Scientific Research Publishing

Journal of Materials Science and Chemical Engineering, 2018, 6, 19-24
http://www.scirp.org/journal/msce
ISSN Online: 2327-6053
ISSN Print: 2327-6045

Formation of Poly-Si Films on Glass Substrates by Using Microwave Plasma Heating and Fabrication of TFT's on the Films

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How to cite this paper: Nakaie, H., Arai, T., Arimoto, K., Yamanaka, J., Nakagawa, K., Kamimura, K. and Takamatsu, T. (2018) Formation of Poly-Si Films on Glass Substrates by Using Microwave Plasma Heating and Fabrication of TFT's on the Films. *Journal of Materials Science and Chemical Engineering*, **6**, 19-24.
https://doi.org/10.4236/msce.2018.61003

Received: August 11, 2017
Accepted: January 1, 2018
Published: January 4, 2018

Abstract

We have developed an apparatus for producing high-density hydrogen plasma. The atomic hydrogen density was 3.0×10^{21} m^{-3} at a pressure of 30 Pa, a microwave power of 1000 W, and a hydrogen gas flow rate of 5 sccm. We confirmed that the temperatures of tungsten films increased to above 1000˚C within 5 s when they were exposed to hydrogen plasma formed using the apparatus. We applied this phenomenon to the selective heat treatment of tungsten films deposited on amorphous silicon films on glass substrates and formed polycrystalline silicon films. To utilize this method, we can perform the crystalline process only on device regions. TFTs were fabricated on the polycrystalline silicon films and the electron mobilities of 60 cm^2/Vs were obtained.

Keywords

Microwave Plasma Heating, Poly-Si, Thin Film Transistor

1. Introduction

Polycrystalline silicon (poly-Si) thin film transistors (TFT's) are used for driving elements of flat panel displays (FPDs) such as liquid crystal display, organic light emitting diode display [1] [2]. Poly-Si films on a glass substrate obtained by solid phase crystallization (SPC) has been investigated [3] [4]. In general, The SPC method requires heating treatment for a very long time in order to improve crystallinity. The process temperature reaches approximately 800˚C. Therefore, we must consider that heat treatment causes the degradation of TFTs reliability.

To reduce the effects of heat treatment, laser annealing was used to obtain poly-Si layers. However, laser annealing requires a complex and expensive apparatus. To overcome these problems, we have proposed a simple heating method, in which transition metals can be heated selectively by exposing them to hydrogen plasma. Mozetic and coworkers reported that the temperature of nickel was increased by the irradiation of hydrogen atoms and reached approximately 300˚C, and from this phenomenon they estimated the density of hydrogen atoms in hydrogen plasma. This phenomenon is attributed to the release of binding energy by the recombination of hydrogen atoms into molecules on nickel surfaces, and as a result, the nickel is heated. We have developed a heating apparatus to form high-density hydrogen plasma, in which transition metals such as nickel and tungsten can be heated to approximately 1000˚C [5].

In this paper, we report that amorphous silicon (a-Si) layers were crystallized by plasma heating of tungsten regions deposited on a-Si/glass substrates. We also present a fabrication process poly-Si TFT's and measured electron mobilities.

2. Experimental Methods

2.1. Crystallization

50 nm-thick a-Si layers were deposited on quartz glass substrate by molecular beam epitaxy (MBE) at room temperature. Then, 60 nm-thick nickel films deposition by thermal evaporation and successive 150 nm-thick tungsten films deposition by sputtering at room temperature were performed on regions which were patterned using lift-off process (Structure A). We also prepared samples without nickel films (Structure B). The a-Si films were then crystallized in the solid phase using microwave plasma heating. Input microwave power is 1000 W, hydrogen gas flow rate is 5 sccm, treatment time is 60 s, and pressure is 30 Pa.

2.2. Poly-Silicon TFT Fabrication

For device fabrication, 100 nm-thick a-Si layers were deposited on quartz glass substrate by MBE at room temperature. Then, samples with structure A and B were prepared. tungsten and nickel were patterned only inside the source and drain regions, and the pattern sizes are smaller than source and drain regions. The microwave plasma heating method was used to perform crystallization. Input microwave power is 1000 W, hydrogen gas flow rate is 5 sccm, treatment time is 60 s, and pressure is 30 Pa. The sample with the structure B was heated for 120 s in addition to heating time of 60 s.

Then, source and drain regions, which were larger than the metal patterned regions, were implanted with arsenic atoms at a dose of 1.0×10^{15} cm^2 and an energy of 50 KeV. Gate SiO_2 layers 150 nm thick were deposited by plasma enhanced chemical vapor deposition (PECVD) using tetraethyl orthosilicate (TEOS) at temperature of 450˚C. Then, the contact holes were patterned by wet etching using hydrofluoric acid. Finally, aluminum films deposited by thermal evaporation and patterned by wet etching to form the contact pad. Sintering

temperature was 350˚C in mixture of nitrogen and hydrogen gases.

3. Results and Discussion

3.1. Crystallization

To investigate the crystallinity of Si layers, we used optical microscope and Raman scattering spectroscope. The optical micrograph of the sample with the structure B after heat treatment is shown in **Figure 1**. The color of a-Si film was red and that of crystallized silicon film was yellow. The poly-Si aria was obtained near tungsten region. The length of the poly-Si aria was about 2 mm.

The crystallinity of the sample with the structure B after plasma heating was investigated by microscope Raman spectroscopy. **Figure 2(a)** shows the spectrum of the yellow aria in **Figure 1**. The spectrum has a Si-Si TO-LO phonon band centered at 520 cm^{-1}, showing the presence of Si crystalline phase [6]. **Figure 2(b)** shows the spectrum of the red aria in **Figure 1**. The spectrum has broad peak centered at 480 cm^{-1}, it's characteristic of a-Si.

The optical micrograph of the sample with the structure A after plasma heating was shown in **Figure 3**. Even though heat treatment was performed for the same period of time as the sample with structure B, whole area of the sample with structure A (2 mm × 15 mm) was crystallized.

The length of polycrystallized region in **Figure 3**. was larger than that in **Figure 1**. It is thought to be attributed to metal induced lateral crystallization

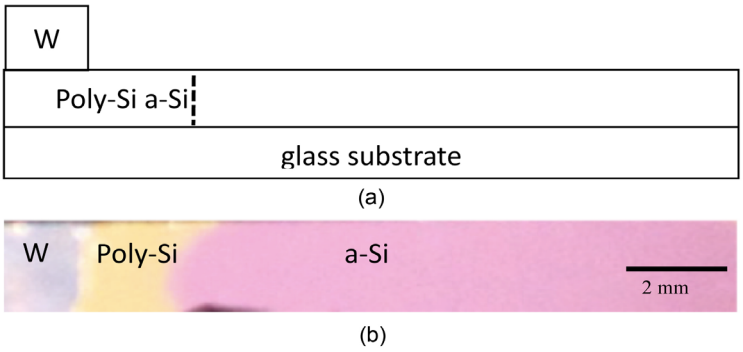

Figure 1. (a) Cross-sectional structure and (b) plan view optical image of sample with structure B after plasma heating for 60 s.

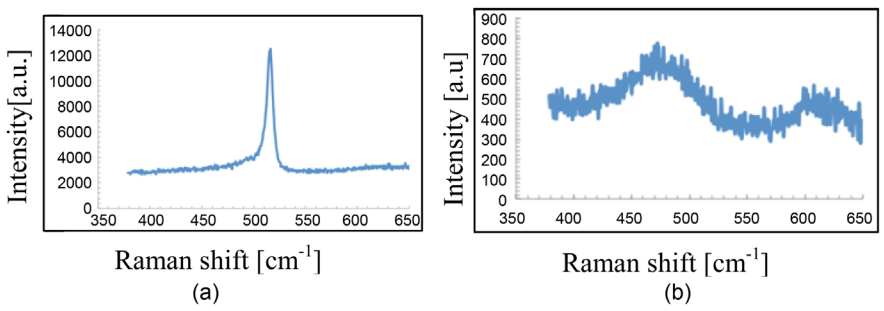

Figure 2. Microscope Raman spectra of sample with structure A after plasma heating for 60 s obtained at (a) red area and (b) yellow area in **Figure 1**.

(MILC) by nickel [7] [8] [9].

3.2. Poly-Silicon TFT Fabrication

Figure 4 and **Figure 5** show I_d-V_d characteristic of the sample with structure B (without Ni) which was heated 60 s and 120 s respectively. Device dimensions are 100 μm of a channel length and 150 μm of a channel width. The gate voltage was changed from 0 V to 40 V with 5 V increment.

Drain current of the 120 s heat treated sample with structure B was twice larger than those of the 60 s heat treated samples.

Effective electron mobilities were derived using the split C-V method. The mobilities of the 60 s and 120 s heat treated samples with structure B are 30 cm^2/Vs and 60 cm^2/Vs, respectively. By elongating the plasma heating time, it was thought to obtain higher electron mobility.

Figure 6 shows I_d-V_d characteristic of the 60 s heat treated sample with structure A (with Ni). The electron mobility is 55 cm^2/Vs. Despite the same plasma heating time, the mobility of sample A is about twice as high as that of the sample with structure B.

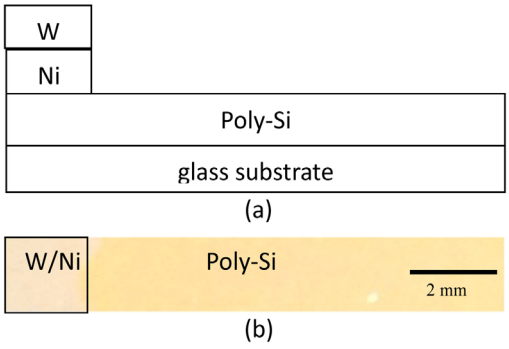

Figure 3. (a) Cross-sectional structure and (b) plan view optical image of sample with structure A after plasma heating for 60 s.

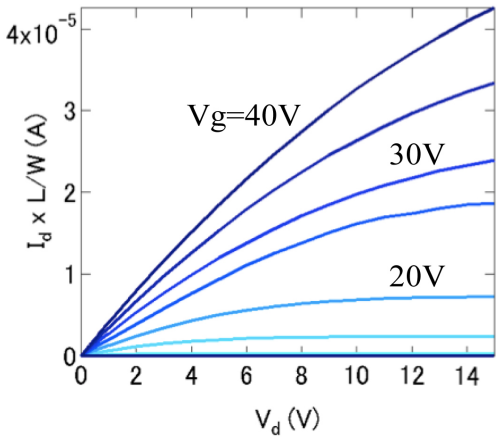

Figure 4. I_d-V_d characteristics of the sample with structure B after annealing for 60 s.

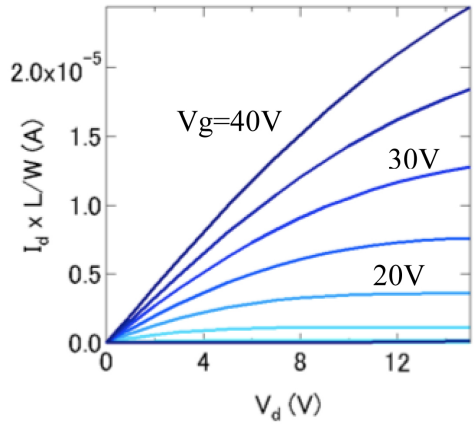

Figure 5. I_d-V_d characteristics of the sample with structure B after annealing for 120 s.

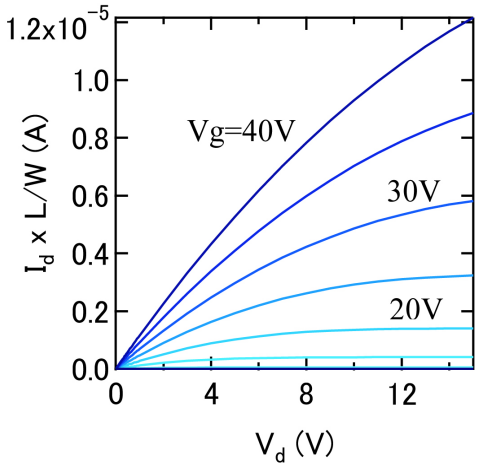

Figure 6. I_d-V_d characteristics of the sample with structure A after annealing for 60 s.

4. Summary

We have developed an apparatus for producing high-density hydrogen plasma. When transition metals were exposed to hydrogen plasma, the temperatures increased to above 800˚C. We applied this phenomenon to the selective heat treatment of tungsten films deposited on amorphous silicon films on glass substrates and formed polycrystalline silicon films. The characteristic of this crystallization technique is to be able to crystallize a-Si films not only just beneath the transition metal films but also laterally in the order of several millimeters. The TFTs were fabricated on poly-Si films formed by the selective plasma heating method and the electron mobilities of 60 cm^2/Vs were obtained. These values are almost the same values as those of the TFT's for driving elements of FPDs.

Current main method for crystallization is laser annealing one, in which multiple scanning is needed for this purpose. Furthermore, laser annealing is unable to heat selectively. Our developed method realizes selective and rapid heating process.

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