silicon nitride containing hydrogen, remote RF plasma, and electron cyclotron resonance (ECR) plasma treatment. Among them, ECR plasma hydrogenation has the advantages of high plasma density in low process pressure, which results in short process time [1]. However, it has the disadvantages of nonuniformity in large area processing and plasma damage during process [2].

Inductively coupled plasma (ICP) has properties of high plasma density in relatively low pressure, good uniformity in large area [3], low plasma damage [4], and simple equipment requirement. Therefore, ICP is a suitable plasma source for hydrogenation of poly-Si TFTs in large area AMLCDs.

In this paper, ICP hydrogenation is described and compared with ECR hydrogenation. Experimental results of the ICP hydrogenation are shown with varying process time, RF power, and device dimension.

2. Experiments

The ICP equipment of this experiment is shown in Fig. 1. 13.56MHz RF enters into 1-turn antenna of silver plated copper with 20cm diameter. The inner diameter of aluminum chamber is 25cm. And, the antenna is separated from the plasma by quartz plate of 2cm thickness. For RF radiation protection, aluminium shield cap with 40cm height covers the antenna and quartz plate. The grounded wafer holder is positioned 7cm below the bottom of the quartz plate. All experiments mentioned in this paper are performed at 20mtorr process pressure and 12sccm H_2 flow rate.

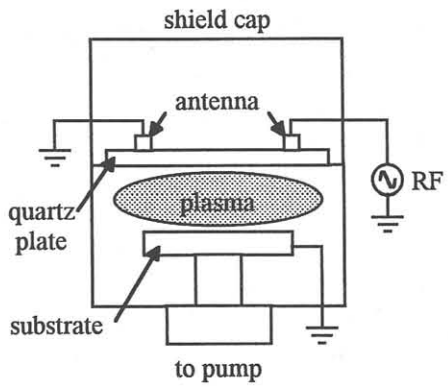

Fig 1. ICP equipment used in hydrogenation experiment. This consists of 13.56MHz 3kW RF generator, 1-turn antenna of 20cm diameter, quartz plate of 2cm thickness, and grounded substrate holder.

The devices used in this experiment are p-channel poly-Si TFT's fabricated with following procedures. Active poly-Si of 400 Å was formed by SPC at 650℃ of amorphous Si deposited by LPCVD. Gate oxide of 400 Å was deposited by LPCVD with mixed gases of SiH_2Cl_2 and N_2O. Gate electrode was 3500 Å poly-Si and capping layers were 2000 Å CVD oxide and 5000 Å BPSG. After metalization, metal alloy was performed in N_2/H_2 ambient at 450℃ for 30min. Finally the devices were passivated with ECR and ICP hydrogen plasma.

3. Result and discussion

The I_D-V_G characteristics of as fabiricated, ECR hydrogenated and ICP hydrogenated devices are shown in Fig. 2. Width and length of these devices are 50㎛ and 1.6㎛, respectively. The extracted device parameters are shown in Table 1. Threshold voltage was measured by

constant current method at V_{DS} = -4V and other parameters are measured at V_{DS} = -1V. For ICP hydrogenation, RF power was 800W and process pressure 20mtorr with H_2. Substrate was located at 7cm below the bottom of the quartz plate. And ECR hydrogenation was performed at 600W microwave power and 0.4 mtorr process pressure. In both case, process temperature was 300℃ and process time was 30min.

After ICP hydrogenation, device performances are remarkably improved. The subthreshold slope of the device is changed from 0.933 V/decade to 0.293 V/decade after ICP treatment while 0.644 V/decade after ECR treatment. The threshold voltage was changed from -5.5V to -4.2V and -2.8V for ECR and ICP hydrogenation, respectively. The mobility and leakage current of ICP hydrogenated device were also improved more than those of ECR hydrogenated device. It is guessed that the reason of this is higher plasma density of ICP plasma than that of ECR plasma. From these results, we can think that ICP hydrogenation is more effective to improve the characteristics of poly-Si TFT.

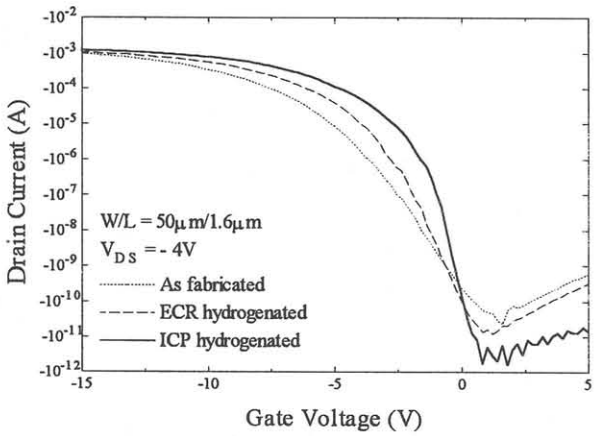

Fig 2. The I_D-V_G characteristics of the p-channel poly-Si TFT's before and after hydrogenation. ECR hydrogenation was performed at 600W, 0.4mtorr, and 300℃ for 30min. The ICP was at 800W, 20mtorr, and 300℃ for 30min.

	V_{TH}(V)	μ_{FE}(cm^2/Vs)	S(V/decade)
As fabricated	-5.5	12.3	0.933
ECR	-4.2	13.8	0.644
ICP	-2.8	15.3	0.293

Table 1. The measured device parameters of p-channel poly-Si TFT's (W/L = 50㎛/1.6㎛) before and after hydrogenation. Threshold voltage was measured by constant current method at V_{DS} = -4V and other parameters were measured at V_{DS} = -1V.

The changes of device parameters are shown in Fig. 3 as a function of hydrogenation time. Gate width/length of the devices used are 50㎛/50㎛, 50㎛/1.6㎛ and 1.6㎛/50㎛. The hydrogenation conditions were 1kW RF power, 300℃ process temperature, and 7cm substrate position below from the bottom of the quartz plate. Threshold voltage and subthreshold slope have strong dependence on gate width and length. Those of short channel and/or narrow channel devices (50㎛/1.6㎛, 1.6㎛/50㎛) are rapidly changed in 60min and almost constant for longer time than 60min. But mobility has relatively loose relation of gate dimension and hydrogenation time. This time relation has been reported by Wu[5], threshold voltage and subthreshold slope are changed in shorter time than mobility.

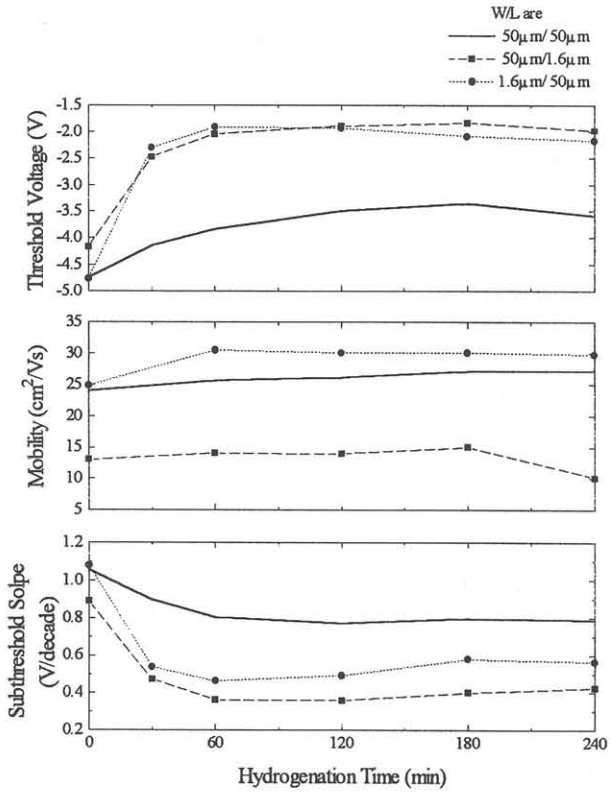

Fig 3. Parameter changes of the devices of W/L = 50㎛/50㎛, 50㎛/1.6㎛ and 1.6㎛/50㎛ versus hydrogenation time. ICP hydrogenation conditions are 1kW, 20mtorr, and 300℃.

For change of RF power, plasma density increases with linear relation as RF power increases. In Fig. 4, relations between parameters and RF power are shown. The process conditions were 20mtorr process pressure, 300℃ process temperature, 7cm substrate position below from the bottom of the quartz plate and 30min process time. Subthreshold slope drastically decreases at lower RF power for all devices and is saturated for higher RF power. But, threshold voltage and mobility are dependent on device dimension. These parameters of long and wide channel device (50㎛/50㎛) are changed by small amount. Threshold voltage has more length dependence than width dependence and mobility does width dependence. Mobility varies linearly with RF power and its increasing rate is larger than that for time. This result matches with diffusion

model of hydrogen because in diffusion process concentration has linear dependence on source density and square root relation with time. And we know that the defects related to mobility differ from those related to other parameters and are slower to be passivated.

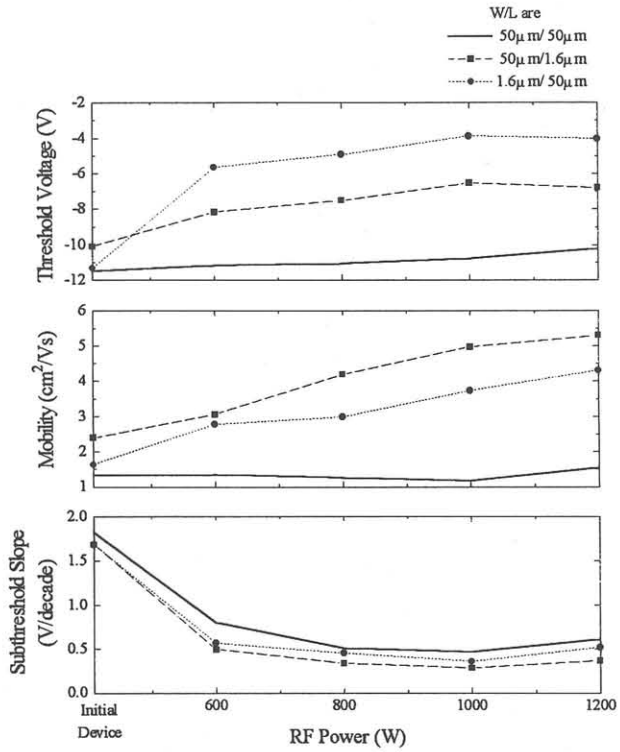

Fig 4. Parameter changes of the devices of W/L = 50μm/50μm, 50μm/1.6μm and 1.6μm/50μm versus RF power. ICP hydrogenation was performed at 20mtorr and 300℃ for 30min.

4. Summary

From the comparison of ICP and ECR, it can be concluded that ICP is the more effective in poly-Si hydrogenation process. ICP hydrogenation has similar effects on device performance according to device dimension and hydrogenation time when compared to other hydrogenation processes. Both threshold voltage and subthreshold slope change quickly during the first 30 minutes of hydrogenation and saturate around 60 minutes. Mobility has a nearly linear dependence on RF power and a weak dependence on hydrogenation time. ICP hydrogenation can be a viable method for large area poly-Si processes.

References

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