Effects of H_2 vs. O_2 Plasma Pretreatment of Gate Oxide on the Degradation Phenomenon of Low-Temperature Polysilicon Thin-Film Transistors

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Abstract

Comparative study on the effects of H_2 vs. O_2 plasma pretreatment of gate oxide on the degradation phenomenon of p-channel low-temperature polysilicon (LTPS) thin-film transistors (TFTs) were performed. After high drain current stress (HDCS) with $V_{gs} = V_{ds}$, the p-channel TFTs pretreated by O_2 plasma showed increased immunity to the degradation of device characteristics such as threshold voltage and maximum field effect mobility because of the higher binding energy of Si-O bond than that of Si-H bond. The investigation of degradation phenomenon of these parameters with the applied power suggests that self-heating can be the major cause of degradation of polysilicon TFTs.

1. Introduction

Low-temperature polycrystalline silicon (LTPS) thin-film transistor (TFT) is widely attracted for the integration of system on panel (SOP). Improving device performances and reliabilities is concerned critical issue. Short-channel device is attractive for improving device performances such as high current drivability and low threshold voltage (V_{th}). However, self-heating-induced degradation increases with decrease in TFT size under a typical DC stress [1].

The channel polysilicon film is interlaid between gate SiO_2 and buffer SiO_2 layers with low thermal conductivity of $1.3 Wm^{-1}K^{-1}$ and the SiO_2 layers build barriers to heat dissipation, which causes self-heating-induced TFT degradation under high power condition. Si-H bond breaking is generally accepted as a degradation model explaining self-heating induced degradation in LTPS TFTs [2].

Oxygen plasma treatment is one of the candidates for the reduction of density of defect states in polysilicon film, and the oxygen-passivated film reveal higher self-heating immunity than hydrogen-passivated film because Si-O bond has higher binding energy than that of Si-H bond [3].

In this study, the self-heating immunity is compared between hydrogen- and oxygen-passivated films. The defect passivation efficiency is also discussed.

2. Experimental

Top gate self-aligned p-channel poly-Si TFTs with width/length (*W/L*) dimension of 4/4 and 16/4 ㎛/㎛ were fabricated using low temperature process. Firstly, stacked SiO_2 and SiN_x buffer layers were deposited on a glass substrate by plasma enhanced chemical vapor deposition (PECVD) not only to suppress the mobile charge diffusion from glass substrate but also to reduce the self-heating effect. Laser crystallization was performed after 50 nm-thick amorphous silicon precursor deposition and dehydrogenation anneal. After the poly-Si active layer patterning, HF cleaning was applied to adjust the V_{th}. After that, the gate oxide pretreatments were splited with O_2 and H_2 plasma, respectively. A 75 nm-thick SiH_4 based gate oxide deposition followed by post thermal treatment to improve gate oxide reliability was performed [4]. After gate patterning, the source and drain (S/D) region was doped by boron based non-mass-separated ion shower. A 500 nm-thick interlayer was deposited and the S/D doped region was thermally activated. Finally, passivation layer was deposited and thermal anneal was applied to improve hydrogenation efficiency.

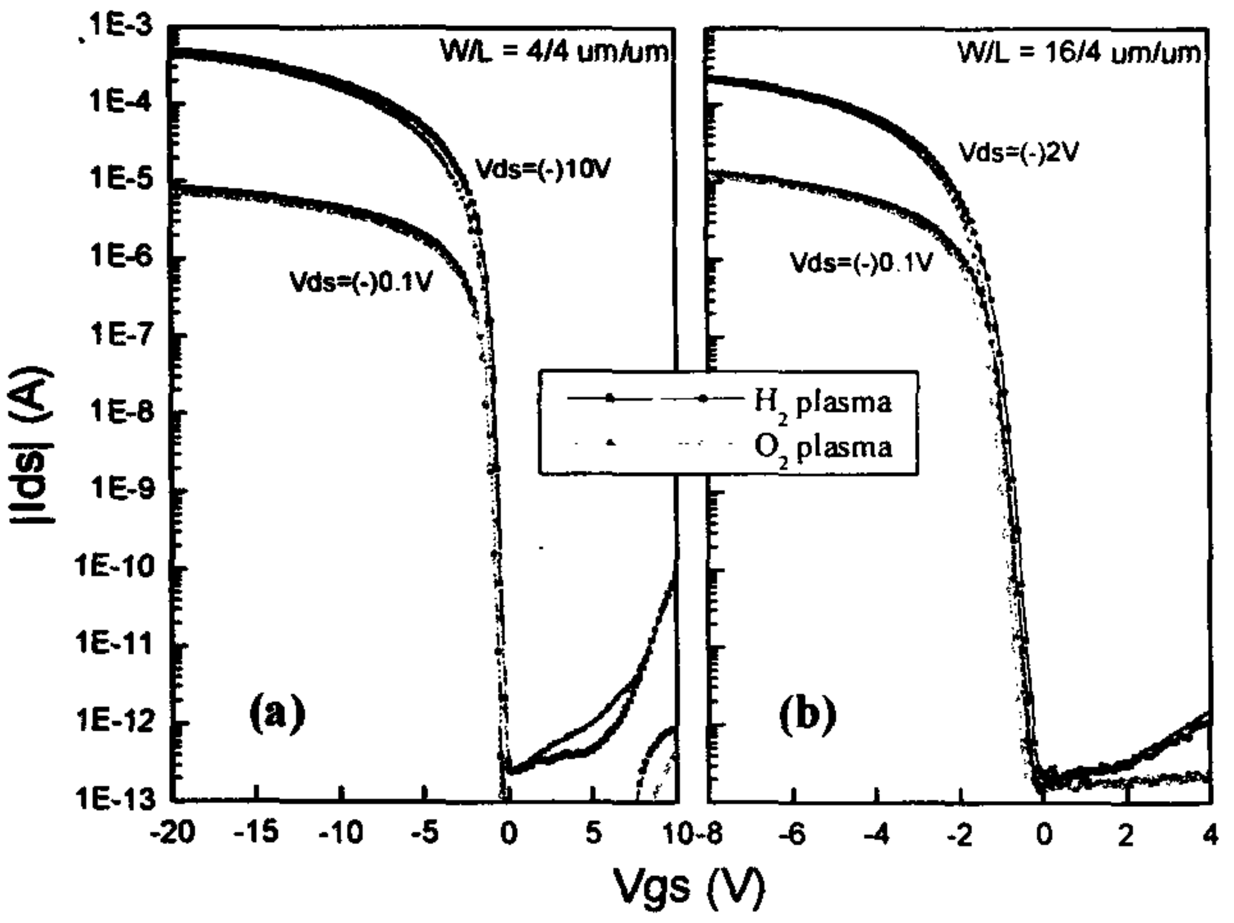

Fig. 1 Comparison of transfer curves (a) W/L=4/4 ㎛/㎛ and (b) W/L=16/4 ㎛/㎛ p-type TFTs treated with H_2 and O_2 plasma, respectively.

3. Results and discussion

Initial transfer curves, and device parameters such as V_{th}, maximum field effect mobility ($\mu_{FE,max}$), and subthreshold slope were compared between H_2 and O_2 plasma treated samples.

Fig. 1 shows the transfer curve comparison. The subthreshod slope was 188 mV/decade and 199 mV/decade for H_2 plasma and O_2 plasma treated samples with *W/L* = 4/4 ㎛/㎛, respectively. The off currents at low gate field in O_2 plasma treated sample showed higher level than those of H_2 plasma treated sample. From these results, it is assumed that trap state density is higher for O_2 plasma treated sample than H_2 plasma treated sample, and that the efficiency of defect passivation with H_2 plasma is superior to O_2 plasma case. It is known that the off current at low field depends on the trap distribution, i.e., trap assisted tunneling [5], and that the subthreshold slope mainly relies on deep level interface states, which is caused by dangling bonds [6].

Fig. 2 shows V_{th} difference as a function of split condition and device dimensions. V_{th} slightly increased by applying O_2 plasma comparing with H_2 plasma, which also can be understood by the trap state density difference. It is known that the V_{th} increases as the trap density increases [7].

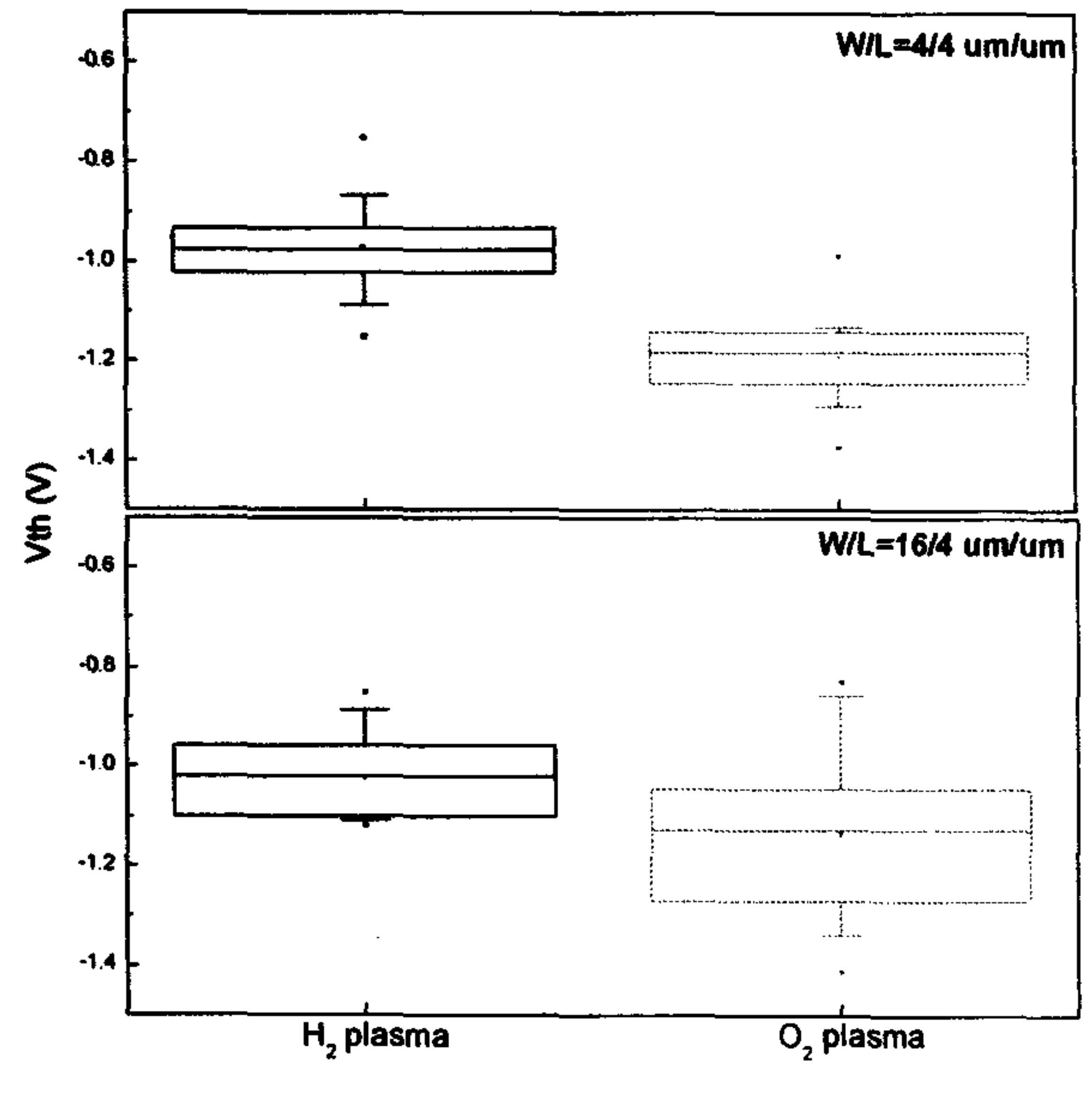

Fig. 2 Comparison of V_{th} between H_2 and O_2 plasma treated sample.

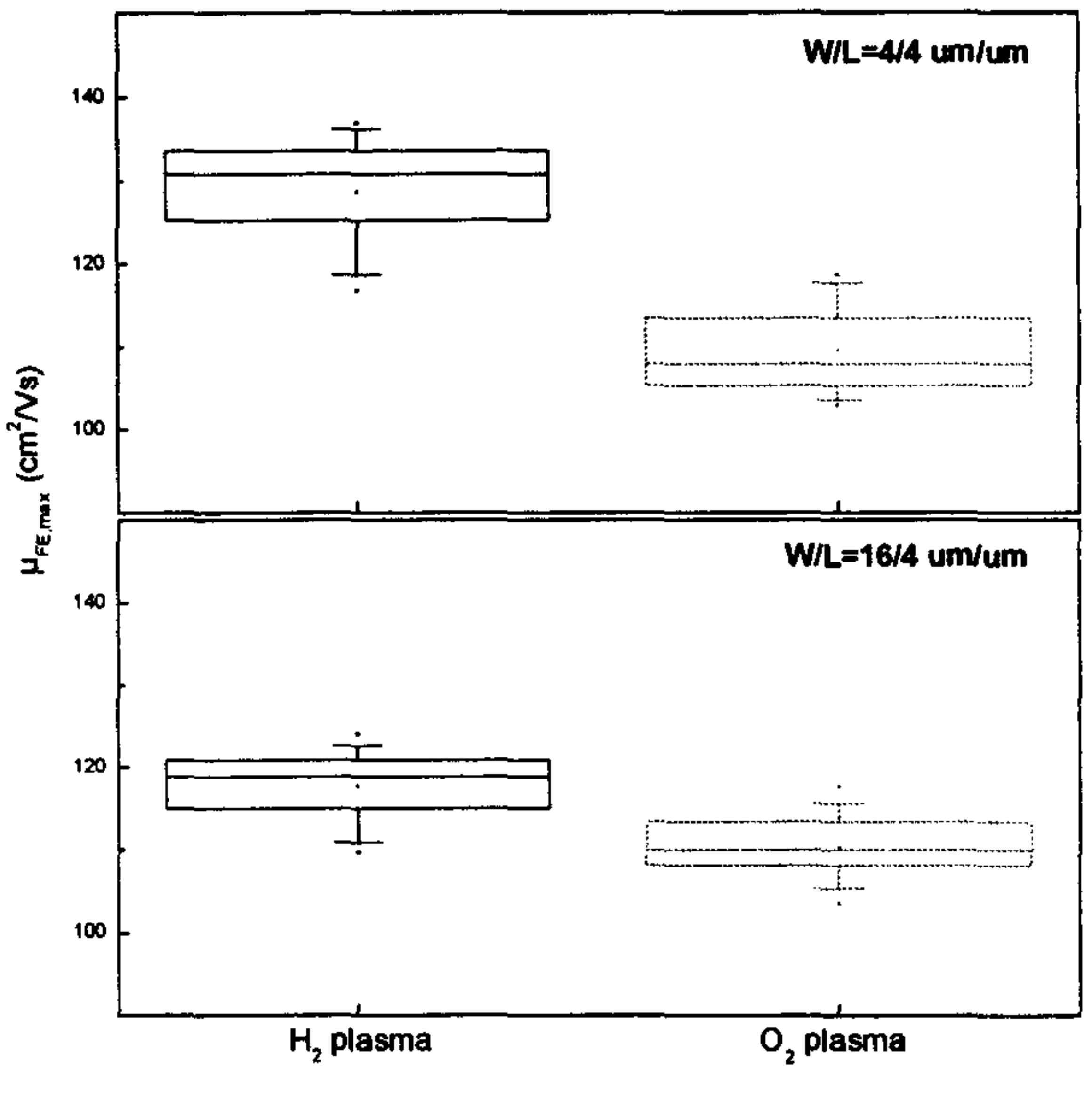

Fig. 3 Comparison of $\mu_{FE,max}$ between H_2 and O_2 plasma treated sample.

Fig. 3 shows $\mu_{FE,max}$ difference as a function of split condition and device dimensions. It is seen that the $\mu_{FE,max}$ of O_2 plasma treated samples is lower than that of H_2 plasma treated samples because $\mu_{FE,max}$ decreases along with the increase of trap density [7].

Although the defect passivation efficiency was better in H_2 plasma treated samples, however, the long-term instability of hydrogenated poly-Si TFTs due to breaking of the Si-H bonds during electrical stress is known one of the major limitations [8]-[9].

The self-heating immunity between H_2 plasma treated and O_2 plasma treated samples were compared by high drain current stress (HDCS), where V_{gs} and V_{ds} were biased to same value for a bias window of between -3 V and -17 V with stress duration of 60 sec. Fig. 4 shows ΔV_{th} as a function of applied bias and applied power. The power was defined by $I_{ds} \times V_{ds}$, where I_{ds} was the initial drain current under the stress duration with $V_{gs}=V_{ds}$. V_{th} shift was observed for over a certain value of bias condition and power, thus heat, which is in good agreement with the NMOS results [1], but the polarity of the V_{th} shift due to the trapping charge type difference. The negative shift might be because hole trapping and self-heating induced Si-H bond breaking. It was found that O_2 plasma treated sample showed better immunity to self-heating than H_2 plasma treated sample because of the higher binding energy of Si-O bond than that of Si-H bond.

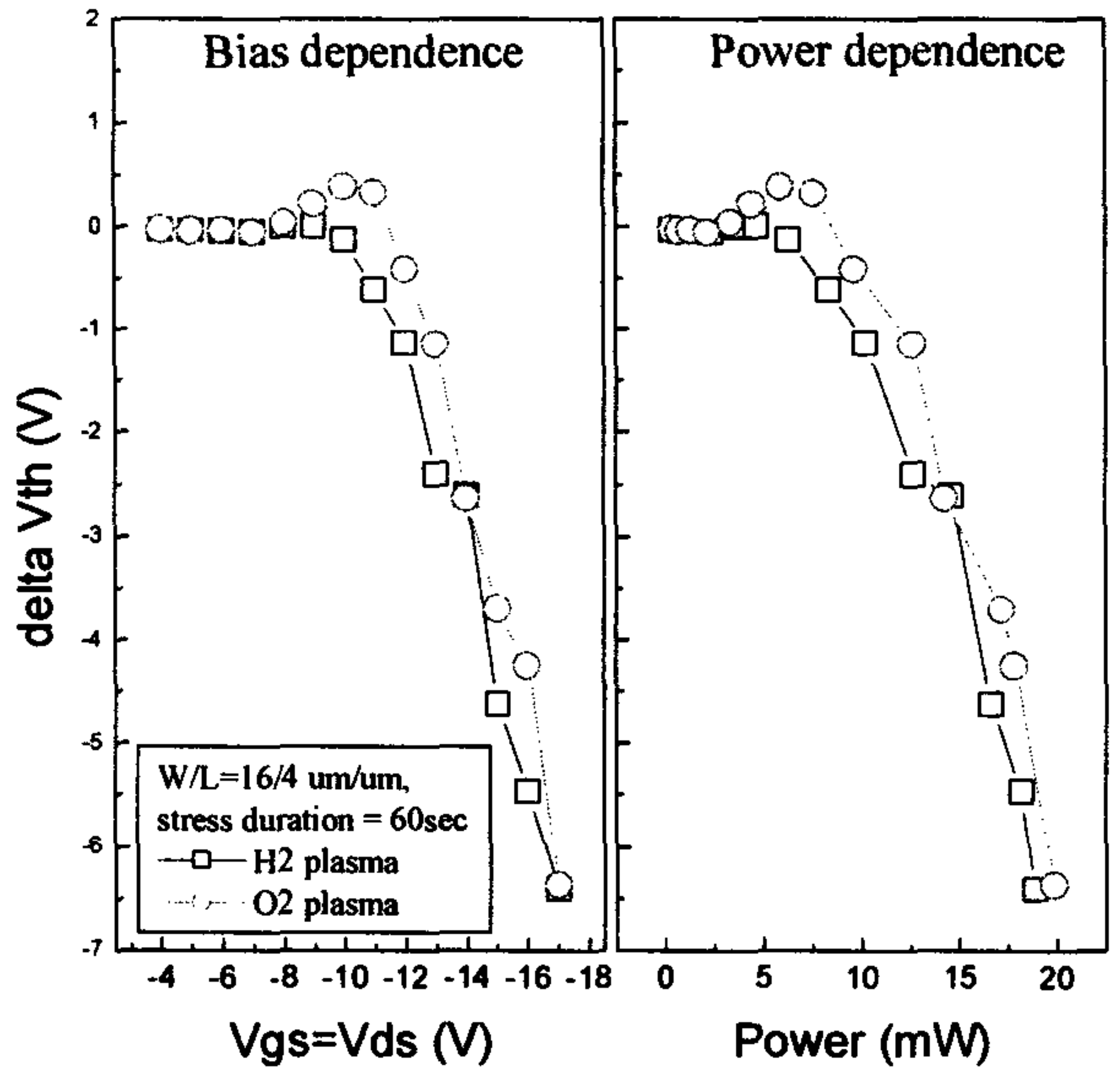

Fig. 4 Comparison of Vth shift as a function of applied bias and power.

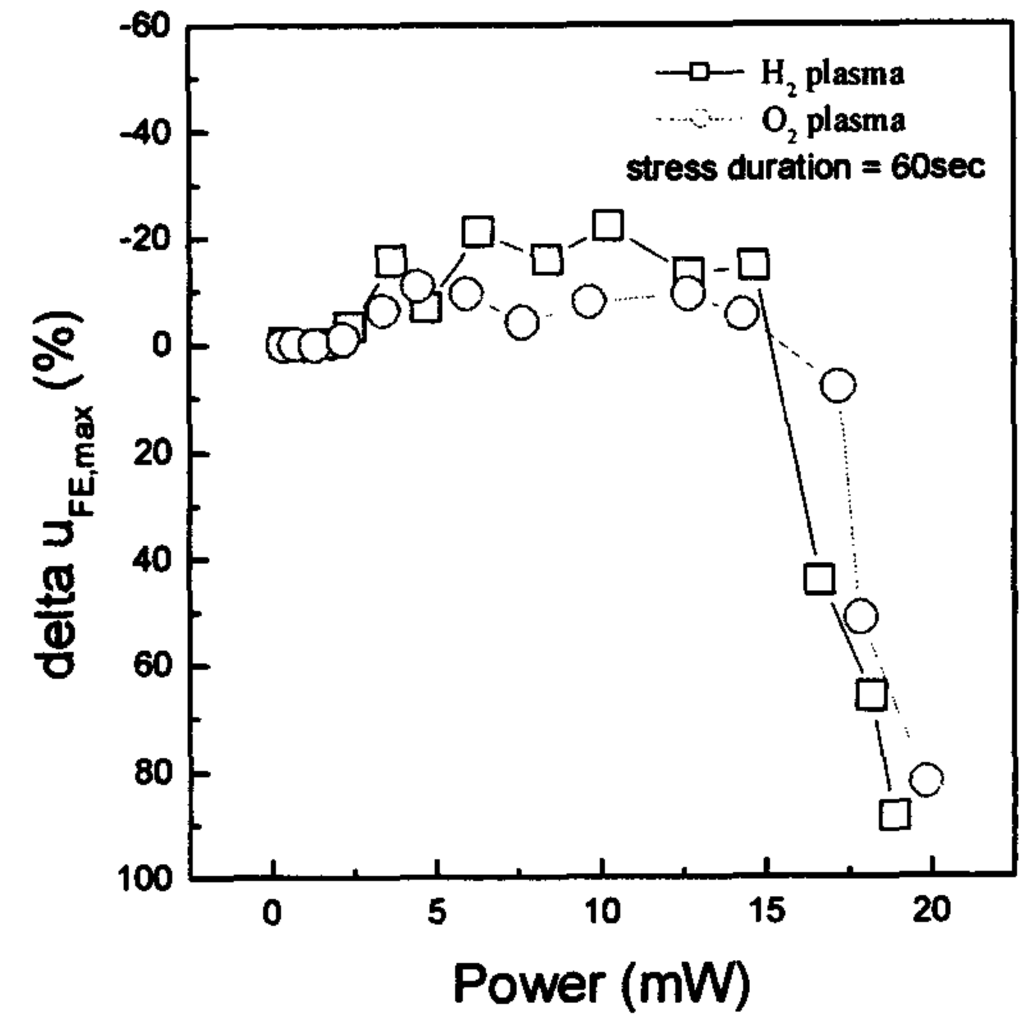

Fig. 5 Comparison of $\Delta\ \mu_{FE,max}$ as a function of applied power.

Fig. 5 shows $\mu_{FE,max}$ degradation as a function of applied power. $\mu_{FE,max}$ degradation (>10%) was observed over around 15 mW of applied power. The degradation was severer for H_2 plasma treated case. Although there could be some overestimation due to the limit of transfer sweep range as shown in Fig. 1(b), it is worthwhile to note that the immunity to self-heating is drastically improved by O_2 plasma treatment.

4. Conclusion

The effects of plasma pretreatment of gate oxide on the initial device characteristics and on the degradation of p-type polysilicon TFTs were studied. H_2 plasma was compared with O_2 plasma with respect to defect passivation efficiency and self-heating immunity. H_2 plasma treated sample showed better device characteristics such as V_{th}, $\mu_{FE,max}$, and subthreshold slope, and thus better defect passivation efficiency than O_2 plasma treated sample. However, O_2 plasma treated sample showed superior self-heating immunity to H_2 plasma treated sample, because the binding energy of Si-O bond is higher than that of Si-H bond. It can be suggested that O_2 plasma treatment could be a solution for improving device reliability with respect to self-heating even though a tradeoff is still found between device performances and immunity to self-heating.

5. References

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