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Hydrogenated Amorphous Silicon Thin Film Transistors Made by Novel Materials

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Microcrystalline silicon films were deposited by diluted-hydrogen method and hydrogen-atom-treatment method at 250°C in a plasma enhanced chemical vapor deposition system and they were characterized by nuclear magnetic resonance, Raman spectroscopy, and optical bandgap measurements. One-mask a-Si:H thin film transistors (TFT's) were fabricated with those novel materials as the channel layer. The highest electron mobilities of the TFT's fabricated by diluted-hydrogen method and hydrogen-atom-treatment method were 1.23 and 1.04 $cm^2/V \bullet s$, respectively without any thermal treatment steps.

1. TEXT

Hydrogenated amorphous silicon (a-Si:H) films are indispensable for many large area devices such as solar cells, contact image sensors, and thin film transistors (TFT's). The factors limiting their applications are the low electron mobilities and light induced degradation of electrical conductivity of a-Si:H[1], which are generally related to the intrinsic network structure[2-4]. Changing instrinsic network of a-Si:H into microcrystalline phase could be the most effective way to improve the characteristics of devices mentioned above. Microcrystalline silicon films could be deposited by diluted-hydrogen method and hydrogen-atom-treatment method at 250°C. In this paper we report Si:H thin film transistors fabricated with those novel materials as the channel layer. These materials were characterized by nuclear magnetic resonance (NMR), Raman spectroscopy, optical bandgap measurements. The I_{ds}-V_{ds} characteristics of TFT's were determined by HP4145 meter.

The conventional (Conv.) method and hydrogen diluted (Dilu.) method employed a $H_2/(SiH_4+H_2)$ fraction of 40% and 90-98%, respectively. The operation pressure was 0.5 Torr, and the RF power density was 0.05 W/cm^2. The hydrogen-atom-treatment (Htr) method involved alternately exposing the growing film surface to hydrogen atoms which are generated by a RF plasma in the same deposition chamber. The growth time was 10 s,the other growth conditions were the same as the diluted-hydrogen method, and the hydrogen treatment time was 40 s. The $H_2/(SiH_4+H_2)$ fraction of Htr method was 90%, the operation pressure was 0.5 Torr, and the RF power density was 0.1 W/cm^2. The deposition temperature was fixed at 250°C.

The nuclear magnetic resonance (NMR) studies[5] were employed to analyze the silicon-hydrogen bonding configurations. Fig. 1 shows the results of NMR spectra. Fig. 1 (a) shows the NMR spectrum for the Si film deposited by the convetional method ($H_2/(SiH_4+H_2)$: 40%). The spectrum includes a narrow Lorentzian-shape spectrum with full-width half-maximum (FWHM) of about 3.4 KHz and a broad spectrum with FWHM of about 23.5 KHz. The narrow line-shape corresponds to the randomly distributed Si-H structure in the a-Si:H network, and the broad spectrum corresponds to the region associated with clustered hydrogen which may contain internal surface, poly-hydride groups, and poly-silane chains. Fig. 1 (b) shows the NMR spectrum of the Si film deposited by Dilu. method in which both the Lorentzian-shape spectrum and the Gaussian-shape spectrum were narrower than those of Fig. 1 (a). Fig. 1 (c) shows the NMR spectrum of the Si film deposited by Htr.method. Sharp line-shape spectrum were obtained from the samples shown in Figs. 1 (c) and (d) .The sharp line-shape should come from molecular hydrogen.

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The Raman spectra were investigated to study the microstructure of Si films deposited by the methods mentioned above. The typical Raman shift is peaked at 480 cm^{-1} for amorphous Si and peaked at 520 cm^{-1} for crystalline Si. Fig. 2 shows the Raman spectra of the Si films deposited by (a) Conv. method, (b) 90% Dilu. method, (c) 98% Dilu. method, and (d) 90% Htr. method. Figs. 2 (a) and (b) show the broad spectra with a peak at around 480 cm^{-1} and having a FWHM of 60 cm^{-1}. The result means that the silicon films deposited by Conv. method and 90% Dilu. method were mostly amorphous phase and possibly with some small fraction of microcrystalline phase. Figs.2 (c) and (d) show the sharp spectrum with a peak centered at 520 cm^{-1} similar having a FWHM close to 15 cm^{-1}. The fraction of microcrystalline phase is much enhanced in the silicon film deposited by 98% Dilu. and 90% Htr. method.

The room temperature optical (Tauc's) bandgap of amorphous silicon is about 1.7 eV, and the optical bandgap of crystalline silicon is 1.1 eV. Fig. 3 shows the optical bandgap of silicon films deposited by different methods. The optical bandgap of sample made by the Conv. method (40% Dilu.) is 1.69 eV, and this value increased a little for the sample made by 90% Dilu. method. As the $H_2/(SiH_4+H_2)$ fraction was further increased, the optical bandgap descreased. 1.64 eV bandgap was obtained when the $H_2/(SiH_4+H_2)$ fraction was 95%. When $H_2/(SiH_4+H_2)$ fraction was increased to 98%, the bandgap was reduced to 1.48 eV. This result suggests that it is easier to obtain microsrystalline silicon with higher $H_2/(SiH_4+H_2)$ fraction in the Dilu. method. With the specified conditions, hydrogen atom treatment method produced sample with a bandgap of 1.56 eV. The decrease of bandgap with increasing hydrogen dilution during deposition suggests that the micro structure was changed with increasing either the volume fraction of the c-Si or the crystallite size. It is also noted that the bandgap of sample deposited by combining the 40s hydrogen plasma treatment with the 90% hydrogen dilution is much lower than those of the 90% to 95% hydrogen-diluted samples, except it was higher than that of the 98% diluted sample. These results show that bandgap reduction of the diluted hydrogen samples is effective in the range between 95% to 98%, and the Htr method is also effective for further bandgap reduction.

Samples prepared by the above methods showing distinct microcrystalline characteristics like the sharp line-shape NMR spectrum, Raman shift, optical bandgap reduction, etc., suggest that the treated films should possess a more compact structure than the conventional ones. These results suggest that with appropriate hydrogen incorporation or atomic hydrogen treatment during the deposition, the degree of crystallinity of hydrogenated silicon films can be systematically adjusted.

The one-mask TFT structure is shown in Fig. 4. In order to confirm the effect of structure change of the materials studied above, thin film transistors based on hydrogenated silicon were fabricated. The Si:H materials made with hydrogen dilution and atomic hydrogen treatment were used as the channel layer of the TFT's. Inverted staggered structures of TFT's with PECVD deposited silicon nitride (SiNx:H) as the gate insulator and n+ a-Si:H for ohmic contact with aluminum source/drain metal were fabricated. The W/L was 2500mμm/ 50 μm.

Table I shows the electron mobility of TFT's made by Conv. method, Dilu. method, and Htr. method. The mobility of the TFT made by 98% Dilu. method is the highest one. The I_{ds}-V_{ds} characteristics of TFT with the highest electron mobility is shown in Fig. 5.

From the NMR, Raman scattering, and optical bandgap analyses, both the Dilu. and Htr methods for silicon films deposition were proved to be effective to obtain microcrystalline silicon film. When the V_{gs} was 40V, the mobilities were 0.53, 0.828, 1.227, and 1.036 $cm^2/V•s$, respectively,for TFT's made by Conv. method, 90% Dilu. method, 98% Dilu. method, and 90% Htr method without any thermal treatment steps. The results of I-V characteristics and electron mobility of the TFT's suggest that both the Dilu. and Htr. methods are very effective to improve the performance of TFT's. So far, TFT made by the 98% Dilu. method gave the highest electron mobility. In our current work, further studies on the standard inverted staggered TFT's are being carried out to investigate the effect of the novel materials on the on/off current ratio, threshold voltage, and leakage current of TFT's.

2. FIGURES AND TABLES

Table I. Electron mobility of TFT's made by seversal methods.

Method	Electron Mobility ($cm^2/V•s$)
Conv.	0.53
90% Dilu.	0.83
98% Dilu.	1.23
90% Htr.	1.04

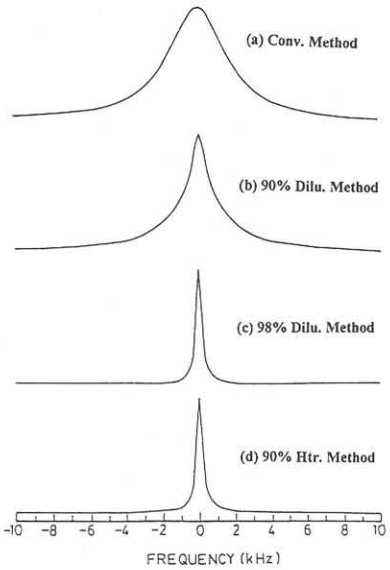

Fig. 1 1H NMR spectra of Si:H samples prepared by (a) Conv., (b) 90% Dilu., (c) 98% Dilu., and (d) Htr. methods.

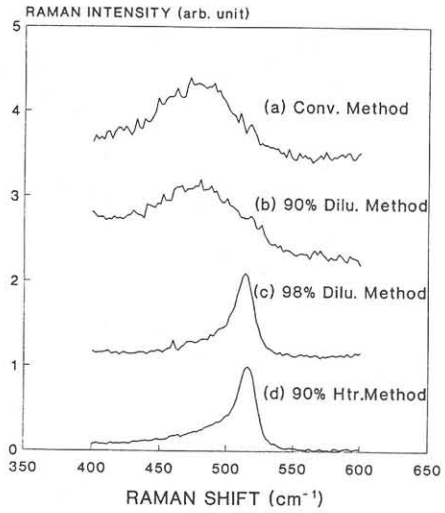

Fig. 2 Raman scattering spectra of Si:H samples prepared by (a) Conv., (b) 90% Dilu., (c) 98% Dilu., and (d) Htr. methods.

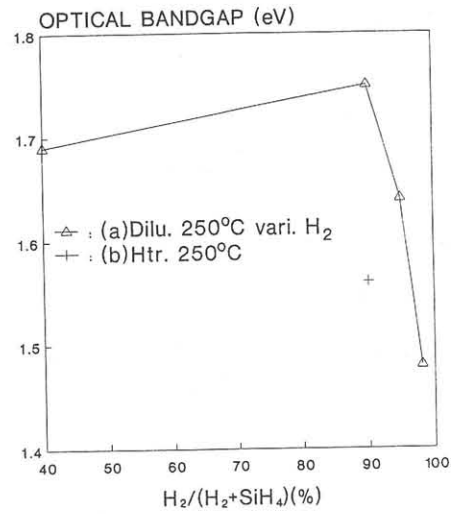

Fig. 3 The optical bandgap of Si:H samples prepared by (a) hydrogen dilution with different dilution ratios and (b) 90% Htr. methods

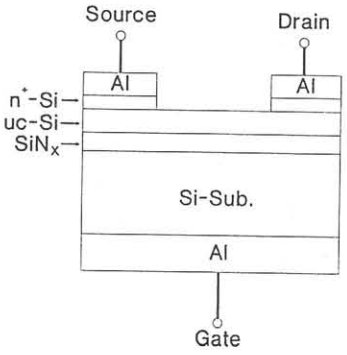

Fig 4 Structure of thin film transistors.

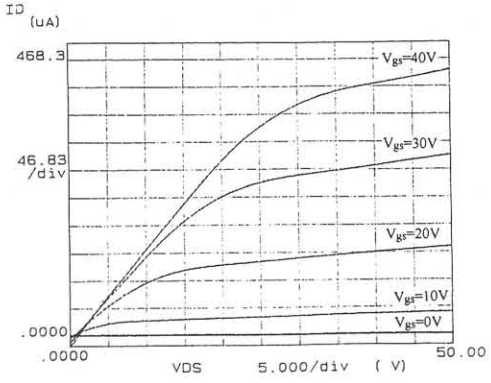

Fig. 5 I_{ds}-V_{ds} characteristics of TFT made by 98% Dilu. method.

3. REFERENCES

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