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# High Mobility Botton-Gate Thin-Film Transistors with Laser-Crystallized and Hydrogen Radical Annealed Polysilicon Films

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High-performance bottom-gate thin-film transistors have been realized for the first time with excimer laser-crystallized polysilicon films. The field-effect mobilities exceeded $220cm^2/Vs$ for electrons and $140cm^2/Vs$ for holes, respectively. This drastic improvement is based on optimization of photogenerated hydrogen-radical annealing (HRA) and laser-crystallization conditions.

## 1. Introduction

Recently, polysilicon (poly-Si) thin-film transistors (TFTs) have received much attention for use in active-matrix liquid-crystal displays (AMLCDs) with on-chip peripheral circuits[1].

Excimer laser annealing has the advantage not only of low-temperature process, but also of local crystallization process that can restrict the crystallized region by selectively irradiating the film. Thus, it is the most suitable crystallization method for fully integrated AMLCDs with on-chip amorphous silicon (a-Si) TFTs for matrices and poly-Si TFTs for peripheral circuits. We have previously reported on the on-chip bottom-gate poly-Si and a-Si TFTs fabricated by excimer laser crystallization of CVD a-Si films[2]. This result indicated that the performance will be improved drastically when the HRA and laser-crystallization conditions are optimized.

## 2. Experimental

Bottom-gate poly-Si TFTs were fabricated by ArF excimer laser-crystallization of CVD a-Si films deposited at 450 °C from disilane. Hydrogen content of the original a-Si film was as low as 3%[3]. Figure 1 shows a schematic cross sectional view of the TFT. Source and drain electrodes of aluminum were formed just on the active Si film to achieve both n-channel and p-channel operations by only changing gate voltage polarity. The gate insulator was 140nm-thick thermal oxide. The device has been annealed in photogenerated hydrogen-radical ambient (HRA) to reduce grain boundary traps. HRA system has been described elsewhere[4].

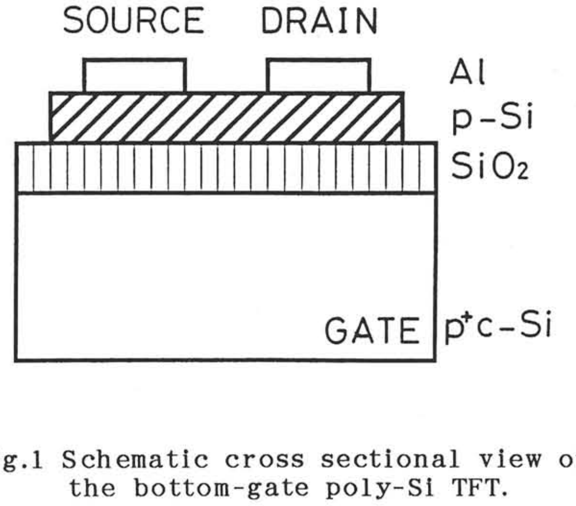


Fig.1 Schematic cross sectional view of the bottom-gate poly-Si TFT.

## 3. Results and Discussions

### 3.1 Optimization of laser-crystallization conditions

The electron mobility has been shown in Fig.2 by open marks as a function of irradiated laser energy density for several Si film thicknesses. The device has been post-hydrogenated just before the measurement as described later. Field-effect mobilities were estimated from $I_d$-$V_d$ characteristics under low drain voltage conditions. Threshold energy density for crystallization was $160 mJ/cm^2$, independent of film thickness. For thin films viz 20nm-thick and 50nm-thick films, electron mobilities increased in proportion to the increase in energy density. This result implys that grain size was enlarged at the interface as well as at the surface by applying higher energy density. However, the amorphization [4] occured at $300 mJ/cm^2$ for 20nm-thick film and at $370 mJ/cm^2$ for 50nm-thick film, respectively. These amorphized Si films were crystallized again by re-irradiating just less than boundary value for amorphization. This recrystallized poly-Si TFT characteristics are also shown in the figure by closed marks. The mobilities were as high as $90 cm^2/Vs$. In the case of 80nm-thick film, however, amorphization did not occur and mobilities were saturated at energy of more than $300 mJ/cm^2$. From these results, the optimum laser-crystallization conditions have been determined as tabulated in Table 1.

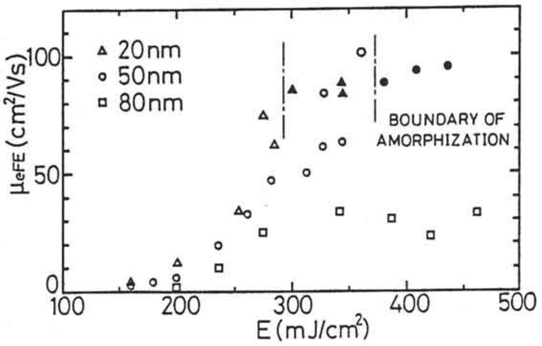


Fig.2 Electron mobilities as a function of irradiated laser energy density.

Table 1. The optimum conditions of laser crystallization.

| | |
|---|---|
| Si film thickness | less than 50nm |
| Laser energy density | $360 mJ/cm^2$ for 50nm-thick Si |

### 3.2 Optimization of HRA conditions

Figure 3 shows drastic effect of HRA. There is no field-effect before HRA since hydrogen atoms in the original a-Si films are not sufficent to terminate grain boundary traps. After HRA at 200°C for 30min, leakage current near $V_g$=0 is reduced, and both electron current for $V_g$>0 and hole current for $V_g$<0 are increased. After HRA at 400 °C, TFTs showed good characteristics with on/off current ratio of more than $10^6$. At 500 °C, the performance of TFTs became worse, but good characteristics revived after once more annealing at 400 °C. This result means that the degradation of characteristics was not occured by the Si network change, but by only desorption of hydrogen from the Si film.

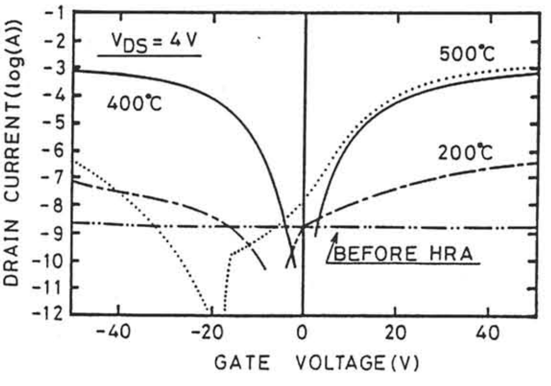


Fig.3 Log($I_d$)-$V_g$ characteristics of TFTs for various HRA temperatures.

Figure 4 shows the mobilities of poly-Si TFTs as a function of HRA temperature. It was found that HRA with decreasing temperature from 400°C or 500°C to 200°C (ramp-mode annealing) is much more effective than that with constant temperature. We believe that hydrogen desorption will occur after HRA with constant temperature, due to keeping the films high temperature after finishing light irradiation. By furnace-annealing in nitrogen ambient, hydrogen desorption began to occur from 350°C. However, ramp-mode annealing can finish at as low as 200°C, so hydrogen desorption is neglected. The optimum HRA conditions have been tabulated in Table 2. It should be noted that optimum total pressure is more than 100 Torr, which is difficult to realize using hydrogen plasma.

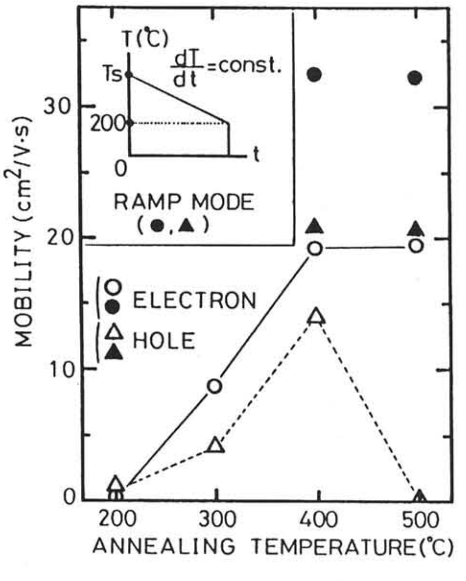


Fig.4 Electron and hole mobilities of poly-Si TFTs as a function of HRA temperature.

Figure 5 shows $I_d$-$V_d$ characteristics of poly-Si TFT formed under the optimum conditions. The solid curves are the results measured by conventional two-point probe method and dashed curves are those by four-point probe method which can eliminate the parasitic resistances formed near in the source and drain. The mobilities of TFTs estimated from results by four-point probe method were 221cm$^2$/Vs for electrons and 143cm$^2$/Vs for holes, respectively.

Table 2. The optimum HRA conditions obtained from this study.

| | |
|---|---|
| Hg partial pressure | more than 0.05mTorr |
| Total pressure | 80~ 180Torr |
| Temperature | 400°C→ 200°C |
| Cooling rate | less than 8°C/min |
| UVlight power density | 200mW/cm$^2$ |

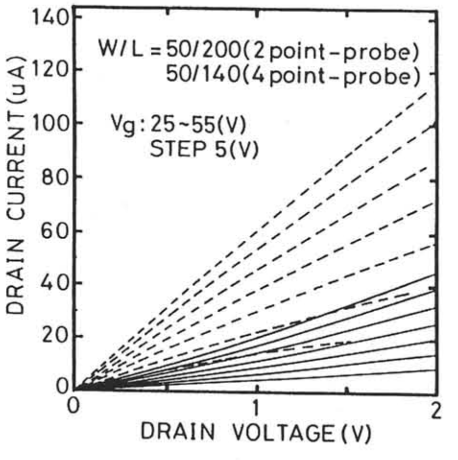


Fig.5 $I_d$-$V_d$ characteristics of poly-Si TFT under the optimum HRA condition.

## 4. Conclusions

High-mobility (221cm$^2$/Vs) bottom-gate TFTs were realized with excimer laser-crystallized poly-Si fillms by the optimization of both crystallization and post-hydrogenation conditions. This good result will be caused partly by the fact that the original CVD a-Si film has high packing density with only a small amount of hydrogen atoms.

## References


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