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S-E-8

XeCl Excimer Laser-Induced Amorphization and Crystllization of Silicon Films

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Laser-induced amorphization and crystallization were observed in thin silicon films. The transition from amorphous to crystalline was reversible and governed by laser energy density. Hydrogenated amorphous silicon was crystallized by multipulse irradiation. The laser energy was first raised from the melting threshold to the amorphization threshold in order to release hydrogen without eruption, then lowered to recrystallize the laser-amorphized region. Using this method, poly-Si TFTs were successfully fabricated at 250°C.

1.Introduction

Hydrogenated amorphous silicon (a-Si:H) TFTs[1-4] are widely used because they can be fabricated at a low processing temperature of about 300°C on a glass substrate. A-Si:H TFTs, however, have a channel mobility lower than 1cm²/Vs, so they cannot be applied to devices operating at a high frequency (>10MHz), such as shift registers. We have experimentally demonstrated that XeCl excimer laser-induced crystallization can be achieved at a low temperature[5]-- a glass substrate was heated no more than 200°C at 600nm below the top silicon layer during and after laser-induced crystallization. We have also reported the fabrication of polycrystalline silicon (poly-Si) TFTs with a high carrier mobility using XeCl excimer laser crystallization of a-Si:H at a processing temperature of 150°C and 250°C[6,7]. In addition, we have found that a thin silicon film can be amorphized by irradiation with an energy density much larger than the melting threshold[8,9].

In this paper, the crystallization and amorphization of a silicon film induced by irradiation with a XeCl excimer laser are characterized and a laser-annealing technique for fabricating poly-Si TFTs is presented.

2. Characterization of Laser-induced Amorphization and Crystallization of Silicon Film

2-1. Experimental

Nondoped and 2%-phosphorus doped hydrogenated amorphous silicon (a-Si:H and a-Si:H,P) films were deposited on a quartz substrate at 250°C using radio-frequency glow discharge (rf-GD). The samples were irradiated with 30ns-FWHM pulses of a XeCl excimer laser in vacuum. The laser beam was formed into a 5mmx10mm rectangle by a lens at the sample surface. The energy threshold for surface melting was determined by time resolved optical reflectivity[10] using an Ar-514.5nm laser beam as a probe light. Since the a-Si:H film contained about 10 atomic percent of hydogen atoms, the samples were irradiated with multipulses whose energy density was increased in about 20mJ/cm² step from 120mJ/cm². This multistep irradiation prevented the eruption of hydrogen atoms which can causes surface roughness. The laser threshold energies for crystallization and amorphization were determined by optical reflectivity spectra and Raman TO phonon Stokes spectra and visual observation[8]. The laser threshold energy for surface roughness was determined by visual observation. Electrical conductivity and the Hall effect were measured. TEM observation and FTIR

measurements were also carried out.

2-2. Results and discussion

Figure 1 shows solidification modes after laser-induced melting of nondoped a-Si:H for laser energy densies between 120 and 350mJ/cm^2 and film thicknesses between 15 and 120nm. Crystallization was initiated when the sample surface was melted by laser irradiation with an energy density between 120 and 150mJ/cm^2. TEM measurement of 30nm-thick silicon film revealed that crystalline grains were not dendritic but roughly circular and their diameter increased to at most 60nm as the laser energy increased. When the a-Si:H film is less than 65nm thick, the film was crystallized throughout.

The film was amorphized through laser-induced melting when the film thickness was less than 50nm. The amorphization threshold was 240mJ/cm^2 for film thicknesses between 15 and 30nm and increased as the film thickness increased, as can be seen in Fig.1. Transient conductance measurements of 20nm-thick silicon film revealed that molten silicon was rapidly quenched within 5ns (=time resolution) and the film was amorphized only when the melt duration exceeded 70ns[9]. We deduce that rapid and homogeneous solidification makes amorphization of the silicon film possible because the heat can be distributed uniformly throughout the film when melting is of a long duration. The transition from amorphous to crystalline was reversible and governed by the laser energy density. The laser-induce amorphous silicon film was recrystallied by irradiation with an energy density lower than the amorphization threshold.

Figure 2 shows change of the electrical conductivity and electron mobility of 2%-phosphorus doped silicon film with the laser energy density. The electrical conductivity and the electron mobility were increased by irradiation above 140mJ/cm^2 to 1300S/cm and 9cm^2/Vs, respectively, at 235mJ/cm^2. These increases were caused by laser-induced crystallization. These values were rapidly decreased with irradiation above 240mJ/cm^2 because of amorphization. The amorphous film was recrystallized by irradiation with an energy density of 235mJ/cm^2 and the electrical conductivity and the electron mobility increased again to 1300S/cm and

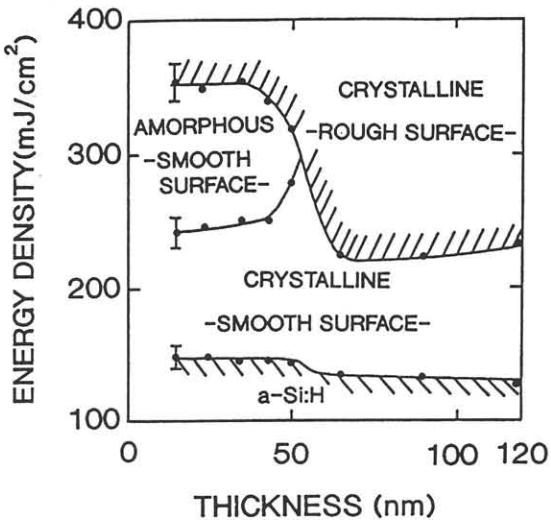

Fig.1 Diagram for laser-induced melt and solidification modes with laser energy density and film thickness.

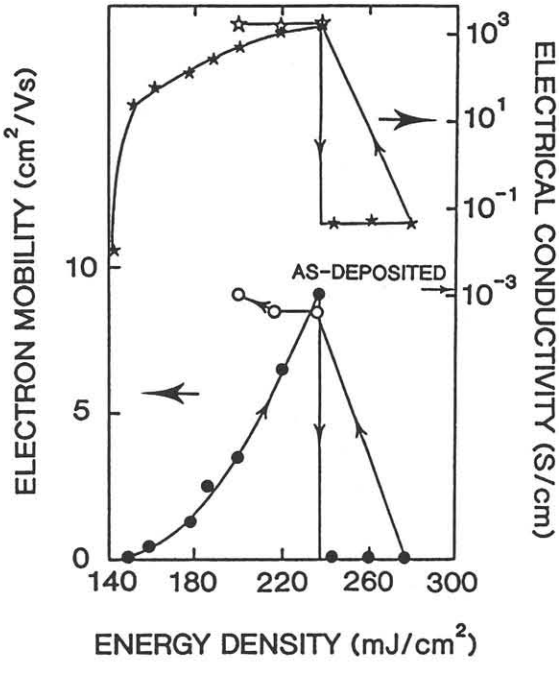

Fig.2 Change of conductivity and mobility for 20nm-thick silicon film doped with 2 atomic percent phosphorus with laser energy density. Solid circles and stars represent changes with increasing energy density monotonously, and open circles and stars represent changes with decreasing energy density after irradiation at 280mJ/cm^2.

8.5cm²/Vs, respectively. These values did not decreased by additional irradiation with laser pulses whose energy density was lower than 235mJ/cm², as can be seen in Fig.2.

Figure 1 also shows the relation between laser energy density and roughness nucleation. The grain size was between 100 and 300 nm, which was much larger than that in the crystalline state with a smooth surface. The threshold for roughness nucleation strongly depended on the film thickness. Although it was 350mJ/cm² for film thicknesses lower than 40nm, it decreased to 220mJ/cm² when the film thickness was above 60nm. This decrease in the threshold for roughness nucleation was probably caused by the hydrogen eruption, because it would be difficult to release hydrogen atoms near the glass substrate interface. Although hydrogen was not detected by FTIR measurements in poly-Si film whose thickness was lower than 40nm, 20% of the hydrogen atoms remained in 100nm-thick film after crystallization.

3. Fabrication and Characterization of Poly-Si TFTs

3-1. Laser Crystallization for Fabricating Poly-Si TFTs

For fabricating TFTs, the thickness of the silicon film must be lower than 40nm, because roughness nucleation does not occur at a high energy density, as can be seen in Fig.1. A laser beam pulsing at a rate of 20PPS was scanned across the sample surface. The energy distribution in the laser beam was spatially formed by using density filters-- the energy density was set to 240mJ/cm² at the center of the beam and it was decreased by steps to 150 mJ/cm² toward both beam edges in parallel with the scanning direction. The a-Si:H film was first crystallized without hydrogen eruption by the multipulse irradiation of the front part of the beam with increasing energy density. The silicon film was then irradiated with multipulse of rear part of the beam with decreasing energy density. Using this method, the a-Si:H film was crystallized completely, because even if the film is amorphized by irradiation of the center of the laser beam with an energy density above the amorphization threshold, the amorphous film is recrystallized by irradiation of the rear part of the laser beam.

3-2. Fabrication Process and Characterization of TFTs

Figure 3 shows the process of fabricating n-channel and p-channel poly-Si TFTs at 250°C using laser-induced crystallization and laser doping with a-Si:H,P and a-Si:H,B films as dopant sources. A 20nm-thick a-Si:H layer was first deposited on the glass substrate at 250°C using rf-GD. Next a photoresist layer was applied and patterned to protect the region not to be doped. A 5nm-thick a-Si:H,P or a-Si:H,B layer was subsequently deposited over the entire surface of the substrate at 120°C using rf-GD. The doped amorphous silicon layer on the photoresist was removed by the lift-off technique. The a-Si:H film was then completely crystallized by laser irradiation. Dopant atoms in the patterned a-Si:H,P or a-Si:H,B layers were incorporated into the underlying silicon layer during the laser crystallization so that a region with a resistivity lower than 1000 Ω / □ was formed. After the irradiation , poly-Si islands were formed. A 100nm-thick SiO_2 layer was subsequently deposited using rf-GD for the gate insulator. Contact holes were opened for the source and drain regions, an Al layer was deposited and the gate, source and drain electrodes were defined. The sample was finally annealed in a hydrogen plasma at 150°C for 10minutes at an rf power of 5W in order to terminate dangling bonds at the grain boundaries in the poly-Si film.

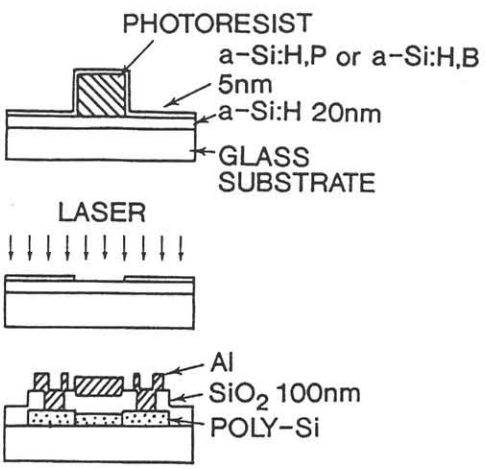

Fig.3 Schematic cross section of the poly-Si TFTs during fabrication.

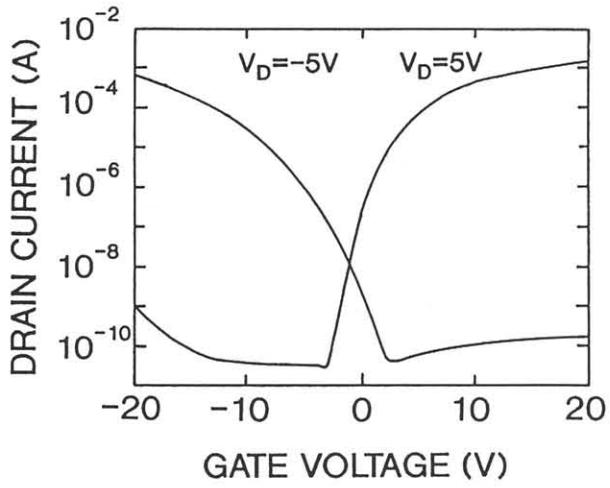

Fig.4 Drain current vs gate voltage characteristics for n-channel and p-channel poly-Si TFTs. Gate width and length are 300 and 30 μ m, respectively.

Figure 4 shows the drain-current vs gate-voltage (I_D-V_G) characteristics of n-channel and p-channel poly-Si TFTs, respectively. The n-channel TFT had an effective carrier mobility in the linear region of 54cm²/Vs and an on/off current ratio of 1x10⁷. The p-channel TFT had an effective carrier mobility of 20cm²/Vs and an on/off current ratio of 5x10⁶.

4. Conclusion

An hydrogenated amorphous silicon film was crystallized through laser-induced melting with an energy density between 120 and 150mJ/cm². Electrical conductivity and electron mobility in polycrystalline monotonously increased as the laser energy density increased. Amorphization occurred with an energy density above 240mJ/cm² and a film thickness lower than 50nm. The amorphization threshold increased from 240 to 280mJ/cm² as the film thickness was increased from 30 to 50nm. Transition from amorphous to crystalline was reversible and governed by laser energy density. In order to crystallize a-Si:H film without the eruption of hydrogen and a laser-induced amorphous phase, multistep irradiation was provided. The energy density first was increased from 150 to 240mJ/cm², then decreased to 150mJ/cm². N-channel and p-channel poly-Si TFTs were fabricated at 250°C using laser-crystallization and laser-doping processes. The n-channel TFT had an effective carrier mobility in the linear region of 54cm²/Vs and an on/off current ratio of 1x10⁷. The p-channel TFT had an effective carrier mobility of 20cm²/Vs and an on/off current ratio was 5x10⁶.

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