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High-Performance Poly-Si Thin-Film Transistors with Excimer-Laser Annealed Silicon-Nitride Gate

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We will present, for the first time, that ArF excimer-laser annealing can improve the electrical properties of silicon-nitride films. This laser pre-annealed film was shown very useful to the gate insulator in the high-performance bottom-gate thin-film transistors with the laser-recrystallized poly-Si film. The field-effect mobility of electrons was as high as $150cm^2/Vs$.

1. Introduction

High-performance thin-film transistors (TFTs) have been receiving much attention to use in high-quality active-matrix liquid-crystal displays[1]. It is the essential factor for these TFTs that electrical characteristics not only of the Si film as the active layer, but also of the SiO_2 or SiN film as the gate insulator should be improved[2]. It is, however, difficult to improve drastically the electrical characteristics of these low-temperature deposited films by only optimizing the present deposition method. Therefore, an innovative technique is strongly required for improving these thin-films after deposition. In case of the Si film, it is well-known that the low-quality film such as amorphous Si film or low-temperature deposited poly-Si film on the glass substrate can be improved drastically by laser-annealing technique[3] since the film can be heated up to its melting temperature. On the other hands, no results have been reported for improving the insulating films after deposition. We have investigated the excimer-laser annealing method to improving the SiN film for the first time.

2. Experimental

Table I shows the absorption coefficient α of the low-temperature deposited SiN film to various excimer-laser lights. ArF excimer-laser light has a photon-energy(6.4eV) much larger than the SiN band-gap(5~6eV), and therefore α to ArF excimer-laser light is very large. It is thus expected that the SiN film can be heated up to high-temperature resulting in the improved film quality, as the Si film, by ArF excimer-laser irradiation without thermal damage to the glass substrate.

The 200nm-thick SiN films were deposited by low-temperature thermal CVD using Si_2H_6 and N_2H_4 at 500^oC[4]. The sample was irradiated by ArF excimer-laser light in a vacuum chamber at room temperature. The laser annealed SiN films were evaluated by microscope observation, FT-IR, BHF etching rate and I-V measurement. Finally the laser-recrystallized poly-Si/SiN TFTs were fabricated using this laser pre-annealed SiN gate.

Table I. The absorption coefficient α of SiN to various excimer-laser lights.

	λ (nm)	$h\nu$ (eV)	α (cm^{-1})
ArF	193	6.4	$>5x10^5$
KrF	248	5.0	$\sim 10^5$
XeCl	308	4.0	———

3. Results and Discussion

First, we observed the surface morphology of the SiN films after laser irradiation. The surface had no change for energies of less than $200mJ/cm^2$. Beyond about $250mJ/cm^2$, a lot of micro-cracks were generated on the SiN film surface. For more than $300mJ/cm^2$, the SiN film was stripped off. These results imply that the SiN film could effectively absorb ArF excimer-laser light energy and was heated up to very high-temperature as expected.

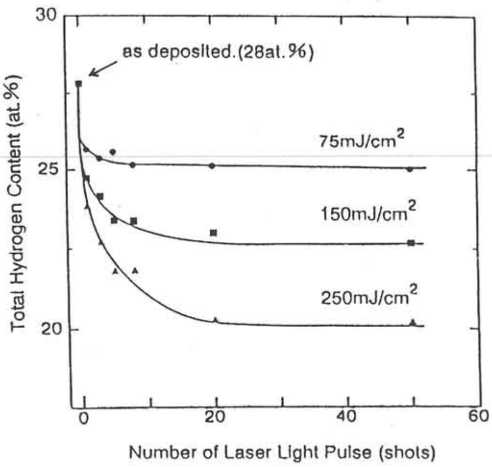

Fig.1 The total hydrogen content as a function of number of laser pulses for various laser energy densities.

Next, hydrogen content was measured by FT–IR for the SiN films irradiated at $75mJ/cm^2$, 150m J/cm^2, and $250mJ/cm^2$, respectively. Figure 1 shows the total hydrogen content as a function of number of laser pulses for various laser energy densities. The total hydrogen content was estimated by sum of two absorptions at $2170cm^{-1}$ due to Si–H bonds and at $3370cm^{-1}$ due to N–H bonds. Since hydrogen content was decreased with the increase in the laser energy, it is expected that film properties were modified by laser irradiation even though the surface morphology is not changed. In contrast to the fact that the hydrogen content in the SiN film furnace–annealed at 1100°C became zero, hydrogen content of only 8% was reduced by laser annealing even at $250mJ/cm^2$. This result can be interpreted by a two layer model with the improved thin top layer on the unchanged thick bottom layer due to very large α of the SiN film. Since it is expected that thermal properties of SiN is equal to those of a–Si, the top region in the laser pre–annealed SiN film can be extremely heated up for no more than several ten nanoseconds, and the maximum temperature may be up to much more than 1000°C in a moment.

For the purpose of verifying the two layer model, we have evaluated the film quality by step by step etching the SiN film from the surface using BHF solution. Figure 2 shows the etching time dependence of the SiN film thickness for various laser energies. A slope of the film thickness vs etching time means the etching rate. The rate at the top region of 15nm–thick was reduced drastically with the increase in the laser energy. The etching rate of the improved region at $250mJ/cm^2$ was equal to that of the film furnace–annealed at 920°C for more than 30 minutes.

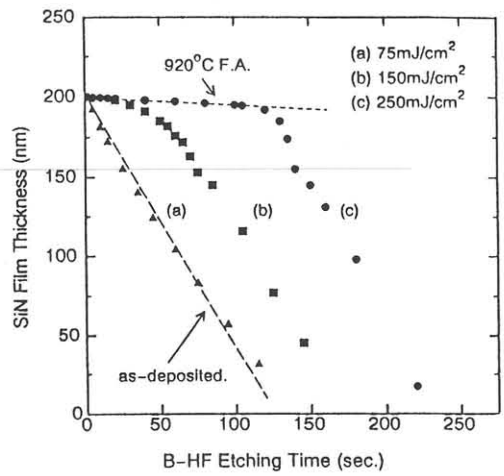

Fig.2 The etching time dependence of the SiN film thickness for various laser energies.

Electrical characteristics of the laser annealed SiN film were evaluated by current–voltage measurement using MIS(Al–SiN(90nm)–Si) capacitor. Figure 3 shows current density vs electrical field characteristics for the as–deposited SiN film and the laser–annealed SiN film. Laser energy density was $150mJ/cm^2$ which generated no micro–cracks on the SiN film. Breakdown filed strength was improved from 5.5MV/cm to 7.5MV/cm by laser–irradiation.

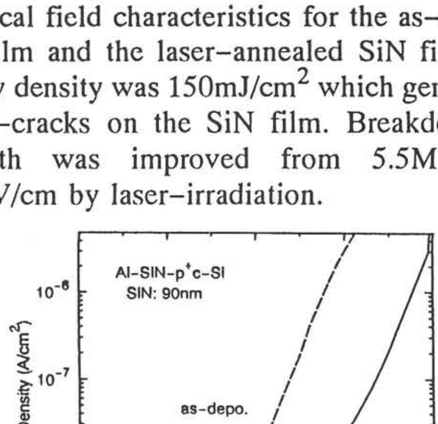

Fig.3 Current density vs electrical field characteristics for the as–deposited SiN film and the laser–annealed SiN film.

4. Poly–Si/SiN TFT Characteristics

It is a basic demand for the high–mobility poly–Si TFTs aiming at the peripheral circuit that they can be simultaneously produced on the same glass substrate with the satisfactorily low off–current bottom–gate a–Si/SiN TFTs used for matrices. This demand can be satisfied only when both TFTs have the same structure and are produced from the same starting material deposited at the same time. These demands can be satisfied, for the first time, by the laser pre–annealing method for the SiN film, as schematically shown in Fig.4.

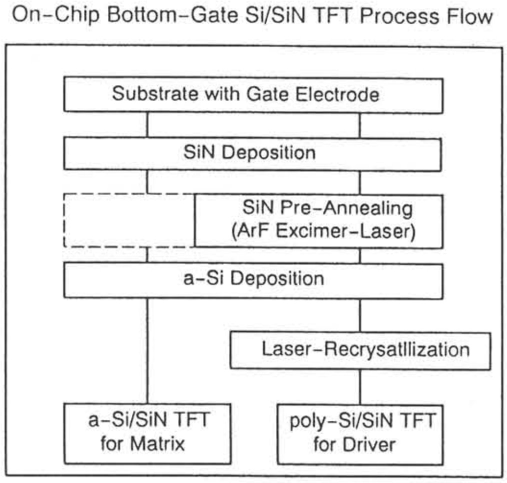

Fig.4 On-chip fabrication process of poly-Si/SiN TFT and a-Si/SiN TFT.

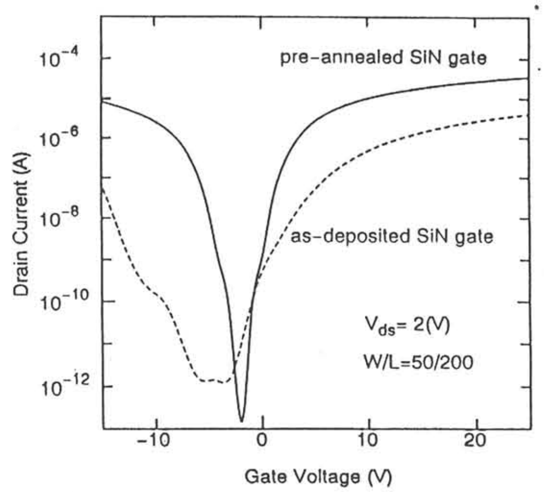

Fig.5 I_d–V_g characteristics of the poly-Si/SiN TFTs with as-deposited SiN gate and the pre-annealed SiN gate.

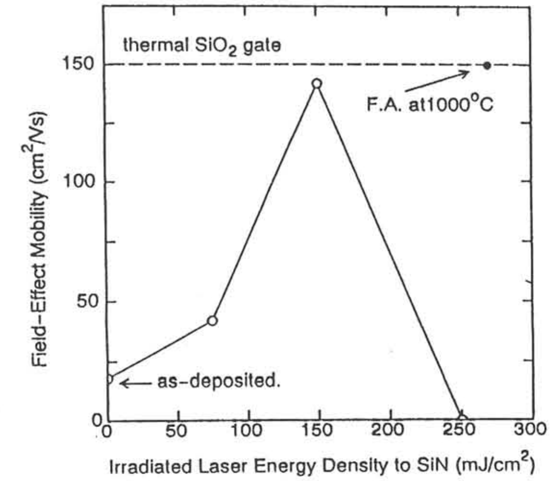

Fig.6 The field-effect mobility as a function of laser energy densities.

There are two additional laser annealing steps compared with the conventional a-Si/SiN TFT process, and a-Si/SiN TFTs can be produced by only skipping excimer-laser recrystallization process. The step of laser pre-annealing the SiN gate can be skipped if desirable. Excimer-laser recrystallization and post-hydrogenation process have already been reported elsewhere[5].

Figure 5 shows I_d–V_g characteristics of the bottom-gate poly-Si/SiN TFTs with the as-deposited SiN gate and the pre-annealed SiN gate. It is expected that no thermal damage is introduced into the pre-annealed SiN film by laser recrystallization of Si since the SiN film has already been heated up to much higher temperature than the melting temperature of Si. TFT performance was improved by the pre-annealing. The mobility and on/off current ratio were enhanced, and the threshold voltage and the subthreshold swing were reduced by laser pre-annealing SiN gate. This is because the improved top region in the pre-annealed SiN film forms the interface between the active Si layer for the bottom-gate structure.

Figure 6 shows the drastic enhancement of the mobility by pre-annealing. The TFT with the unannealed SiN gate showed the mobility of as low as 20cm^2/Vs. At the optimum energy of 150mJ/cm^2, the TFT had the mobility of as high as 150cm^2/Vs which was equal to that of the bottom-gate laser-recrystallized poly-Si TFTs with thermal oxide gate or 1000°C furnace-annealed SiN gate.

5. Conclusion

We have applied the excimer-laser annealing method to the SiN film for the first time. It was shown that high-performance bottom-gate poly-Si TFTs can be achieved by excimer-laser pre-annealing the SiN gate. The mobility was improved from 20cm^2/Vs to 150cm^2/Vs by laser pre-annealing the SiN gate.

Reference

1) M.Takabatake et al.: IEEE Trans. Electron Devices **ED-38** (1989) 1303.
2) T.Serikawa et al.: IEEE Trans. Electron Devices **ED-36** (1989) 1929.
3) T.Sameshima et al.: IEEE Electron Device Lett. **EDL-7** (1986) 276.
4) B.C.Ahn et al.: Conf. Record of the IDRC'91, p.85.
5) K.Shimizu et al.:Jpn. J. Appl. Phys. **30** (1991) 3704.